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International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects

Sponsored by United States Department of Energy and International Energy Agency

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INTERNATIONAL WORKSHOP ON THE DESIGN, CONSTRUCTION, AND OPERATION OF SOLAR CENTRAL RECEIVER PROJECTS

Sponsored by
United States Department of Energy
and
International Energy Agency

ABSTRACT

The International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects was convened in Claremont, California, from October 19 to October 22, 1982. It was organized by Sandia National Laboratories for the United States Department of Energy. Representatives from the six major international projects--Themis (France), Sunshine (Japan), IEA/SSPS (Spain), Eurelios (Italy), CESA-1 (Spain), and the Barstow Pilot Plant (USA)--exchanged information on their respective central receiver plants. This document contains the papers presented at the Workshop, as well as summaries of the four group sessions and the final panel discussion.

PREFACE

The International Workshop on the Design, Construction, and Operation of Central Receiver Projects was organized by Sandia National Laboratories for the U. S. Department of Energy. The idea of holding a workshop was proposed in 1980 and initial response from all six major central receiver projects was enthusiastic. All of the participating projects made major inputs in establishing the structure and content of the Workshop.

Questions and comments on this workshop may be addressed to A. C. Skinrood, Sandia National Laboratories, Livermore, California 94550, U.S.A.

The Commission of European Communities has offered to host a Second International Workshop on the Design, Construction, and Operation of Solar Central Receivers to be held at ISPRA, Italy, in the spring of 1984. Information on this workshop may be obtained from Joachim Gretz, Commission of the European Communities, I 21027 ISPRA (VA) Italy.

INTERNATIONAL WORKSHOP ON THE DESIGN, CONSTRUCTION, AND OPERATION OF SOLAR CENTRAL RECEIVER PROJECTS
OCTOBER 19-22, 1982

Co-chairmen: A. C. Skinrood, Sandia National Laboratories
L. Astrand, International Energy Agency

October 19, 1982

INTRODUCTION

WORKSHOP INTRODUCTION

Lars Astrand
International Energy Agency

The International Energy Agency (IEA) is cosponsoring this workshop and, as a representative of the IEA, let me welcome you. We are proud to cosponsor such an important workshop as this. Looking at the program and knowing that the contributors really know their business in their fields, I feel confident that this workshop will greatly advance our knowledge of central receiver thermal solar power technology. The central receiver concept is certainly a promising one. In order to advance the technology, we all have to learn from our mistakes as well as from our successes. This workshop is one way, and a very good one, to further our common aim--to make solar energy competitive in the power industry. To exchange information, to discuss our problems, and to contemplate how we can improve are necessary for us all. Therefore, we are all very grateful that the DOE has arranged this truly international workshop. In particular, Sandia Laboratories, and especially my cochairman Al Skinrood and Joe Genoni, have worked diligently to make this possible.

Many of you have perhaps heard of the IEA as some kind of an oil club, which is not entirely correct. So let me say a few words about the IEA and what it stands for and what it does.

The International Energy Agency is an autonomous body which was established in November 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Program. Its members are basically the same as the OECD members. In fact, all OECD members are also IEA members with the exception of Finland, France, and Iceland. In addition, the European Community takes part.

The objective of the IEA is to carry out a comprehensive program of energy cooperation among its member countries. The basic aims of the IEA are the following:

1. Cooperation among IEA-participating countries to reduce excessive dependence on oil through energy conservation, development of alternative energy sources, and energy research and development;

2. An information system on the international oil market as well as consultation with oil companies;

3. Cooperation with oil-producing and other oil-consuming countries with a view to developing a stable international energy trade as well as the rational management and use of world energy resources in the interest of all countries;

4. A plan to prepare participating countries against the risk of a major disruption of oil supplies and to share available oil in the event of an emergency.

The last aim is perhaps more spectacular and publicized, but it is not by accident that the list starts with cooperation on energy research and development. Our long-range aim certainly is to replace foreign oil with new and better energy sources. And it is in this context that this workshop is important. Likewise, it is not by accident that we have this workshop here in the US, for the US certainly is the most active member of the IEA.

However, I should say a few words about the IEA R&D activities. They are governed by a committee on research and development which logically enough is chaired by an American, Dr. Donald Kerr of the Los Alamos Scientific Laboratory. Unfortunately, he is unable to attend this workshop, so I have to substitute for him. The R&D actions of the IEA deal with reviews of national programs and energy technology commercialization; furthermore, there are a number of collaborative R&D projects. One of them concerns Energy Technology Systems Analysis, and the others can be divided into four groups: conservation and end use, fossil fuel, fusion, and renewable energy. In this context, the latter is perhaps the most interesting, so let me give you a rundown on the cooperative activities in that field. They range from hydrogen and biomass conversion to geothermal energy, ocean energy, wind energy, and solar energy. The solar energy activities again fall into two cateogries, solar thermal power and solar heating and cooling. Solar thermal power is the Almeria project of which we will hear much more during the coming days, so I will just say something on the other solar projects or "tasks" as we call them.

The following questions have been or are being studied:

- The performance of solar heating and cooling systems, including assessment of the status of simulation and modeling.
- Establishment of a standard procedure for measuring thermal performance.
- Development of a reporting format.
- Optimization.
- Validation of similar models.
- Coordination of R&D on solar heating and cooling.
- Performance testing of solar collectors.
- Use of existing meteorological information for solar energy applications.
- Systems performance of evacuated tubular collectors.
- Central solar heating plants with seasoned storages.

It should be noted that in the last task, central solar heating plants, the central receiver concept has been studied.

Two new tasks are now being started:

- Passive and hybrid solar low-energy buildings.

- Advanced work on solar radiation and pyranometry.

In addition, a workshop on array factors in large collector fields will be arranged in September of next year.

So, as you can see, the IEA tries to help its member countries through coordination of energy R&D. We are thus particularly pleased that the DOE has been able to make this workshop a truly international one. We will try to make our contribution toward a successful Workshop. I wish you all every success during these coming days.

WORKSHOP INTRODUCTION

Alan C. Skinrood
Sandia National Laboratories

On behalf of the Department of Energy and the International Energy Agency, I would like to welcome you to the International Workshop on the Design, Construction, and Operation of Solar Central Receiver Projects. The purpose of the Workshop is to exchange information on projects which are currently in operation or which will be completed in the near future. It is important to exchange information on central receiver projects for two reasons. First, the central receiver concept does not scale well to small sizes, so complete system experiments tend to take long times to build and are relatively costly. Second, many technology options exist within the central receiver concept, such as the receiver configuration (external or cavity), heat transport fluid, and energy storage method. No single country has sufficient resources or test facilities to explore all aspects of central receiver technology.

In 1980, when we began organizing the Workshop, the response from each of the six major central receiver projects--CESA-1, Eurelios, International Energy Agency, Sunshine, Themis, and Solar One--was enthusiastic. All of the projects appointed representatives to coordinate the Workshop's format and have sent well-qualified delegations to this meeting.

On the first two days of this meeting, we will hear presentations from representatives of each of those projects. We will then break into groups to discuss four major topics: design and construction, staffing, maintenance and reliability, and evaluation and data exchange. On the third day, the findings from two groups will be summarized; a tour of the Barstow Pilot Plant has been planned for the remainder of the day. We will complete the reports of group findings on the final day and conclude with a panel discussion of reactions to this and future international workshops.

U.S. SOLAR THERMAL STATUS AND OUTLOOK

Gerald W. Braun, Director

U.S. DEPARTMENT OF ENERGY
Division of Solar Thermal Energy

The United States Department of Energy (DOE) has concentrated on the development of three major technical options in the field of solar thermal energy: central receivers, parabolic troughs, and parabolic dishes. Each option is specially suited for a particular energy market. While central receivers are considered primarily for bulk electric energy production, and parabolic troughs address industrial process heat requirements, parabolic dishes meet the dispersed or decentralized electric energy requirements in this country and, potentially, in other industrialized countries. None of these technologies, however, are ready for consideration relative to the needs of nonindustrialized countries.

Systems representing all three major concentrating collector approaches have been deployed throughout the United States. The 10 Megawatt Central Receiver Pilot Plant in Barstow, California, the world's largest central receiver facility, is proceeding smoothly through its initial checkout phase. The development and operation of this system have contributed to the technology of electric power generation in the United States by employing innovative control concepts that have been both successful and interesting to the electric utility industry. The receiver technology introduced through this project is also a step forward in the production of steam at modern turbine inlet conditions. These two accomplishments are independent of solar energy and represent a developmental spinoff to other technology areas.

In the United States, there have already been many commercial initiatives to install solar thermal systems. Southern California Edison Co. has requested proposals for a 100 megawatt central receiver project and Georgia Power Co., a utility that is involved in the Shenandoah Solar Total Energy Project, has become very active in commercializing parabolic trough systems for industrial process heat. Similarly, some major oil companies, including Atlantic Richfield, have initiated technological and commercial efforts in central receivers. There have also been initiatives by entrepreneurs and equipment suppliers relative to utility customers and other industrial customers for these technologies.

The cost of these systems has been coming down and the readily attainable cost reductions have been achieved. Conversely, conventional energy prices continue to rise, although the rate of increase has slowed recently. A gap still exists between what these systems can be built for and what people can afford to pay for them. Currently that gap is perhaps a factor of two or three. In general, this can be bridged by subsidies that are already in place or that may be put in place, by price reductions related to volume production or technological breakthrough, and in an unfavorable scenario, by further price discontinuities in conventional energy. It is unclear which of these effects will dominate, but one or more of them will result in the closing of this gap.

In the interim there are other problems that must be addressed. The first and perhaps the most important is that installed systems do not perform as they were designed to perform. In even very good cases, recorded performance has not been within a factor of two of what was predicted in terms of annual energy production, although peak performance of the systems is often quite good. There are issues also in terms of how to achieve further cost reductions. There are advocates who suggest pursuing design breakthroughs and others who say that costs will come down if the hardware can be mass produced. There are others still who suggest that the normal process of incremental innovation will provide the desired cost reduction effect.

In addition to these problems, the future applications for central receiver technology must be addressed. DOE has focused almost exclusively on bulk electric power, yet there are other applications for central receivers that may be more important in the long term. One of them is the production of fuel. In fact, DOE recently established a goal that central receivers will be used ultimately for the production of fuel and that development to this end will occur unless it is shown to be unfeasible.

The United States solar thermal program has been in transition during the period of 1981 and 1982. Previously the emphasis was on near-term applications and engineering. Now DOE is emphasizing long-term opportunities and basic research and development. There are three major areas where our emphasis has been and will continue to be placed, however. These are the operation of installed systems, the use of existing test facilities, and the development of advanced concepts with supporting research programs.

Government spending for solar thermal energy increased annually through 1981 as indicated in Figure 1. In 1982 and 1983, spending levels decreased, representing the end of the period when there was heavy investment in the construction of large systems and test facilities. These systems are in place now. The funds that are available in 1982 and (according to congressional committee action) will be available in 1983 will be, in DOE's view, adequate to fund a very healthy research effort, to continue technology development using the existing facilities, and to operate installed systems such as Barstow, Shenandoah and others. DOE has been through a period when the level of government expenditures on solar energy in general was seriously debated. The congressional action this year essentially resolves that debate and the figures reflect an intended equilibrium funding level for solar energy programs.

Areas of interest for our research programs include advanced concepts in materials and the development of high temperature receivers. Examples of what have been looked at, but not pursued very actively, are applications for high temperature solar heat sources relative to fuels and chemicals processes (i.e., the production of hydrogen by purely thermochemical processes). Many ideas for high temperature receivers have been

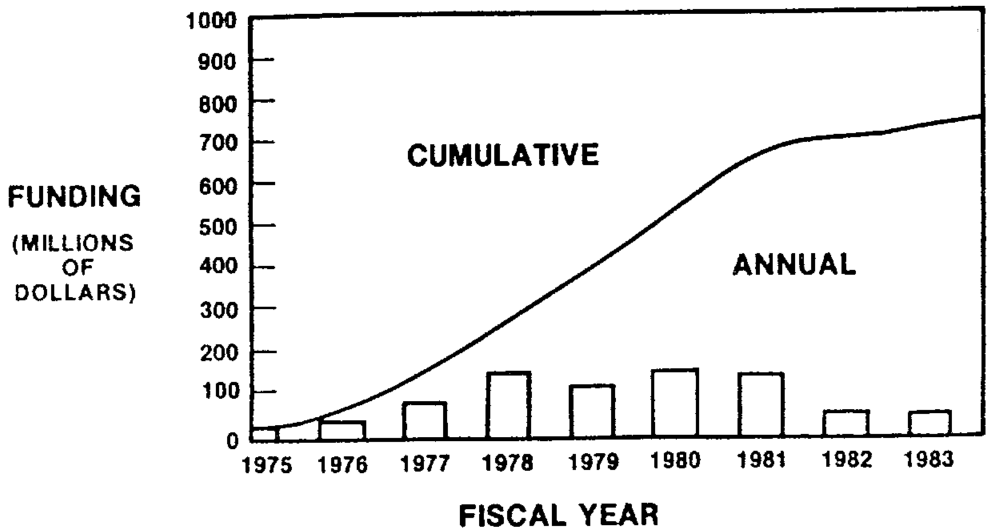


Figure 1. Solar Thermal Technology Program Funding

proceeding slowly through the development cycle because of the emphasis on more near-term concepts. Now as our research program expands, some of these high temperature concepts can be evaluated more aggressively. For example, Sandia National Laboratories has initiated a development effort that addresses the potential of absorbing heat in particles as opposed to the walls of the heat exchanger. This, of course, addresses the fundamental difficulties in heat transfer at high temperatures and high flux. It is in the early stages of evaluation and development, but is an example of the kinds of things that DOE will be considering in the future.

DOE is also investigating the possibility that heliostats can be manufactured much more cheaply if materials other than metal and glass are used. Polymeric materials used in tension to form a stretched membrane heliostat is one of the different concepts. We don't know whether these design-related cost breakthroughs will be viable, but we will be pursuing them in a portion of our efforts. Much of the research activity will be performed at the Solar Energy Research Institute (SERI) as it becomes more of a major factor in the program.

It is becoming clear as DOE plans test programs for the advanced facilities that there is more than one perspective to address. Utilities are interested in energy production and the evaluation of systems for that purpose, while laboratories and industry are interested in evaluating basic central receiver technology. Additionally these large, powerful facilities have the potential to be used in a scientific sense to advance basic knowledge. A very simplified schedule for the 10 Megawatt Central Receiver Pilot Plant addresses two of these three areas of interest. In the present activity DOE is pursuing an understanding of technology. As the system comes to equilibrium, a better understanding of the energy production capabilities of the technology will be gained. Beyond 1987, we will understand the ways to use such tools for scientific purposes. The use of this facility as a resource will not end in 1987, but rather the next five years will provide a better understanding of how to use it in the future.

Our future plans for the installed systems depend on the availability of component test facilities. In the United States the present success of the Barstow project is due in large measure to the work that was done at the Central Receiver Test Facility in Albuquerque, New Mexico. There exists also an overlap between installed systems and test facilities. Miniature systems can be tested at component test facilities; similarly, large components can be tested within the context of large systems. To distinguish between test facilities and installed systems is somewhat artificial. In any event, we have two key test facilities that will be used in the future: the Central Receiver Test Facility at Albuquerque, and the Parabolic Dish Test Site at Edwards Air Force Base.

The Central Receiver Test Facility involves all of the components of a solar powered molten salt electric power system. In the past it has been used for the evaluation of industrial designs of heliostats and receivers, and more recently, tests of a molten salt storage subsystem.

The Parabolic Dish Test Site at Edwards Air Force Base has recently completed a very significant technical milestone. It has demonstrated an overall solar to electric conversion efficiency of close to 30 percent using a Stirling engine and parabolic dish. That is significantly better than anything that has been attempted or proposed using central receiver technology. This is not to suggest a comparison, because the two technologies are quite different in application and economics, but it is a very significant milestone, nevertheless.

Government programs have promoted the transfer of technology by involving the Department of Energy in cost-shared design efforts, an example of which is the repowering designs that have been underway for some time. DOE recently began the preliminary design phase of four more cogeneration/repowering projects that will also be cost-shared. The location of these potential projects is in the southwestern United States and Hawaii--areas of good sun availability. Most of the projects involve utility applications with a substantial range of technological approaches and system sizes. Although the range of system sizes is within a factor of five, these are relatively small projects because of the issue of raising money to build privately financed central receiver systems.

The International Energy Agencys' Small Solar Power System project is a good example of the teamwork that is possible in future international efforts. The work at the Central Receiver Test Facility and Barstow are also examples of teamwork in a more confined setting. This activity, if it can be practiced in the future, can open up many possibilities for cooperation among countries, companies and institutions. The framework for this interaction can be conferences, workshops and ad hoc meetings among government, utility and industry leaders to discuss their relative perspectives. Within the IEA committee structure there are a number of groups addressing both the present situation and the long-term possibilities for cooperation.

The outlook for central receiver technology in the United States and for international cooperation is very good. The market in the United States for central receivers will develop since it is only a matter of time before the cost and value gap is bridged. Recognizing that the gap will be bridged, DOE programs are turning to the longer-term potential for central receiver technology.

DOE is committed to the transfer of the technology that has been developed over the last ten years and to the effective management of the investment that exists in major facilities. Further, DOE recognizes the need for a creative approach to the use of research tools available to us. The opportunities for international cooperation are better than ever, in the sense that our government programs are turning from engineering to more scientific issues. The barriers to cooperation, therefore, can come down. We will not be dealing with things of immediate commercial interest, so that technical data and insight can be freely exchanged if a framework can be established to do so. Certainly, we are committed in the United States to support such cooperative endeavors. As scientists and engineers our goal is to add to the store of knowledge. The tools are at hand. What we need is a spirit of cooperation and commitment.

THEMIS

THE THEMIS PROGRAM

Louis P. Drouot
Head of Solar Techniques Department
French Agency for the Management of Energy

This general presentation is intended to assess the Themis project framework from the French Agency for the Management of Energy (F.A.M.E.) point of view. A more detailed technical presentation can be found in Mr. Hillairet's article.

Born in 1975 following the first oil crisis, the French Agency for Energy Conservation (A.E.E.) devoted its time and efforts towards saving energy both in industry and in housing. This effort was expanded by our government in 1978, when the French solar energy authority, known as COMES, was created: it concentrated on R&D pertaining to new and renewable energies. Early this year, these two agencies were merged together to create F.A.M.E., which includes geothermy and heat distribution networks. This decision now gives the French government the tool it needs to be able to implement a very ambitious and diversified program, calling at the same time on energy conservation and on new and renewable energies development (Figure 1).

An important part of the R&D program set up by F.A.M.E. is the thermodynamic conversion program. On one side, the program devotes itself to the development of components and systems, among them the THEK program which deals with parabolic dishes. These could be used not only for heat generation purposes or electricity generation but also in stand-alone systems, for example to refrigerate and conserve fish, a useful application in the developing countries. On the other side, the program calls for the implementation of pilot plants in order to experiment with these components and thermodynamic cycles. Such a pilot plant is nearing completion near Ajaccio, in Corsica, and is due for operation early next year. Partial tests have already been run. It was a distributed collector parabolic trough array and a rankine cycle turbine (Figure 2).

Preliminary design phase of Themis dates back to 1976, when the THEM project was being run by C.N.R.S. and E.D.F. This early phase included location trade-offs, which eventually led to the choice of Targasonne near Odeillo, in the Pyrennees mountains. The go-ahead was given for the construction phase in 1979, E.D.F. becoming project leader and issuing the necessary calls for tender. CETHEL was thereafter chosen as the main contractor for the heliostat field. The construction phase is being completed this year, and final tests are being run. The experimental operation program will begin by the end of 1982 (Figure 3).

Themis total cost of 128 MF (1979 francs) (i.e., some 25 M$) for construction was shared between E.D.F., COMES, and the local territory and district. It must be underlined that because of the location site which had been chosen, an extra-cost plagues the civil work and earth removal. A special new road had to be constructed also. All that renders comparisons with the initial budgeting somewhat difficult. Altogether, and not taking into account some 14 MF which had to be borne in 1982 for the

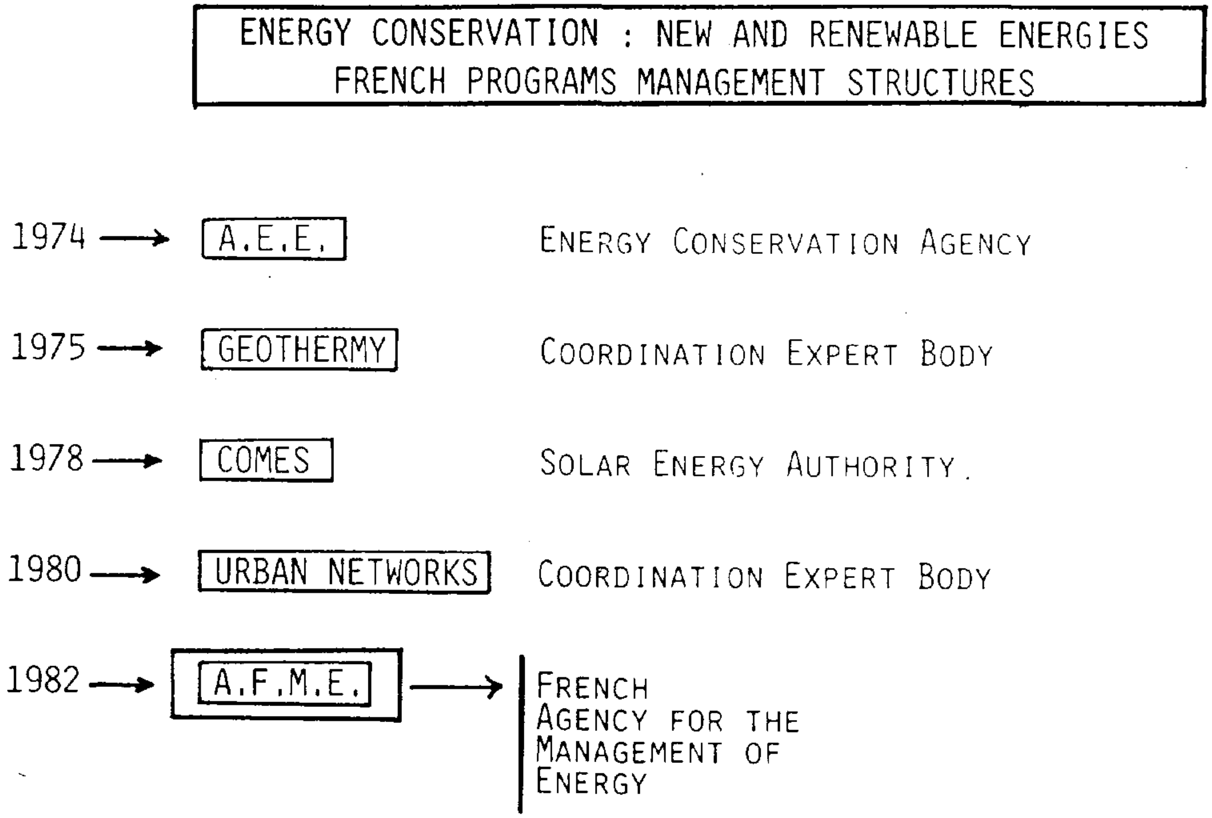


Figure 1. French Programs Management Structures

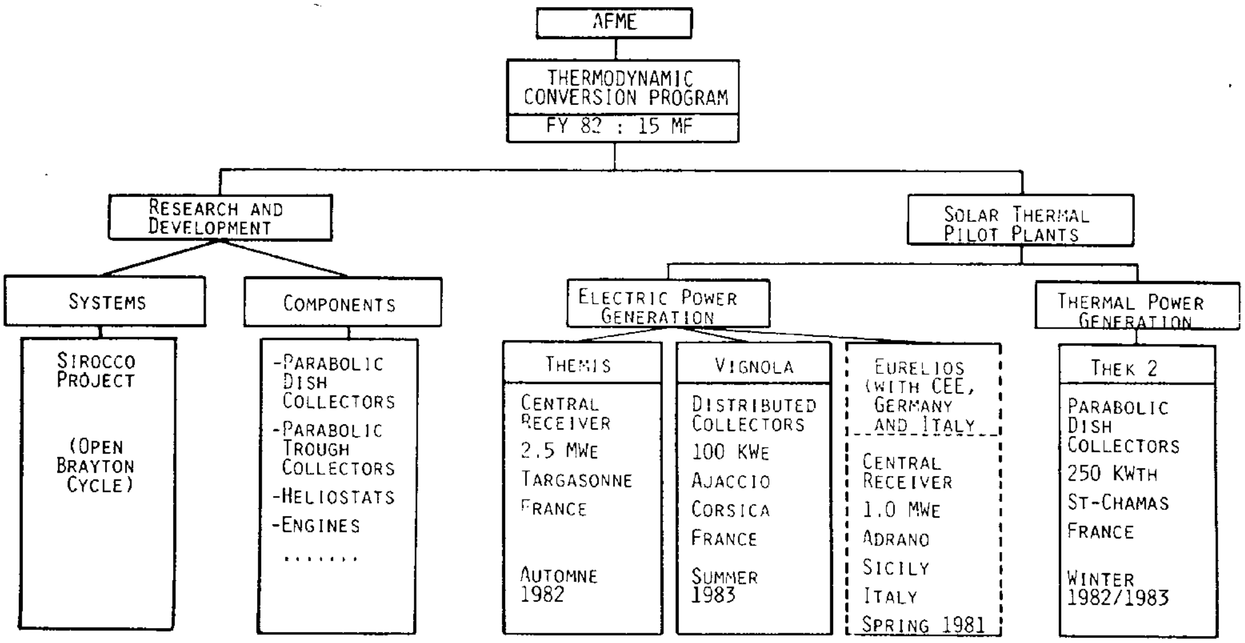


Figure 2. Thermodynamic Conversion Program

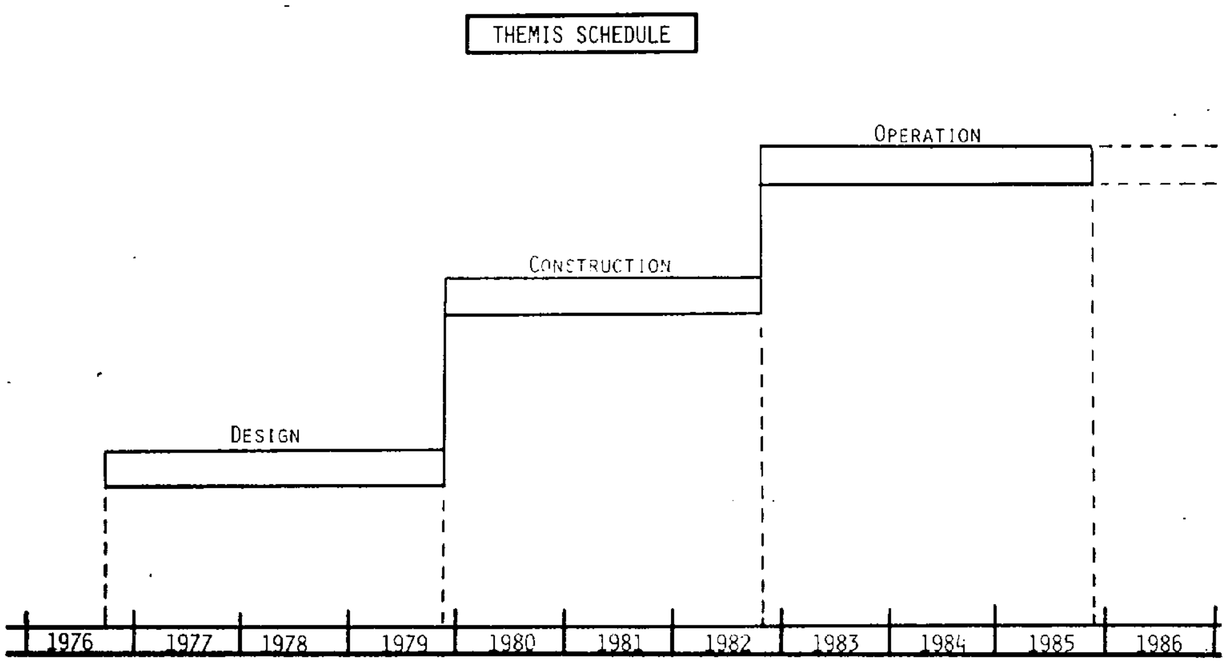


Figure 3. Themis Schedule

heliostat field repairs, it can be said that the cost target which had been set was fully met by the partners (Figure 4).

The Themis program is being organized right now along two axes: first, the operation and maintenance program (O&M) which is aimed at providing the technical support necessary for routine operation, grid correction, and other procedures related to Themis normal functioning, and second, the experiment program which is aimed at improving our knowledge of such systems by observing carefully and testing different configurations. These two main aspects of the Themis program are, of course, closely coordinated. Operation of the system is supervised by the plant manager, who belongs to the E.D.F. operations department. The structure and contents of the experiment program itself are defined by two interacting committees that are described later in the paper (Figure 5).

The total annual cost of operation for Themis, roughly 23 MF (i.e., 4 M$), is mainly due to the manpower associated with O&M and experiment programs. In order to assess the minimum energy production costs in the future, among other things we shall focus on the O&M team manpower; the years to come will confirm whether the figure of 37 people is adapted or not. The general thought today is that this number is somewhat oversized (Figure 6).

The Themis experiment program has two major outgrowths. On a short-term basis, it shall be devoted to the assessment of today-technology, qualification and control of components, and overall technical and economical performance. On a mid-term to long-term basis, it shall focus on a number of new technologies that would pave the way for possible cost reductions. The landmark right now is 1985, when we think it possible to wrap-up a first cycle of experiments in order to reassess the whole concept and check it against "market acceptance" should that apply, while going ahead with new developments (Figure 7).

The Themis experiment program is being defined and coordinated between the partners. A management committee takes as inputs the financial constraints of each party, as well as the experiment technical proposals made by the scientific committee. It comes up with a decision on both budget and technical contents of the experiment program. On-site coordination is insured between the experiment team manager and the operations plant manager (Figure 8).

Without any doubt, the choice of the location has led to a number of new problems not likely to be encountered on a "fair" siting. Among those, heavy winds and lightning storms bring with them a number of risks that Themis has already faced. On the other hand, and despite these drawbacks, the site carries with it a number of advantages: low price of the land, large number of sun-hours, and air-purity due to the altitude. In our opinion, these advantages offset the drawbacks. Themis is just beginning to run trial tests and should be in full operation by the end of 1982. It will soon prove to be a very useful, flexible, and valuable R&D tool that will make its own original contribution to our knowledge of central receiver systems operation and performance.

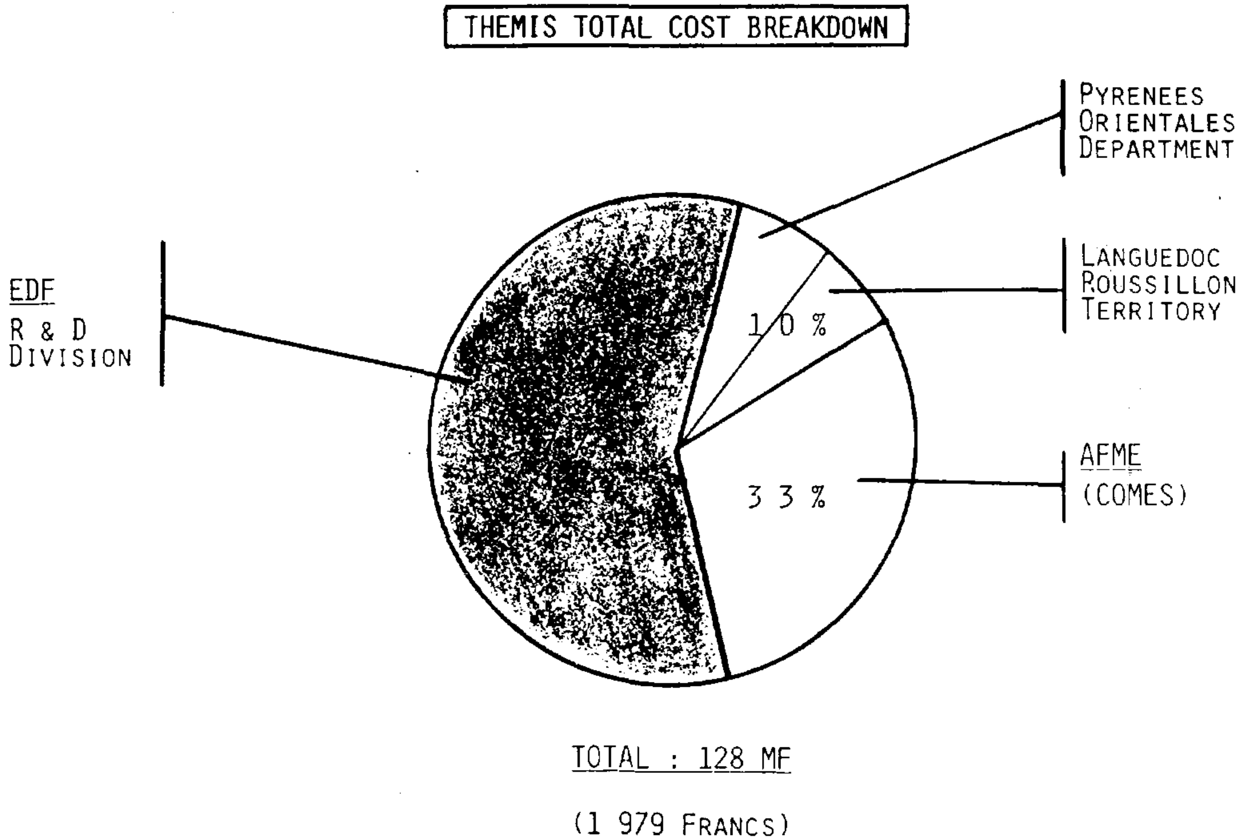


Figure 4. Themis Total Cost Breakdown

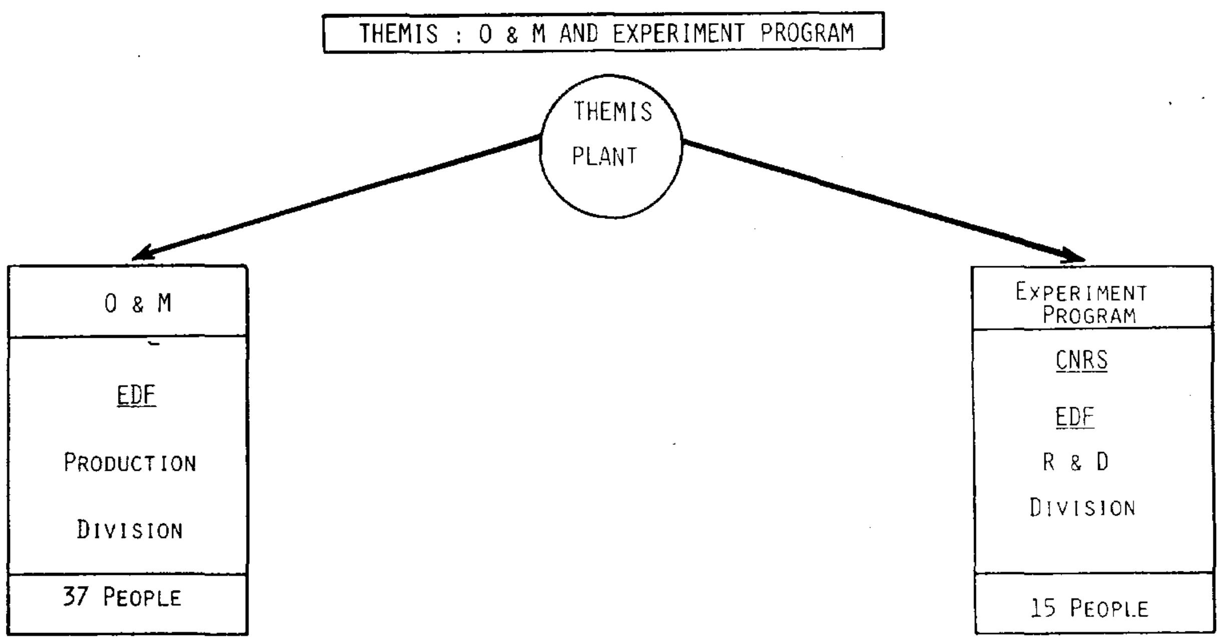


Figure 5. Themis: O&M and Experiment Program

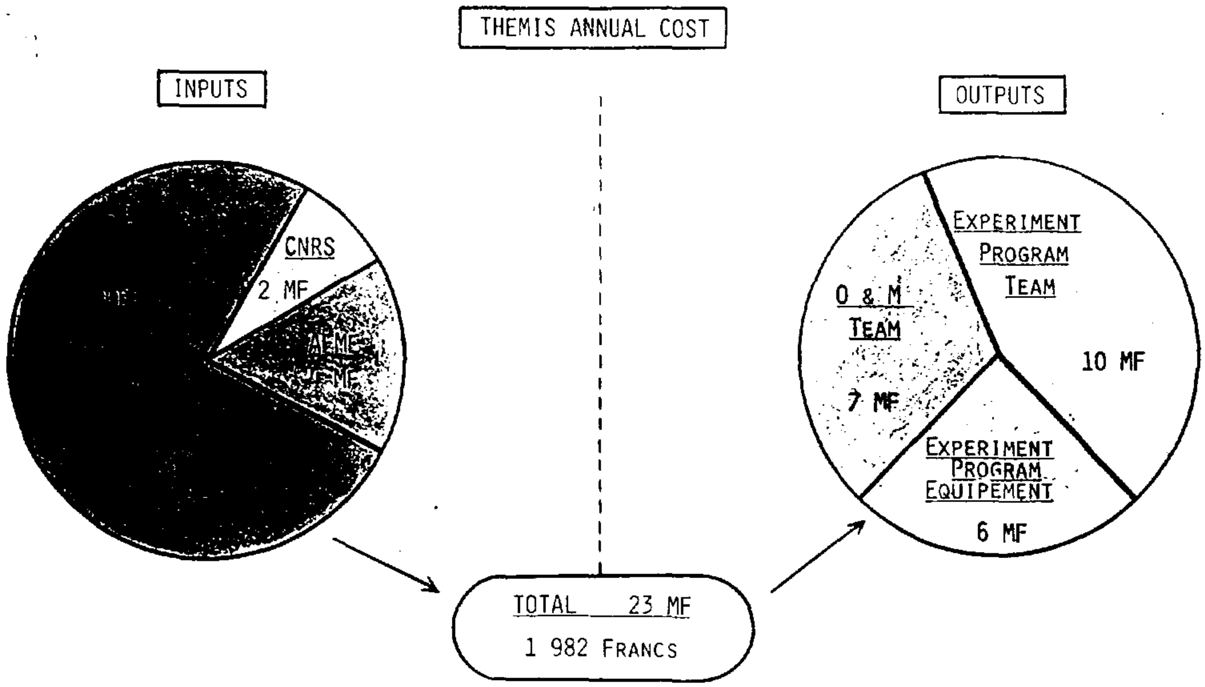


Figure 6. Themis Annual Cost

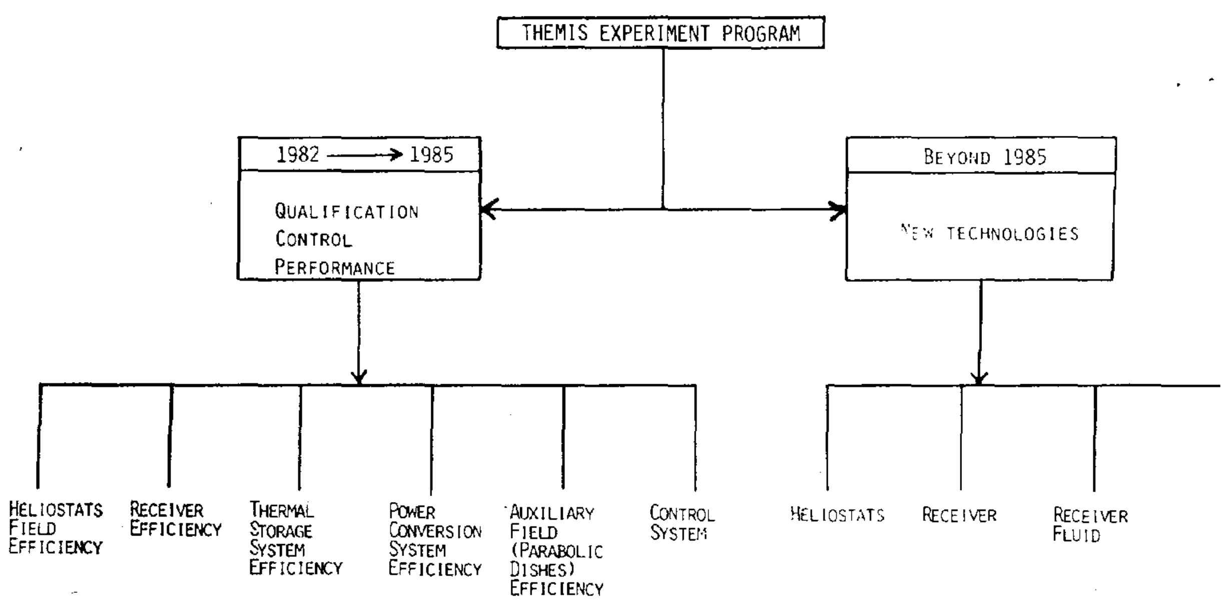


Figure 7. Themis Experiment Program

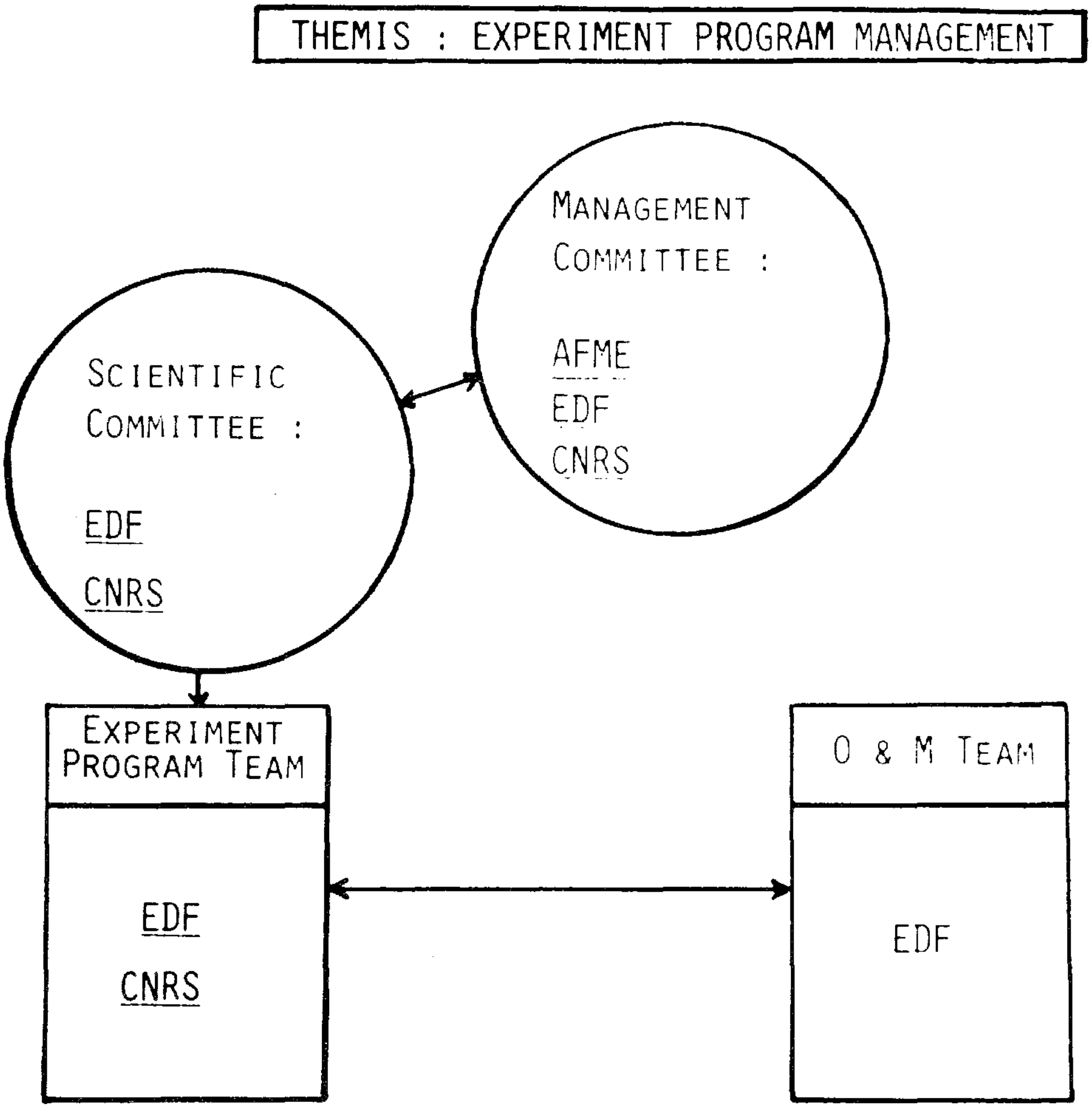


Figure 8. Themis: Experiment Program Management

2,500 KW THEMIS SOLAR POWER STATION AT TARGASONNE

M. Jean Hillairet
Chief of Themis Design Project

Introduction

Electricite de France (E.D.F.) decided to build an electric solar tower plant, producing 2.5 MW, called Themis, in the south of France at Targasonne.

The construction began in October 1979 and was supposed to last two years. However, we shall need three years. I will give you the reasons presently.

To begin with, I will show some Themis slides to remind you of its main characteristics and individual features.

The Place

Site before Themis Project (January 1980)

Targasonne is a mountainous, windy, snowy, stormy and cloudy place. For the first solar power plant, this presents serious problems. But we didn't suppose a solar plant was so sensitive to these things. On the other hand, for an experiment, it's a wonderful site. All the problems must arise--it's fate.

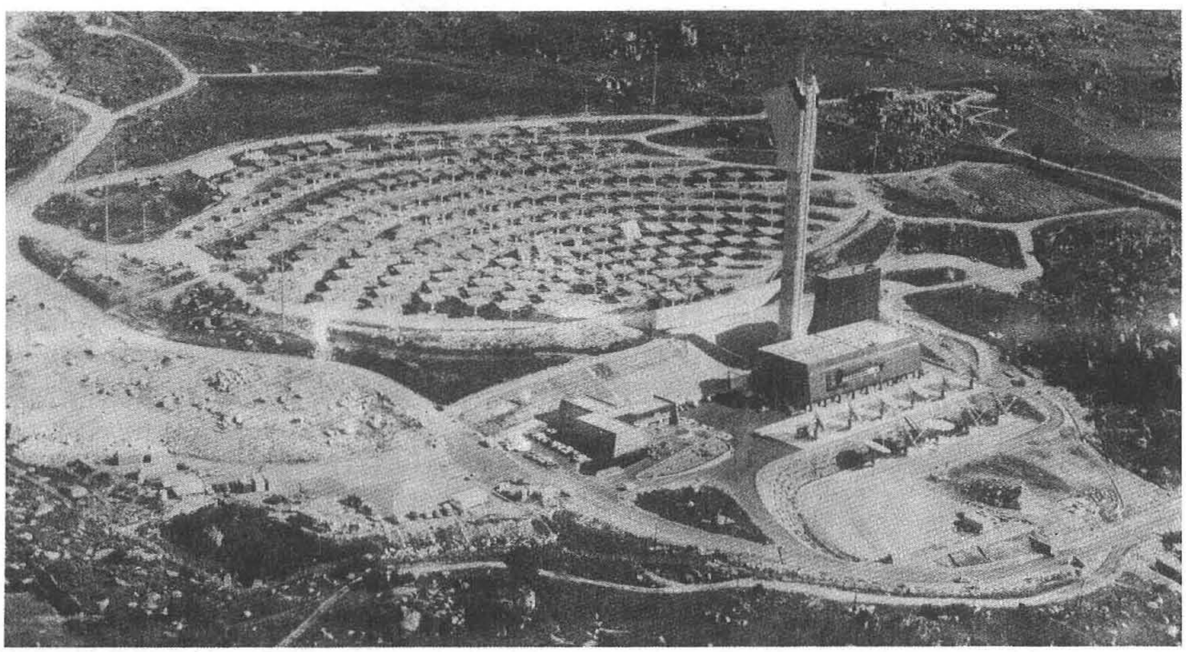
It is a mountainous place; the height is 1.700 meters; the roads are narrow. The plant is isolated. The ground is either granite stones or peat. The area is classified as an historical French Monument and the name is the chaos of Targasonne, that goes without saying. It isn't easy to site the heliostats.

The place is snowy. The snow storms cover the plant, principally the heliostat field. The heliostats are at fifty centimetres above the ground, and their movements in the snow can be dangerous.

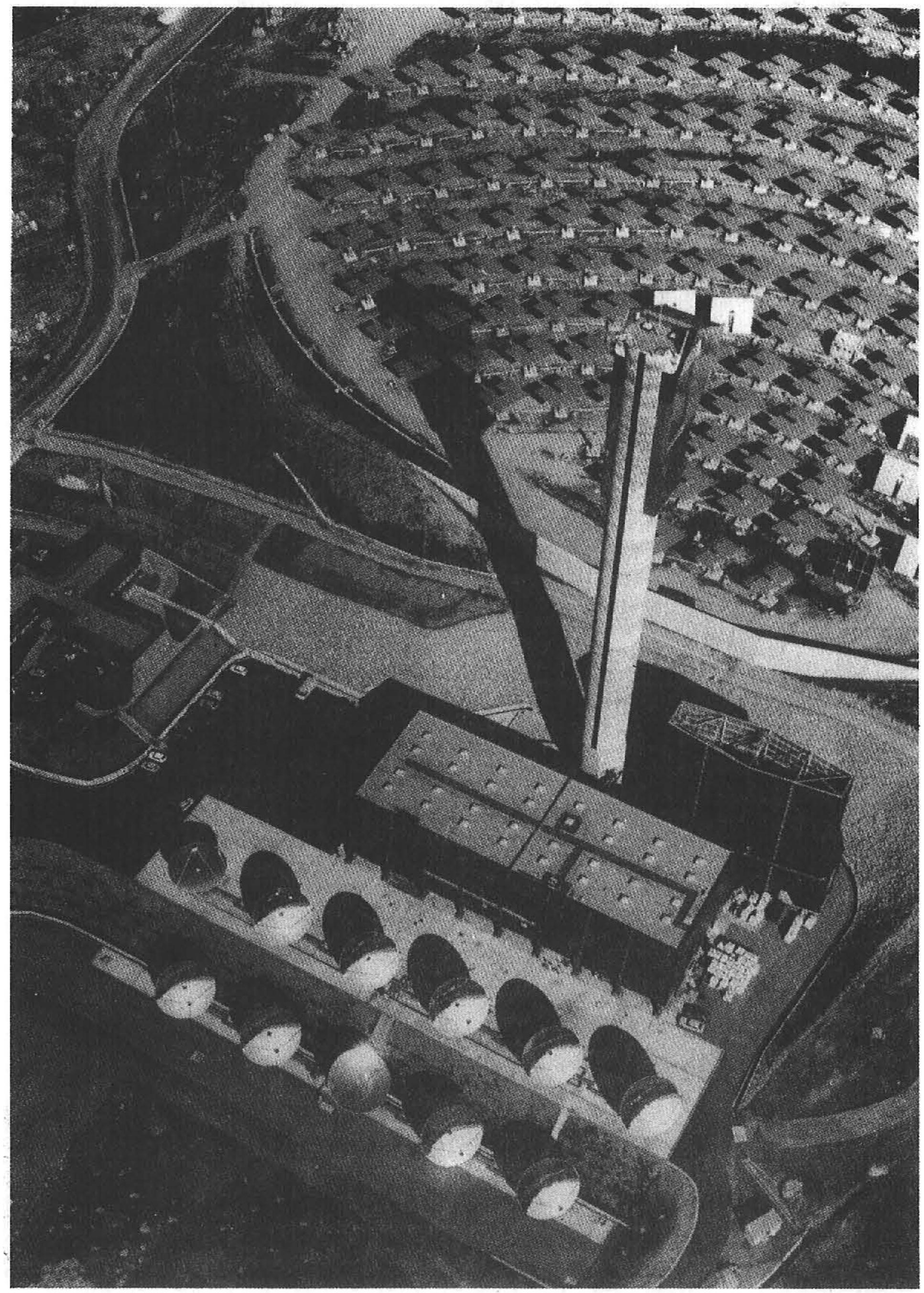
Likewise, the behavior of the electric batteries of the heliostats when the temperature is fifteen degrees below zero can be abnormal. The lack of cooling water creates difficulties; the air in the exchangers is too cold. In fact, we face all the problems of freezing.

The place is windy, a big calamity for us. I shall speak about this later; the subject is very interesting. Mr. Lemaignen, "Cethel" heliostat supplier, will give you details in Group A. In the same way, I shall discuss the fact that the place is cloudy and stormy later. Wind, cloud and storm are the three enemies of solar plants--without counting the cost.

Overall Plant Description

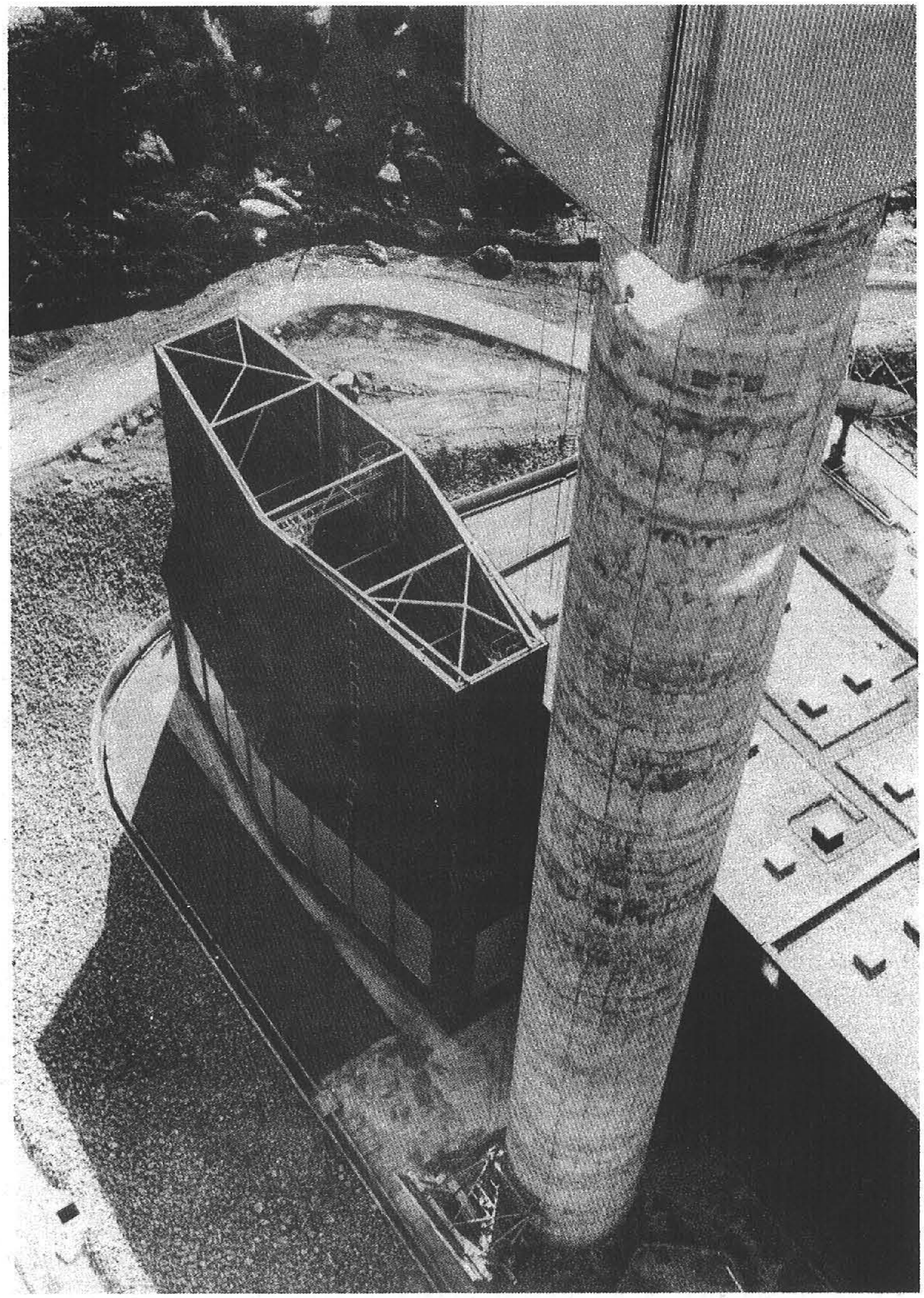


Overall Themis View (1)



Overall Themis View (2)

On this slide, you see the heliostat field which covers an area of 50,000 square metres; the concrete tower which has a height of 100 metres; the factory with molten salt storages, turbo-alternator, air cooling (which is a prototype), control room and repair shop. In front of this is a small heliostat auxiliary field composed of dish mirrors with an individual receiver.



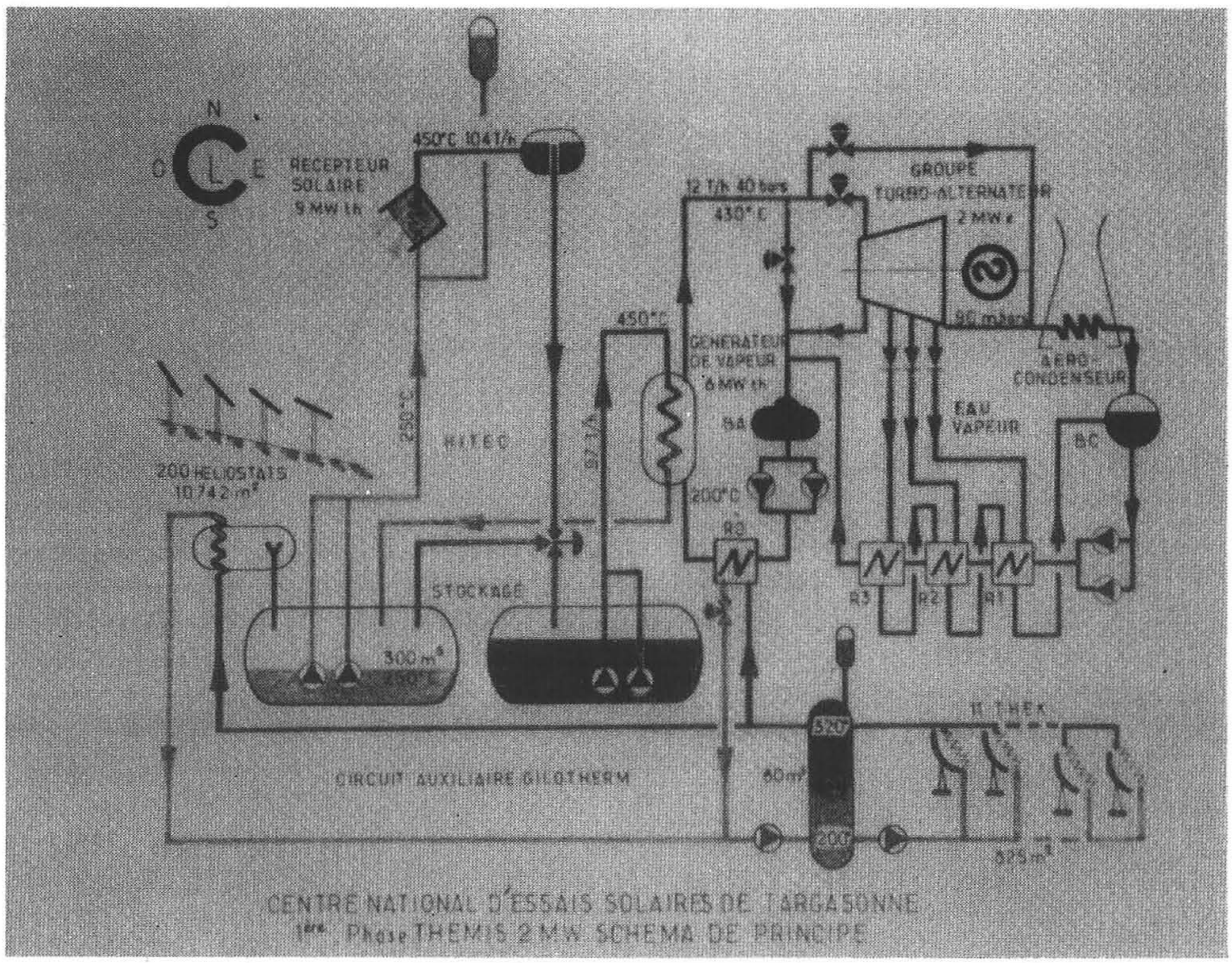
Overall Themis View (3)

Themis Function

The Themis functions in this way: the cold salt is stored at 250°C in a big storage tank of 300 cubic metres. Pumps send it to the receiver. The receiver is a box. The box is closed when there is no sun, and open when there is sun. Salt goes out at 450°C and goes down to a second storage tank of the same volume. If the salt isn't at the right temperature, it comes back either to the entry of the receiver or to the first storage tank.

The secondary circuit is classical. A steam generator feeds the turbo-alternator with steam at 410°C.

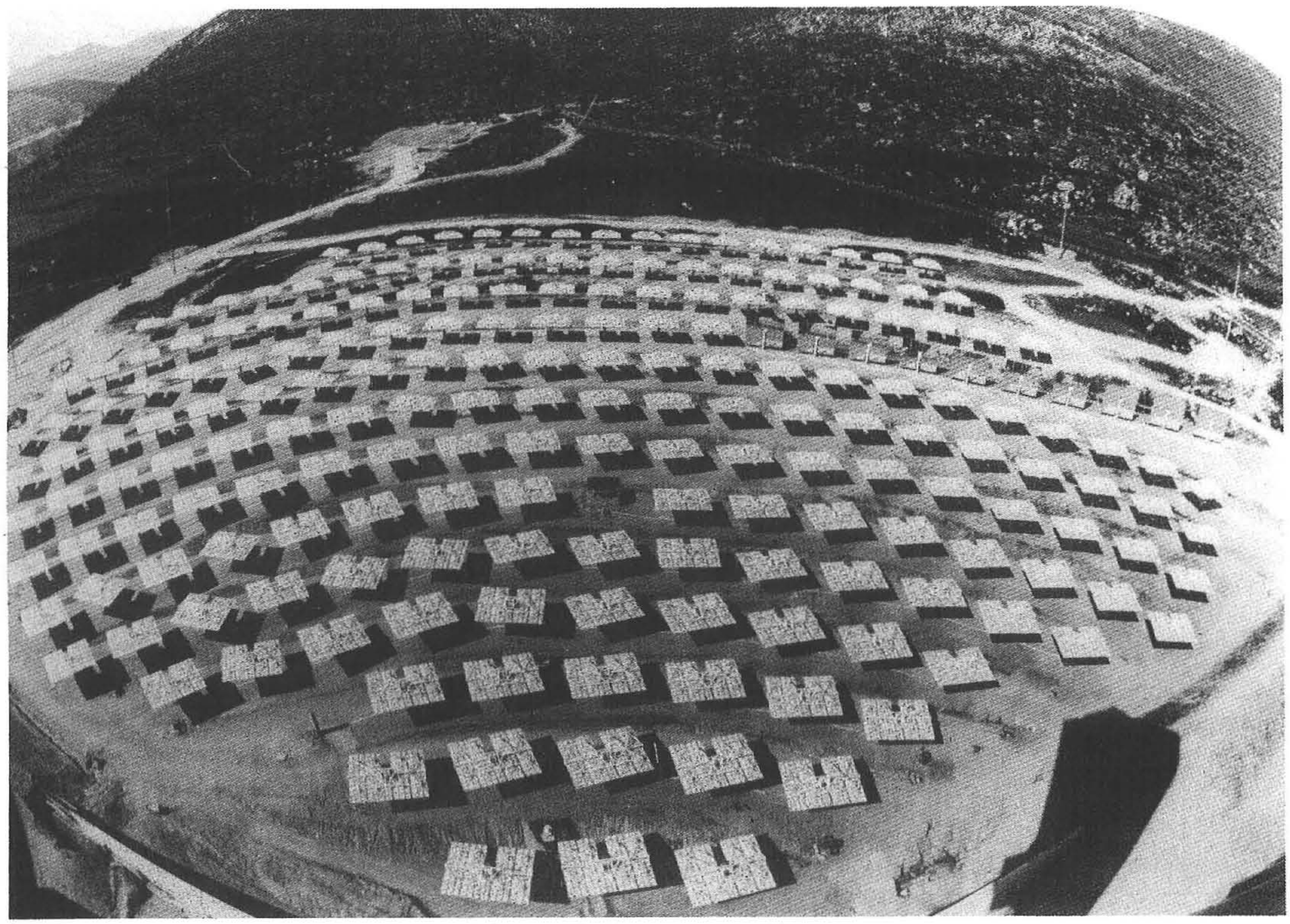
The auxiliary heliostats and a single storage tank of 80 cubic metres keep the salt circuits at a temperature of 250°C in order to keep the salt from solidifying.



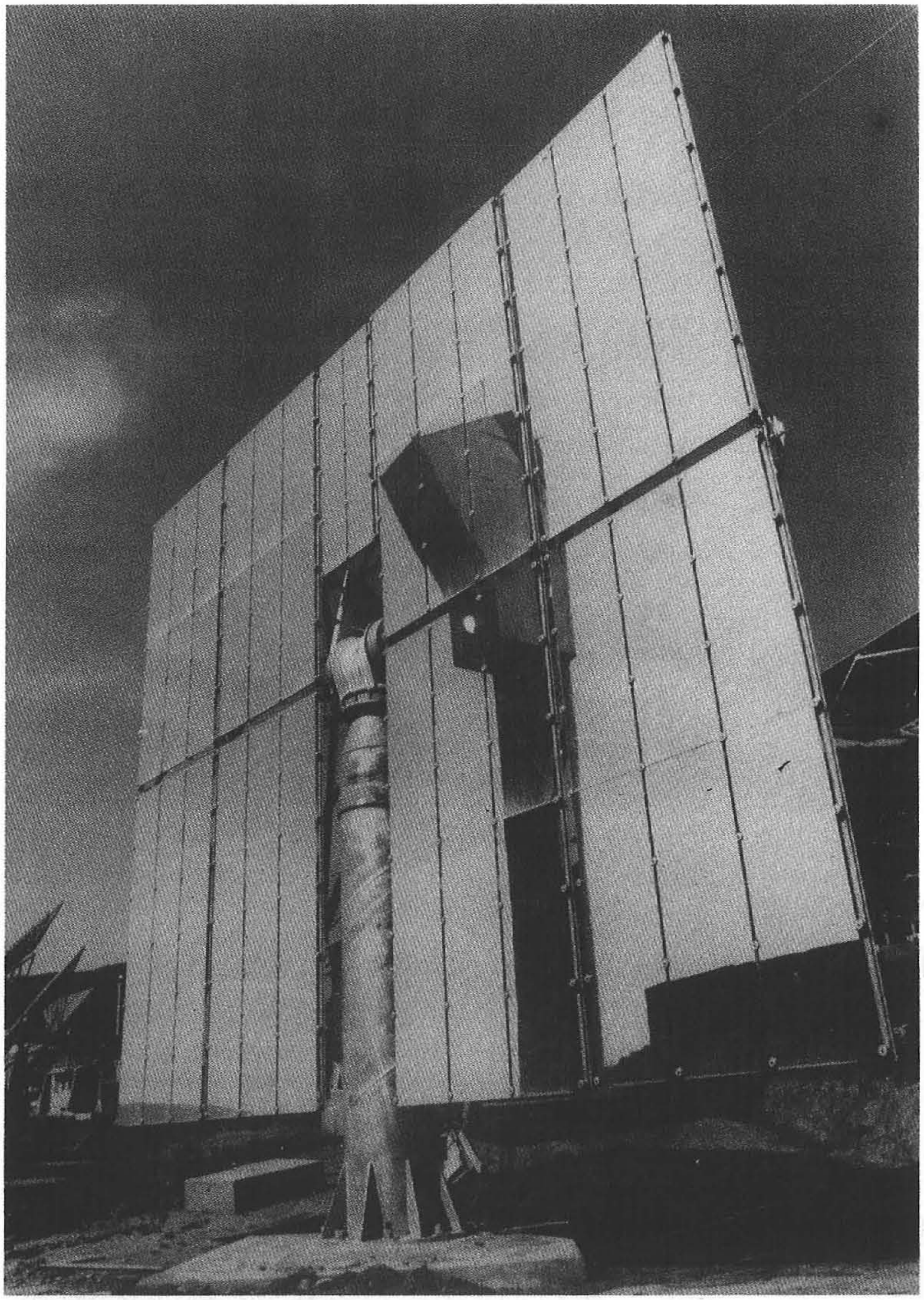
Simplified Themis Diagram

The Heliostats

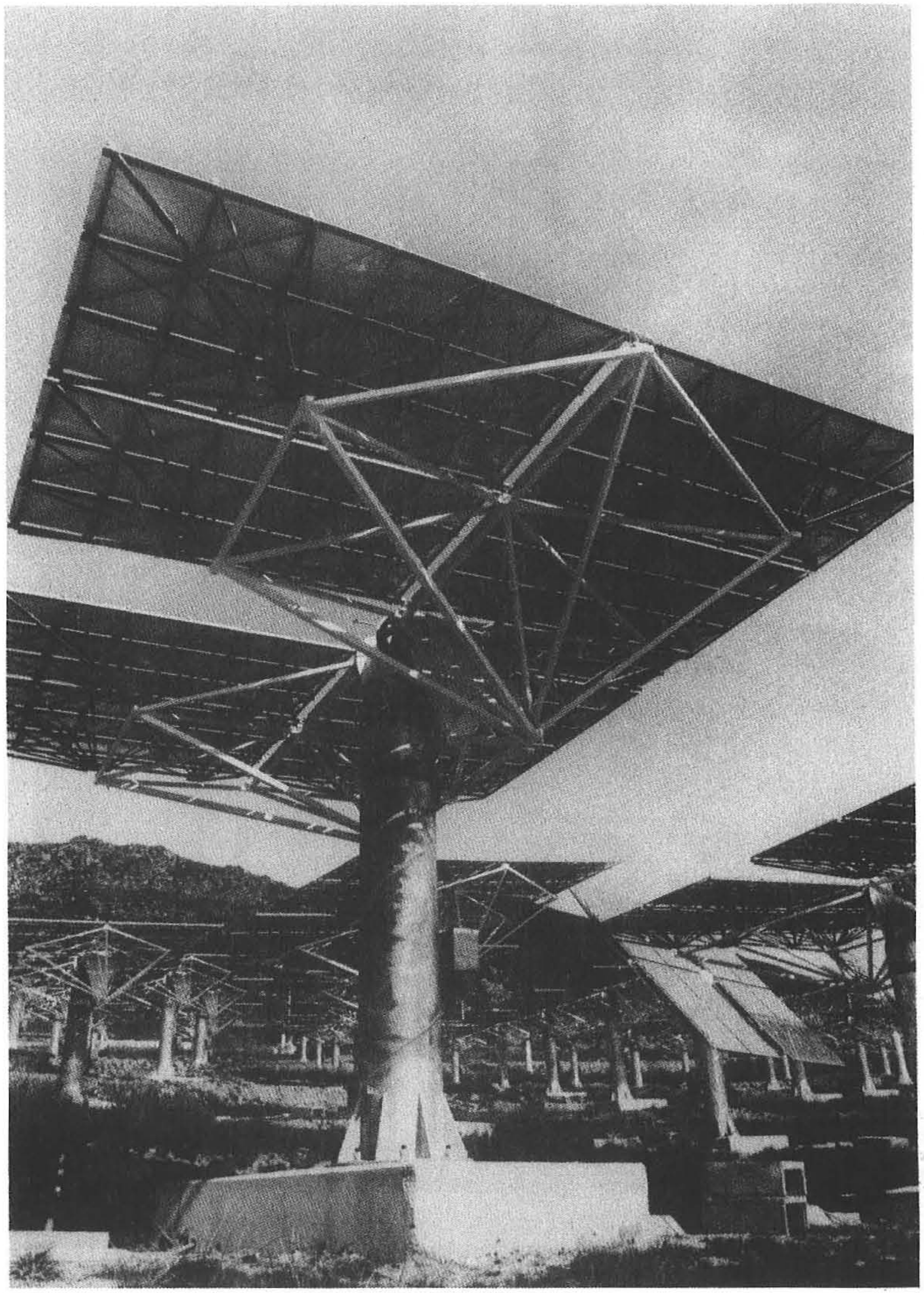
Two hundred heliostats of 54 square metres make up the main field. The mirrors are in "sandwich" glass kept all together by an iron framework. The electro mechanical control system is composed of shafts and gears. It's important to understand the risks of accident. Each engine is under the central control. But a battery near the foot of each heliostat brings the mirrors into a horizontal position with independent control. The heliostats can function in wind speeds of up to 50 Km/h. In the horizontal position, they resist storms if the wind reaches 160 Km/h. At first, the supports "were" in concrete.



Overall Heliostat Field



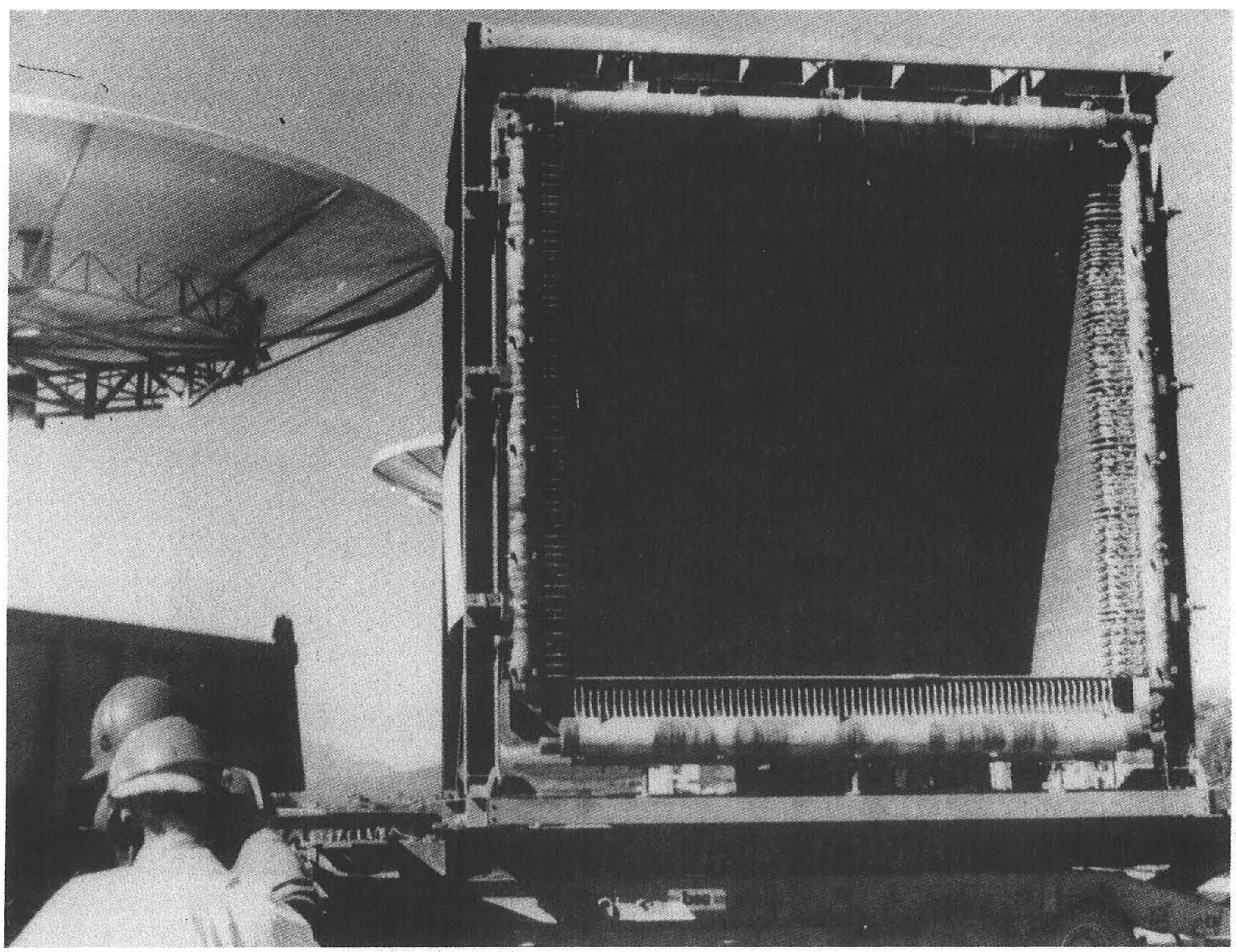
Mirrors of Heliostat



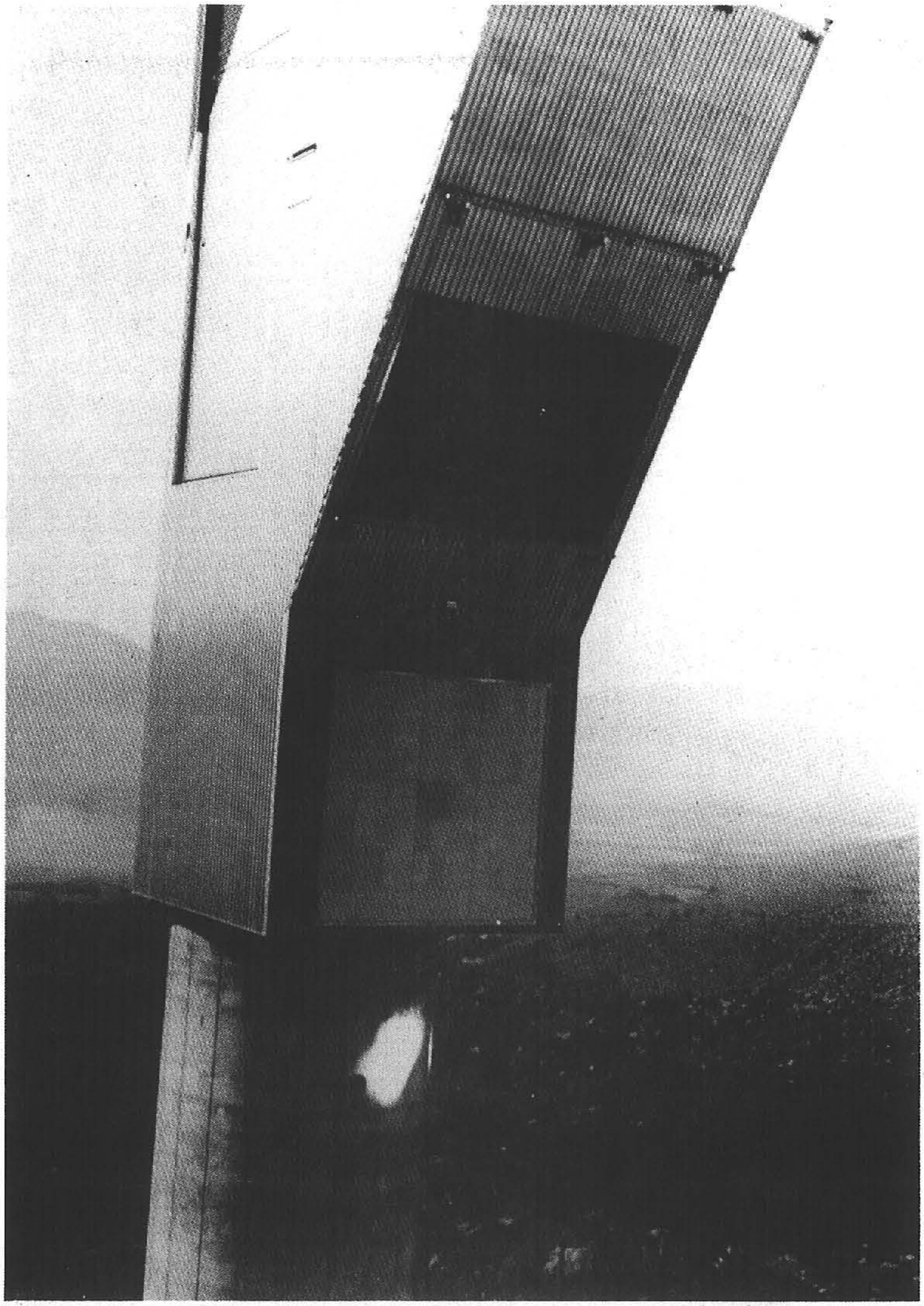
Iron Framework of Heliostats

The Receiver

The receiver is a cubic cavity clad with steel tubes on each face. The molten salt goes over the tubes in series. The regulation isn't easy because we don't know where the hottest point is, and, with the great distance covered by the salt, the time of response is too slow when there are fast moving clouds. The door allows us to keep the receiver hot and to minimize the heat losses in the night or when there is no sun. A camera system studies the sky and calculates if the clouds are important enough or not to close the door; this give us 20 minutes notice.



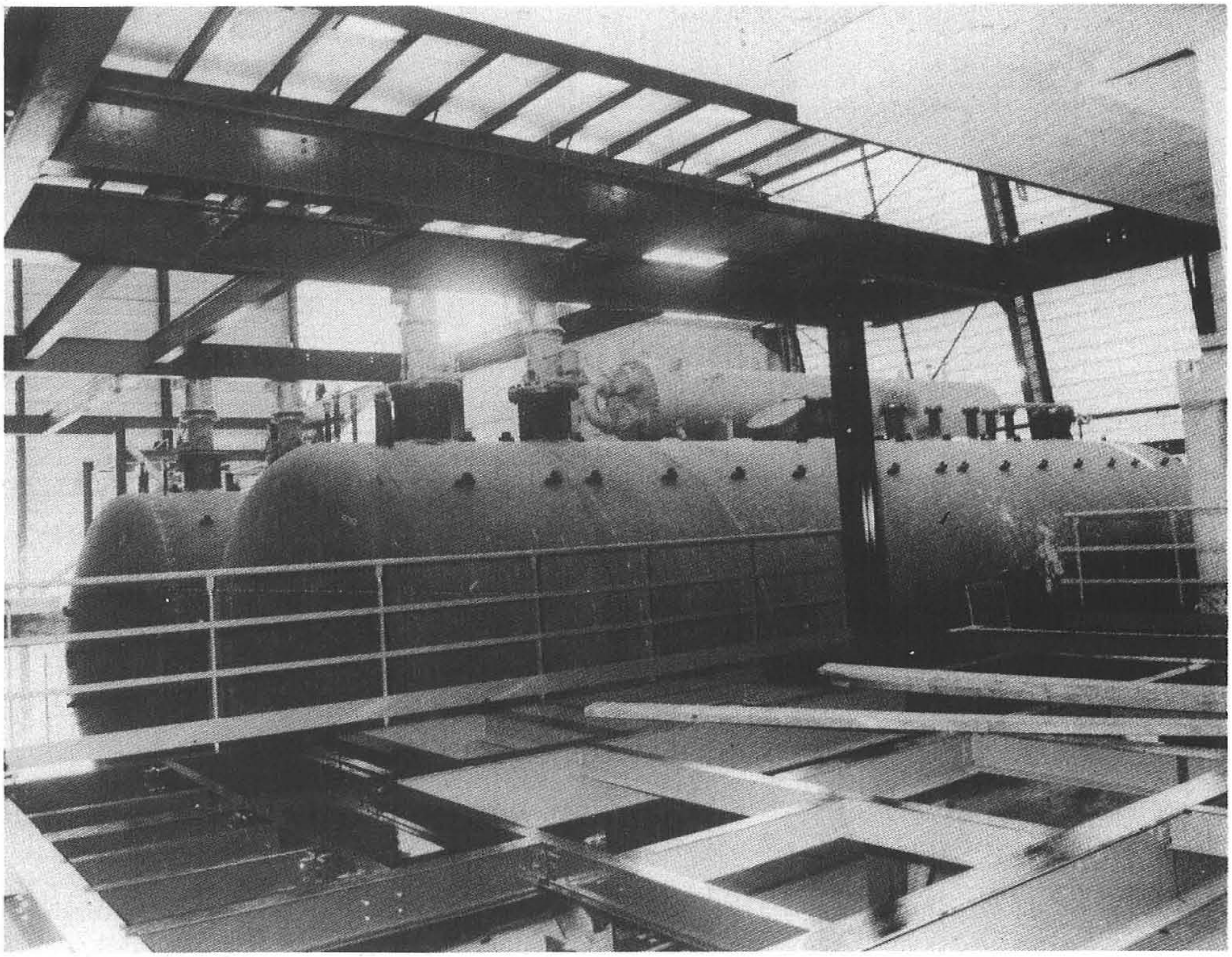
Receiver Manufacture



Receiver With Closed Door in the Tower Top

The Molten Salt Storage

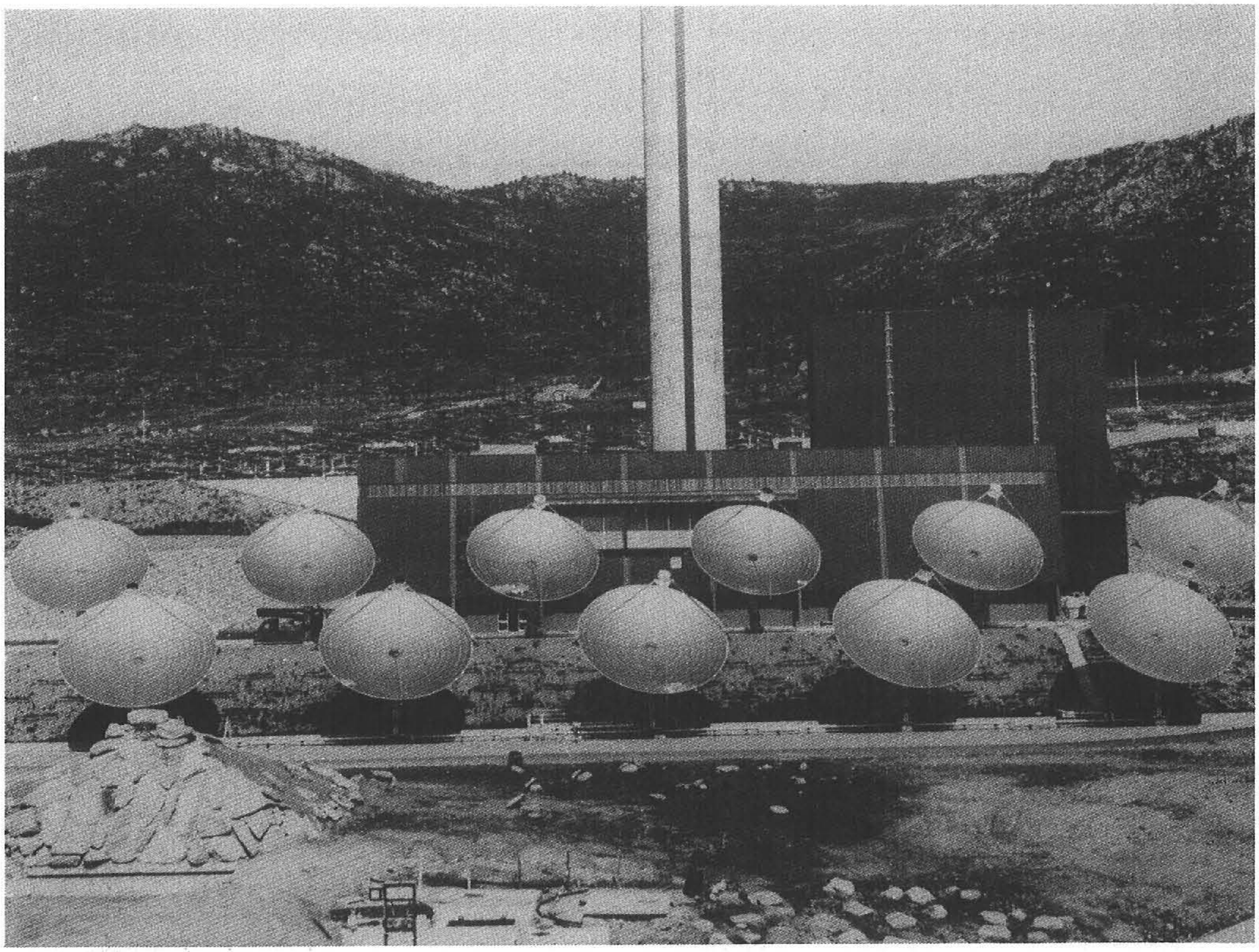
Our storage is very important. But there are only five hours of sunlight.



Molten Salt Storage Tanks

The Auxiliary Heliostats

Eleven dish heliostats of 70 square metres give us auxiliary heat. No problem with them--even if the supplier went bankrupt.



Auxiliary Dish Heliostats

The Control Room

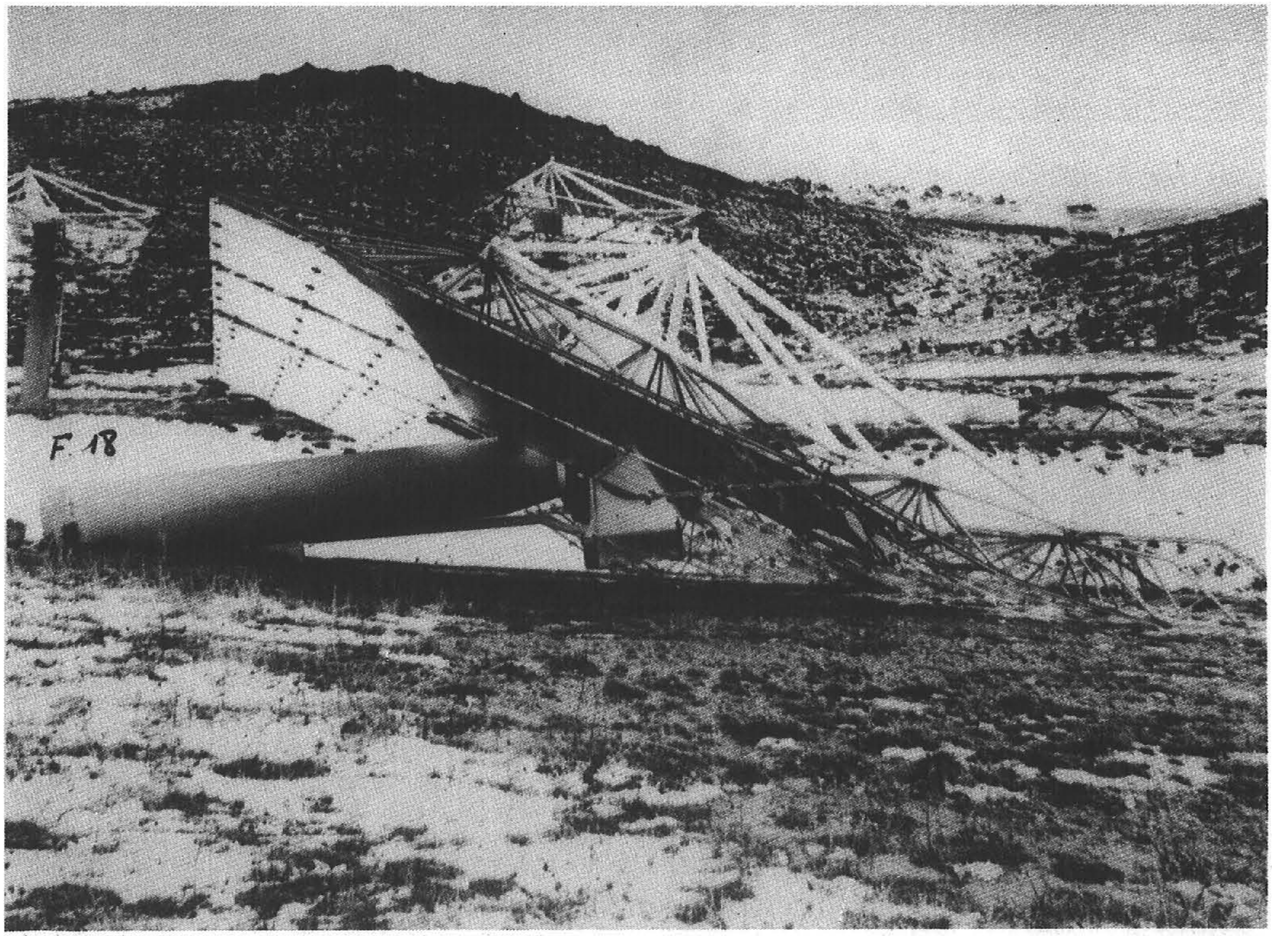
We foresee a control system that is up-to-date, like the system studied for future nuclear plants with electronic bus, programmed automatons, and a master computer. But it's late--1 or 2 years. For the time being, we have a provisional control system that is obviously less up-to-date.

Electrical Output

We hope to supply 3 million KWh a year, with an output of 16%. We have at Targasonne 2,400 sunny hours a year, that is to say, 1,700 June noonday hours.

But, I think you will find all this technical information in the Themis papers.

Heliostat "Crashes" and the Wind



Damaged Heliostat

Twice in 1980, in October and December, we had very bad weather. In the night--it's obvious, the problems cannot come in the day--a gale, perhaps a short hurricane, destroyed a lot of heliostats. The first time, four heliostats fell on the ground and 22 of the others were blown off the horizontal position. The headman on duty reset them horizontally, taking personal risks to handle the control system at the heliostat legs. The second time, same thing: ten heliostats on the ground and 15 of the others left the horizontal position. All the concrete supports were fractured.

We had seven meteorological stations in the place, but those nights they were not on line. We didn't know the wind speeds. We think that the wind speed was over 160 Km/h. We think too the wind went for the mirrors perpendicularly to the rotation axis, pressing against the side, forcing the gears which slid over the shafts and turning the heliostats, so breaking the legs. Perhaps, the strengths were above the design calculations.

Yet, there are no definitive conclusions on those accidents. But, we think the wind direction isn't horizontal in a mountainous country; it approaches the heliostats obliquely. The application point of strength is nearer the side than the center, and so the torque moment becomes destructive.

The repair costs were very expensive--one third more than the initial cost of the heliostat field: reinforcement of pedestals into the ground; replacement of all the heliostat legs (the alternate stresses, tractions and compressions destroyed the concrete unless it was prestressed); we made metallic legs. Finally, we bolted the heliostats themselves on their legs like a cap on a car petrol tank; therefore, the horizontal position is "mirrors facing the sky."

Mr. Lemaignen will speak to you on this subject with a lot of details,if you wish, in the following days.

Heliostats and the Thunder-storms

On this slide, you see the protections against thunderbolts. We have a lightning-rod in the tower top and 3 wires above the heliostat field (you see the 6 posts). But, in spite of those, we had a lot of electrical damage certainly because we are in the track of the storms and not below them.

Lightning Rods

Receiver, Salt Circuits and Clouds

We have a small receiver. The entry area is 16 square metres; the solar focus is nearly 700. As the distribution isn't homogeneous, the solar flux in the center is 800 Km/m^2. The regulation isn't easy, even dangerous.

Today, we think a flat receiver will be sufficient but in a box with a door, so there isn't heat loss when the sun is absent. We are convinced that the heat balance sheet is positive enough over a year to justify the cost without difficulties. However, it's more difficult to do the same on an equatorial circular receiver--every sun has its black spot.

For the same reasons, the salt choice is very interesting, contrary to the water-steam choice. With this last fluid, problems of starting are very difficult; we met those problems in the graphite-gas nuclear plants with the forced-circulation water boilers. When the plant starts, the receiver is cold. The water must circulate in the tubes to drain off the solar heat; then, the water must separate from the steam and drain off the main circuits. The water transfers are important, the losses too. It's a problem for a desert plant without speaking of the chemistry of the water. We think that in cloudy country and for a plant which has to have a lot of daily startings, the cooling fluid must not boil as sodium, salts or gas. The salts seem the more economical.

Heat Storages

We have two heat storages. The first is the main salt storage with 2 tanks--one cold, the other hot. In each of them, when we hope to have an even temperature, it's the contrary: the salt stratifies itself about 30°C a night between the top and the bottom of the tanks. The second is the auxiliary "gilotherm" storage with one tank--hot on the top, cold at the bottom. We hoped to have a greater difference of temperature, but it's the contrary--the fluid homogenizes itself, about 30°C a night. Our conclusion is that we think natural laws exist even in solar technicalities--not too much stratification, not too much homogenization. It's a good design when you have heat storage in reserve; it quickly loses its properties with the time.

Cost

The cost is the true enemy of solar tower plants--at least ours. Today, we have spent 37 million dollars (with the $ at 7 F). The initial estimate was 23 million dollars. Therefore, the increase is 60%.

But, we don't forget we have spent money on the research solar center with design offices, measurements, facilities of extending and transforming the plant. We have spent a lot of money too on adapting the ground. Finally, we have spent on the new electrical control system. We think a French standard solar tower plant of 2.5 MW costs 32 million dollars. The increase is limited to 40%.

We have a working team of 37 persons which costs 1 million dollars a year. With a production of 3 million kWh a year, we think this will come to 1.5 $/kWh.

In E.D.F., where we have a lot of nuclear, hydraulic, coal, oil and diesel plants, two fast nuclear plants and even a tidal power station, this solar plant is more expensive than anything else.

You know the nuclear cost price is 0.03 $/kWh, the coal cost price is 0.06 $/kWh, and the oil cost price is 0.08 $/kWh. Then, you understand solar energy is 50 times more expensive than nuclear energy. A more just comparison is with a small diesel plant of 20 MW; the cost price is 15 times more expensive. (Roughly, imagine the same production a year with 13 heliostats instead of 200, and a tower of 6 metres instead of 100.)

Conclusions

Today, the solar plant handicaps by comparisons with other plants are:

- the great area--3,400 Km^2 to produce the same energy as a nuclear plant of 3,600 MW.

- the production during 1,700 hours a year against 7,000 hours a year.

- the output of 16% against 40%.

- and obviously the cost.

But, I don't remember how many times the first small French nuclear plant ran, how much its output was, and how much money it cost. Perhaps, the conclusions of our former chief of the first nuclear project were as pessimistic as our conclusions about solar energy today. I think so.

SUNSHINE

A 1 MWe CENTRAL RECEIVER TYPE SOLAR THERMAL ELECTRIC POWER PILOT PLANT

Agency of Industrial Science and Technology,
Ministry of International Trade and Industry
and
New Energy Development Organization

1.0 Introduction

Our founding Organization of the Sunshine Project is the Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI). This Project is put forward by the Senior officer for developing programs. New Energy Development Organization (NEDO) is entrusted with the project and it is administered by the Director belonging to NEDO. The technical manager of the project is the Director of the Engineering Development Department of the Electric Power Development Co. Ltd. (EPDC). This facility is to be evaluated by NEDO from the technical and economical standpoints and by Sunshine Project Promotion Headquarters from the political standpoints.

The major supplier of our 1000 kW pilot plant is Mitsubishi Heavy Industries Ltd. (MHI), and the operator of the pilot plant facility is EPDC.

The objectives of this project are to search for technical and economical feasibilities of solar thermal electric power generation plants with a central receiver tower. They are more definitely to verify the technical feasibility, to obtain various data and information for construction, to accumulate various experience for plant operation, to compare with another 1000 kW class solar thermal electric power plant plane parabolic system, and to clarify the problems to be solved until the practical use.

This project was planned in 1974 in AIST as part of the Sunshine project. The schedule of this electric power plant operation studies is shown in Fig. 1.1.

The fundamental design of this project was made in 1977 and construction finished in 1981. Since the approval of the government on August 31, 1981, operational studies including electric power generation have been conducted.

A committee to select the most suitable site was formed in 1975 and consisted of the members of AIST-MITI, solar energy researchers, mechanical engineers and electric power engineers.

The site conditions of the solar plant such as insolation time, climate, natural calamities (earthquakes and typhoons, etc.), available area, traffic, and electric power services and other matters were investigated as a whole. The local people's opinions and wishes were especially taken into account.

After a comprehensive evaluation of these conditions, a former salt field at Nio-Cho in the western part of Kagawa Prefecture of the island of Shikoku was chosen in 1976.

The Nio-Cho is located at N34°12' and E133°39' and its altitude is 5.9 m. The area is open in the direction from the north-west to south and backed by a hill in the other direction as shown in Fig. 1.2. The normal direct insolation at noon in all seasons in the site is about 800 W/m^2 and sunshine hours per year are above 2200 hours. The average atmospheric temperature is 15.8°C. As for wind conditions, the average speed is 12 km/h with a maximum of 130 km/h,which is over ten times the average speed. The average number of days of rainfall in a year is 37 days. The characteristics of it are almost suitable for a solar facility, but the site has considerable partly cloudy weather and morning haze.

2.0 Solar Facility Design

2.1 Basic Design Criteria

Basic design conditions for the pilot plant were finalized by the above-mentioned committee by considering the results of the R&D of the Sunshine Project and the site characteristics in 1976.

The overall system was designed to be able to generate 1 MWe in 2 hours after southing on June 22, summer solstice, according to the specified insolation value of 750 W/m^2 (design point). The energy storage capability amounts to 3 MWeh. The basic design conditions are shown in Table 2.1.

2.2 Facility Description

Concentrated solar energy on the receiver generates high pressure saturated steam. The steam is taken out from a drum at the top of the receiver and then charged into the steam accumulators.

An impulse turbine for electric power generation is driven by the steam from the steam accumulators. A conceptual diagram of the system mentioned above is shown in Fig. 2.1. The specifications of the pilot plant are arranged in Table 2.2.

2.3 Functional Requirements

The designed output of electricity is 1000 kW at 3.5 m/sec wind velocity on the design point (summer solstice). The design performance of the system is shown in Table 2.3.

3.0 Solar Facility Characteristics

The heliostat is shown in Fig. 3.1 (a) and (b). Each heliostat is 4 meters by 4 meters and composed of 16 mirrors. This type of heliostat is called a G-L mount heliostat. The rotating axis is parallel with the earth's axis. Supposing that triangle ABM is an isosceles triangle in the Figure, AM indicating the receiver and BA indicating the sun, MB will become, in any case, a line to divide the angle equally which is composed of the sun, mirror and receiver.

The mirror is installed perpendicularly to MB, the reflected solar radiation is parallel with AM, namely, it reaches the receiver. Therefore, if the axis C is revolved at the same speed of 15°/h as that of the sun, tracking can be performed exactly. The altitude of the sun changes according to the season of the year, so that the revolution correction is made by changing the direction of BA once a day.

A receiver is a device which receives the solar radiation collected with the heliostat system and converts it into heat. As the absorbing surface's temperature becomes high and thermal loss arises due to convection air currents and radiation, it is indispensable to develop a receiver with good conversion efficiency from solar radiation to heat or with the most absorbing efficiency. The structure of the receiver is shown in Fig. 3.2 (a). The receiver is a cavity receiver with a cone-shaped and cylindrical membraneous wall. The inner surface of the cone and the outer surface of the center pole are the heat receiving surfaces. The receiver, which has a steam drum at the top of it, generates saturated steam by natural circulation. The receiver under operation is shown in Fig. 3.2 (b).

The thermal storage system is composed of 5 steam accumulators. The capacity of the accumulators is 3 hours of rated output. The maximum pressure of the accumulator is 40 ata. The structure of the accumulator is shown in Fig. 3.3.

The power conversion system is shown in Fig. 3.4. An impulse type steam turbine is used for power generation and the steam condition at the turbine inlet is 12 ata and 187°C (saturation). The steam condition at the receiver outlet is 40 ata and 249°C (saturation).

Operation and control of the solar plant system in normal condition are as follows:

(a) Heliostats are driven at the speed of 0.125° per every 30 seconds accordingly as the sun rotates in the daytime. Revolution correction is made once a day.

(b) Steam flow rate from the receiver is controlled to keep the pressure at the receiver outlet constant. Feedwater flow rate is controlled to keep the water level in the steam drum constant while steam flow rate changes.

(c) The steam pressure at the turbine inlet is controlled to be constant by a valve at the outlet of the accumulators.

In an emergency operation, the plant is operated as follows:

(a) The operation mode of the heliostats is immediately changed from the normal to emergency mode. In this mode, the eastern half of the heliostat is adjusted half an hour later than the correct time, and the western half is adjusted half an hour faster. All heliostats are driven at normal speed in this situation in order to be able to get back to the normal mode quickly.

(b) Heliostats are stowed in the flat position to avoid wind load when the wind velocity exceeds the design velocity.

(c) An emergency diesel generator has to be furnished, because it is difficult to drive all heliostats manually.

(d) When the receiver is in an emergency condition, e.g., water level in the steam drum is too low, the heliostats are controlled to transfer to the emergency mode.

The data acquisition system is shown in Fig. 3.5. A mini-computer is furnished for plant operation and data logging. A data logger is furnished for data logging which is used for system analysis.

Figure 3.6 shows the items to be measured by the data logger.

A reflected beam sensor is furnished to measure the tracking error of a heliostat. The sensor detects the deviation to the reflected beam from the designed direction as shown in Fig. 3.7 (a) and Fig. 3.7 (b).

4.0 Solar Facility Construction

Conceptional Design including feasibility study and R&D of the components was initiated at the same time of the starting of the Sunshine Project, July 1974, by MHI under the contract to the AIST. The basic specification of the solar pilot plant was finalized through the detail designing in FY 1977. After the manufacturing design was carried out in 1978, construction lasted for two years from 1979. The schedule of the construction was already shown in Fig. 1.1.

EPDC was responsible for the foundation, utility and power generating buildings. For the main solar thermal pilot plant, MHI was responsible.

The installation and assembling of all the components and systems were completed in March 1981. Following the check out of the components and systems, functional tests of the pilot plant were carried out for about five months from April. The first try to generate 1 MW electricity was put in operation successfully on August 6, 1981, near the end of the testing and adjusting period. The pilot plant passed all functional tests and examinations for an electric power generating plant at the end of August 1981 by the government office of MITI, and the pilot plant was approved as a power test plant. The operational studies by EPDC have been carried out since September 1, 1981.

Total cost of the solar pilot plant facility is 5000 MY. The items of the cost are shown in Table 4.1. The cost of the heliostat system is about half of it.

5.0 Solar Facility Performance

5.1 Collector System

Heliostats are designed and installed in 1 degree of tracking error. Seasonal and transient changes of the tracking error of 4 heliostats were measured by reflected beam sensors. The tracking errors are about within 1 degree, but sometimes over 1 degree as shown in Fig. 5.1.

5.2 Receiver System

The absorbing efficiency of the receiver proved to agree with the design value as shown in Table 5.1. Collected light energy is measured by 64 heat flux meters and the absorbed energy is evaluated from steam flow rate at the receiver outlet. Absorbing efficiency is defined as the absorbed energy divided by the collected light energy.

Natural circulation of water in the receiver was checked and confirmed to be in good circulation of water.

Air convective heat transfer coefficient on the receiver surface was also measured to be about 6 $kcal/m^2h^\circ C$ in the velocity range of wind 0-0.3 m/sec as shown in Fig. 5.2.

5.3 Storage System

The temperature distribution in the gravity direction in accumulators was examined in each accumulator. It is found that the temperature difference is always in 2°C, both in the operation of heat charging and in the operation of heat discharging as shown in Table 5.2. The accumulators as a heat storage are proved to be used at the full capacity.

5.4 Total Plant System

The plant system as a solar power generating station has been operated successfully except for a few trivial failures. Some typical examples of the operation performances are shown from Fig. 5.3 (a) to Fig. 5.3. (c). Electricity is generated when the pressure in the accumulators is increased sufficiently in a few hours after the heat charging, and the more the insolation, the more the electricity output. It is quite a reasonable result.

A relation between the electricity output and the insolation is shown in Fig. 5.4. The figure indicates the threshold value of insolation necessary to generate electricity in the weather conditions at Nio. The direct insolation at Nio, as shown in Fig. 5.5, varies widely from day to day. Therefore, the optimal operation corresponding to the variation has to be selected for maximum electricity output.

6.0 Operation and Maintenance

The pilot plant is not aimed to be operated at night, but in daytime only. During the operational studies which are planned to be carried out for two and a half years, four modes of operation are scheduled. The modes are as follows:

1) The mode with a standard load pattern having a rated output of 2 hours or 1 hour (only in winter) in the evening and reduced output for the daytime.

2) The mode with a constant load of a half-rated output.

3) The mode with a constant load of rated output.

4) The mode following the insolation pattern.

It is expected from the results of the operation with these load patterns that the most suitable operation mode with some appropriate load patterns will be chosen for the solar plant at Nio. The reflectance of the mirrors reduces about 4% in two weeks after cleaning, because the site is near the sea shore. Therefore, it does not get worse. The cleaning method is to mop up by hand. So it takes about 15 days by 6 workers to clean all of the mirrors. The storage system of this plant has a capacity of 3 MWhe with 5 steam accumulators. Heat loss of them was unexpectedly large during the early days of operation. It was due to the thermal loss at the supporting part of the accumulators. After that, thermal insulation of that part was improved so as to reduce the heat loss. The data acquisition system has been in normal operation. But it is becoming clear that more detailed information should be added. So a few modifications of the system are under consideration.

The pilot plant of 1 MWe is a small capacity power plant with the rate of the parasitic load being relatively rather large. It amounts from 17% to 18% even in rated power operation. To reduce this load, time for powering of the pumps was rearranged. The rate of parasitic load was reduced by about 20% by the rearrangement of the pumping power time.

7.0 Summary

We experienced a few problems in a year. The utilization factor of thermal energy was low at the beginning of the operation, because heat loss from the accumulators and pipes was large. As the result of improvement in the thermal insulation of the accumulators and the leakage of steam from valves and a decrease of the number of operating accumulators from 5 to 2, the utilization factor was increased from 0.35 to 0.79.

Optical system efficiency is dependent on the season. The main cause is considered to be condensed moisture on the mirror surfaces of the heliostats at night.

For future projects, it is essential to solar power plants to prevent the small losses of heat which are gathered from a wide area. It is also necessary to keep the matching between the solar collector system and thermal storage system.

The confirmation of the reliability of the heat receiver is important. Heat absorbing tubes in the receiver experience violent temperature cycles every day and night and in every shadow from clouds even in sunny days.

Thermal insulation materials and valve and pipe joints which have both good thermal insulation and small heat capacity as characteristics must be developed in parallel with the development of main components.

8.0 Future Plans

We are confirming for the present Nio pilot facility to operate without any more troubles. We also consider that the facility should be examined thoroughly in technical and economical points and the data of operation should be gathered as much as possible. We are going to operate some modes following our schedule. That is, they are operating modes of 1000 kW constant electric output, of 500 kW constant electric output and mode following the insolation pattern.

For the aim of economical and reliable facilities, development of components has been continued from the standpoint of a long-term schedule. Furthermore, in this situation of very high construction cost, investigations to cut costs drastically should be at first strongly pushed and the results of other tower electric plants including thermal-electric hybrid systems should be examined and evaluated.

It is important to clarify the problems to be solved until the practical use of solar thermal energy is achieved.

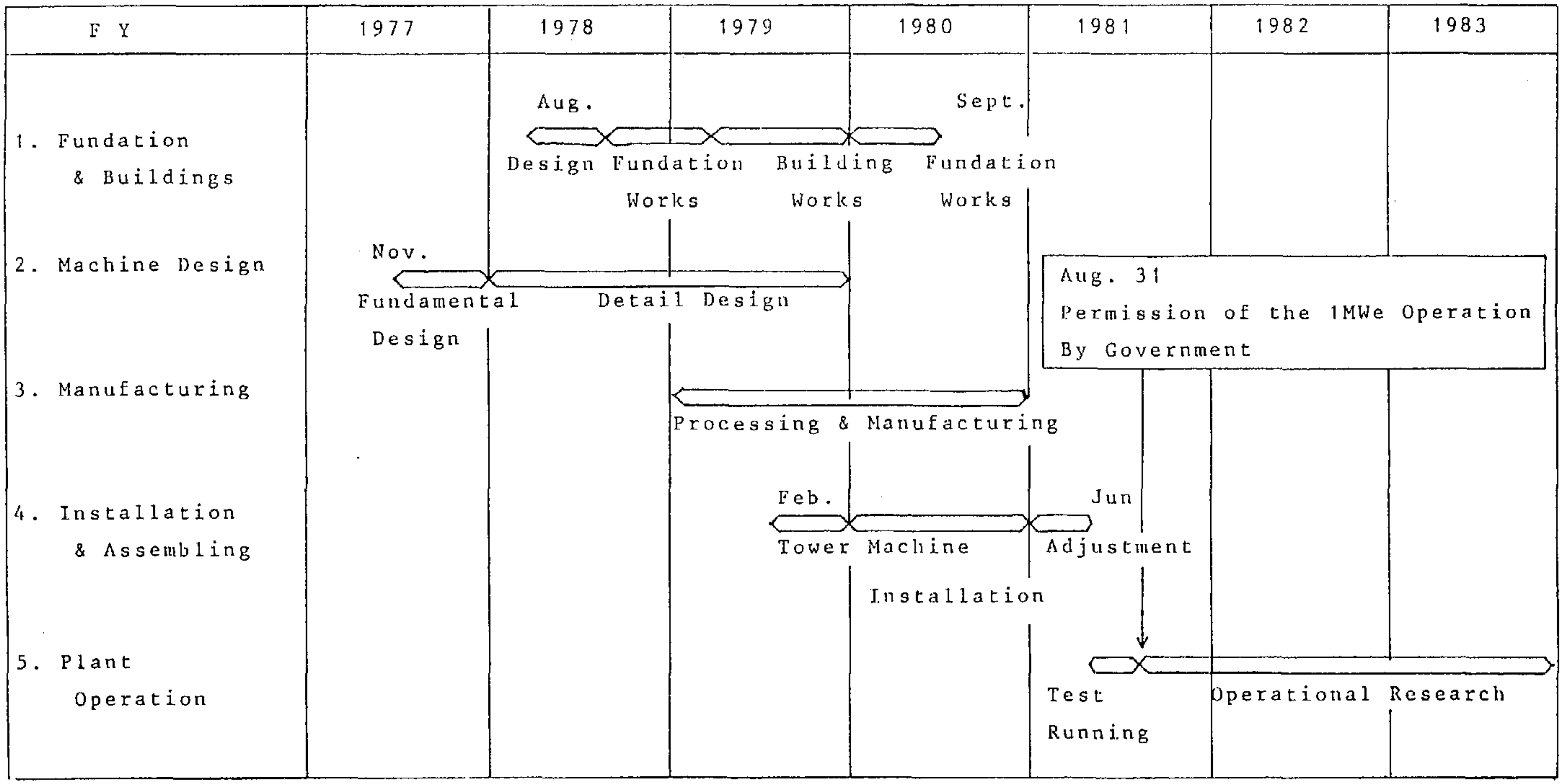


Figure 1.1 Schedule and Milestones of SUNSHINE Project

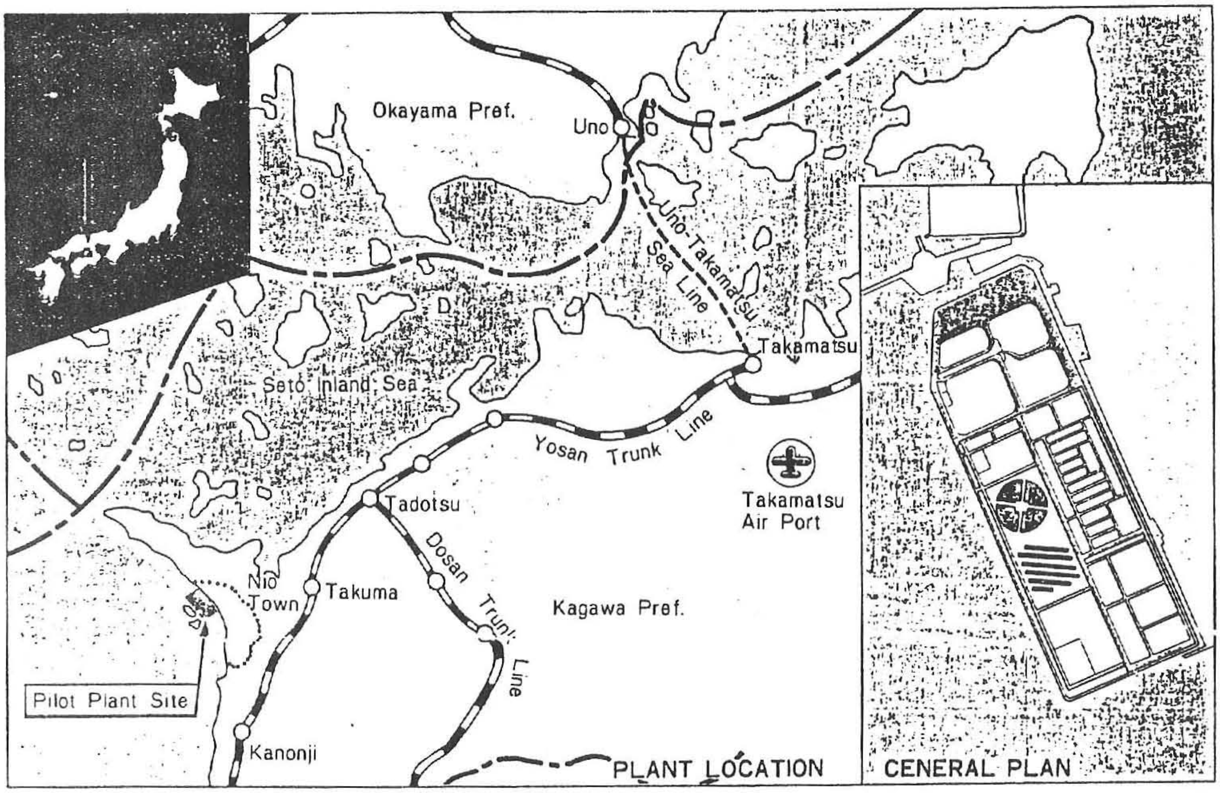


Figure 1.2 Site of the Pilot Plant

Table 2.1 Basic Design Condition

Electric Power Output	1,000kW (Gross)
Insolation	0.75 kW/m^2 at 2hours after southing on June 22 (Summer solstice)
Heat Storage Capacity	1,000kW_e × 3hours
Wind Velocity (10 m from G.L.)	3.5m/s for full performance 10.0m/s for operation 50m/s for survival
Seismic Acceleration	Up to 0.2 G
Coolant for Condenser	Sea Water, 28°C(max), 7°C(min)

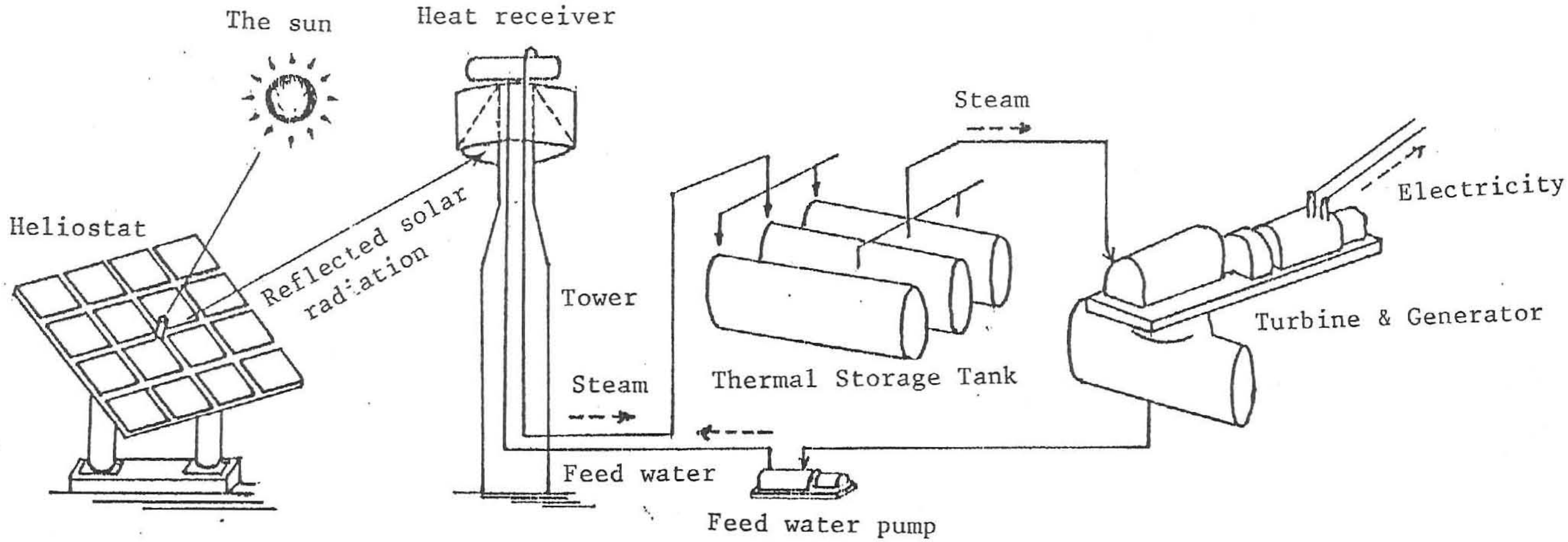


Figure 2.1 Conceptual Diagram of the Pilot Plant

Table 2.2 Specification of the Pilot Plant

Heliostat	reflctor area	16 m^2 (4m × 4m)
	number of heliostats	807
	total reflective surface area	12,912 m^2
Receiver	cone-shaped cavity type	
	diameter of cavity	8.5 m
	steam at receiver outlet	40 kg/cm^2, 249°C
	steam flow	9,200 kg/h
	tower hight	69 m
Thermal storage	steam accumulator	60 m^3 × 5 units
	pressure range	13~40 kg/cm^2 abs.
Turbine	impulse turbine	
	inlet condition	12 kg/cm^2, 187°C

Table 2.3 Design Performance of the Plant

	Partial efficiency	Cumulative efficiency	Energy output
			kW
Direct normal radiation		1.0	9,684
Availability of reflector	0.862	0.862	8,348
Reflectivity	0.88	0.759	7,350
Concentration efficiency	0.985	0.748	7,242
Absorbing efficiency	0.822	0.614	5,950
Turbine generator efficiency	0.168	0.103	1,000
Total plant efficiency		0.103	1,000

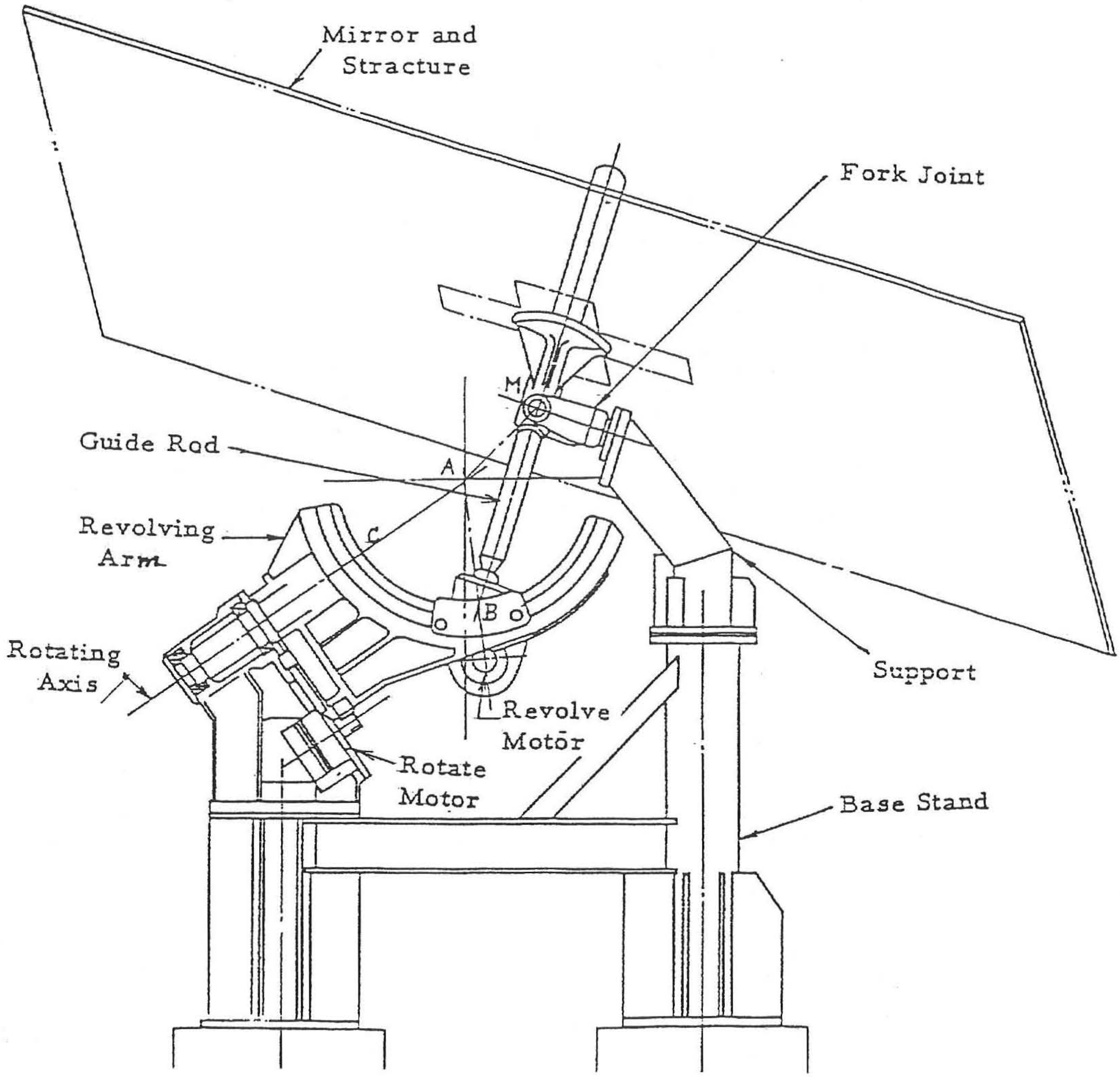
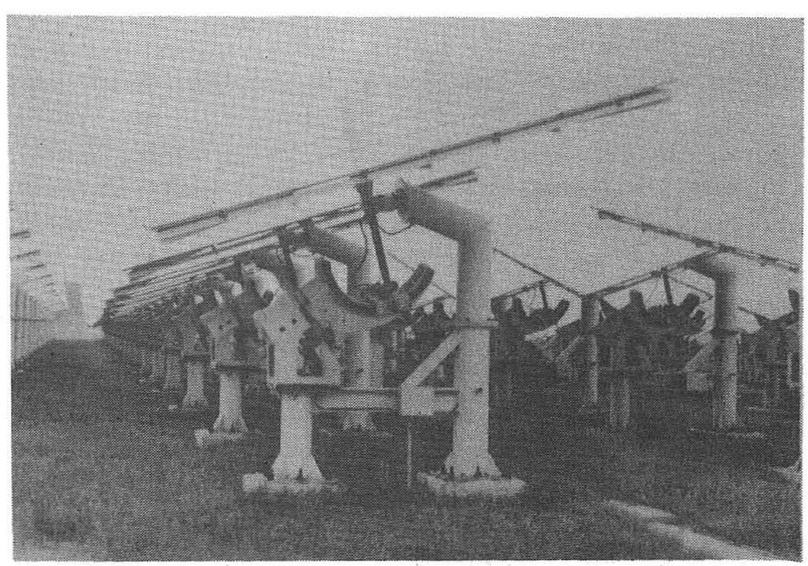


Figure 3.1(a) G-L Type Heliostat

Figure 3.1 (b) Heliostat



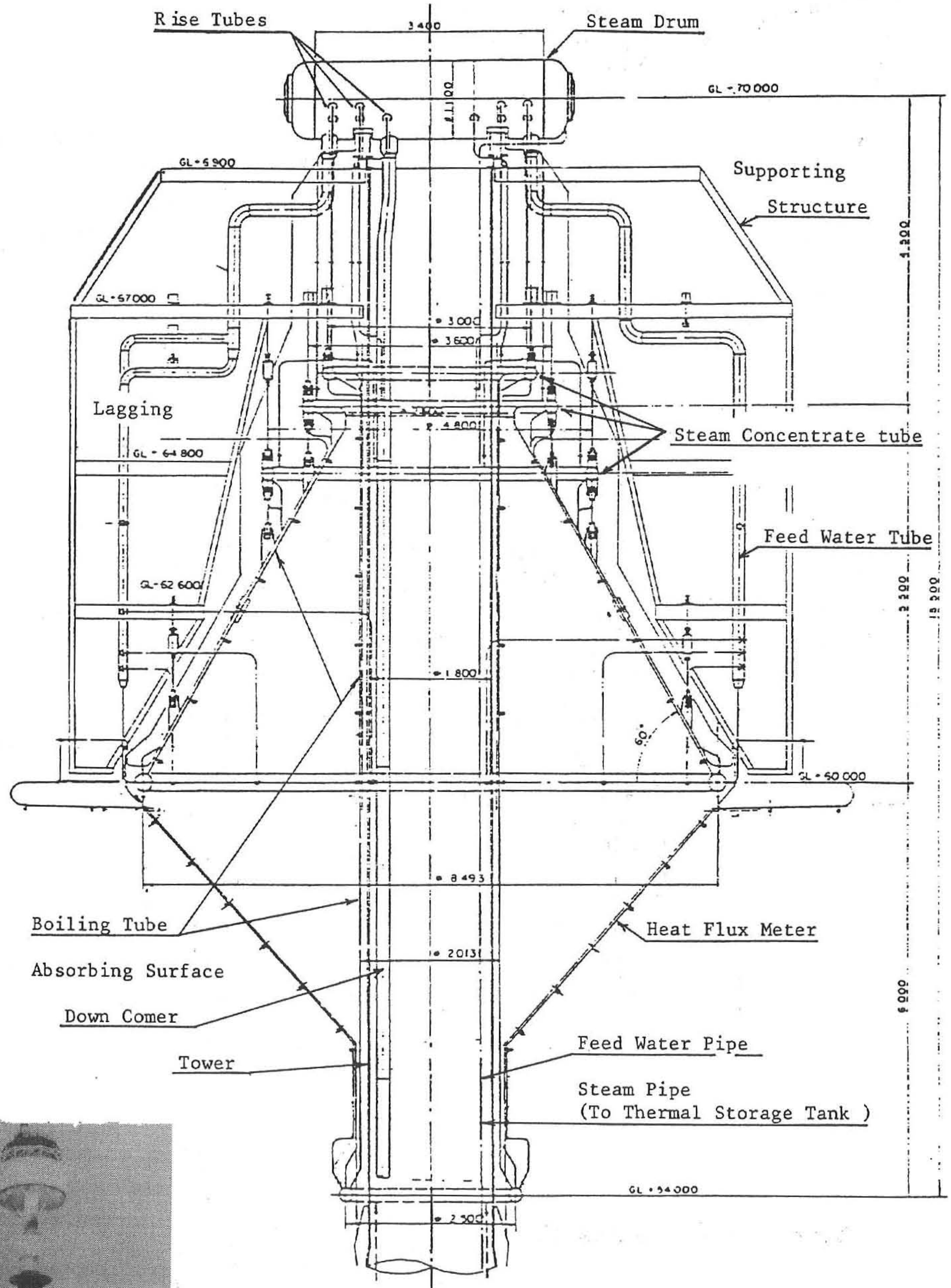


Figure 3.2(a) Cavity Type Receiver

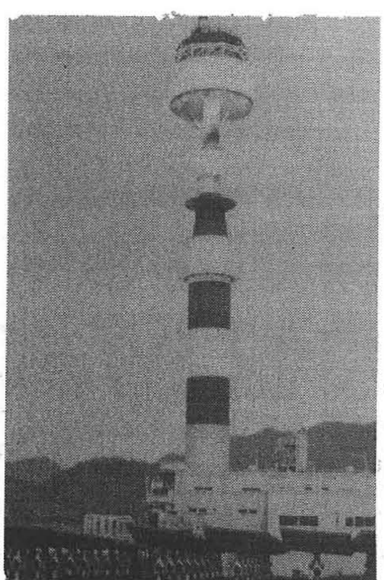


Figure 3.2(b) Receiver Under Operation

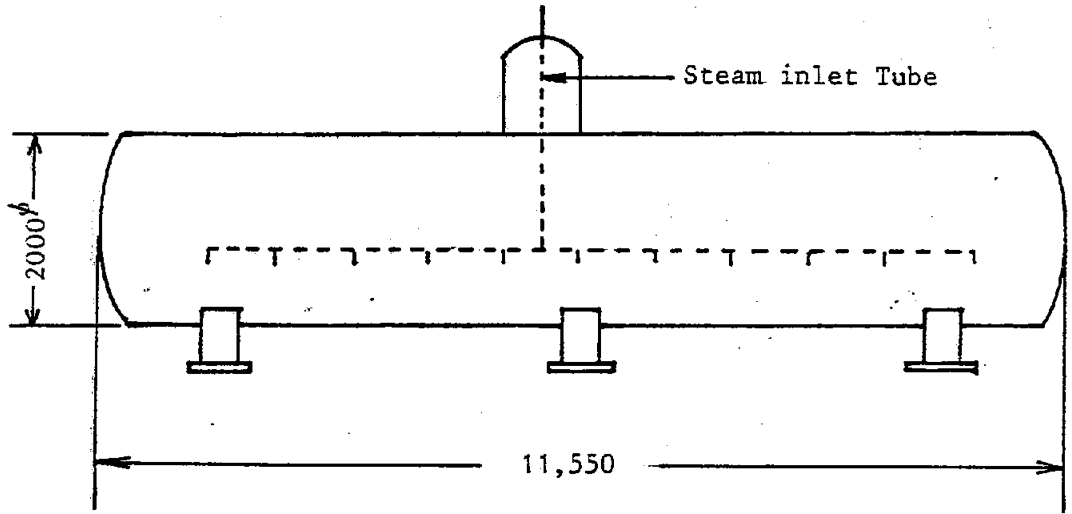


Figure 3.3 Structure of Accumulator

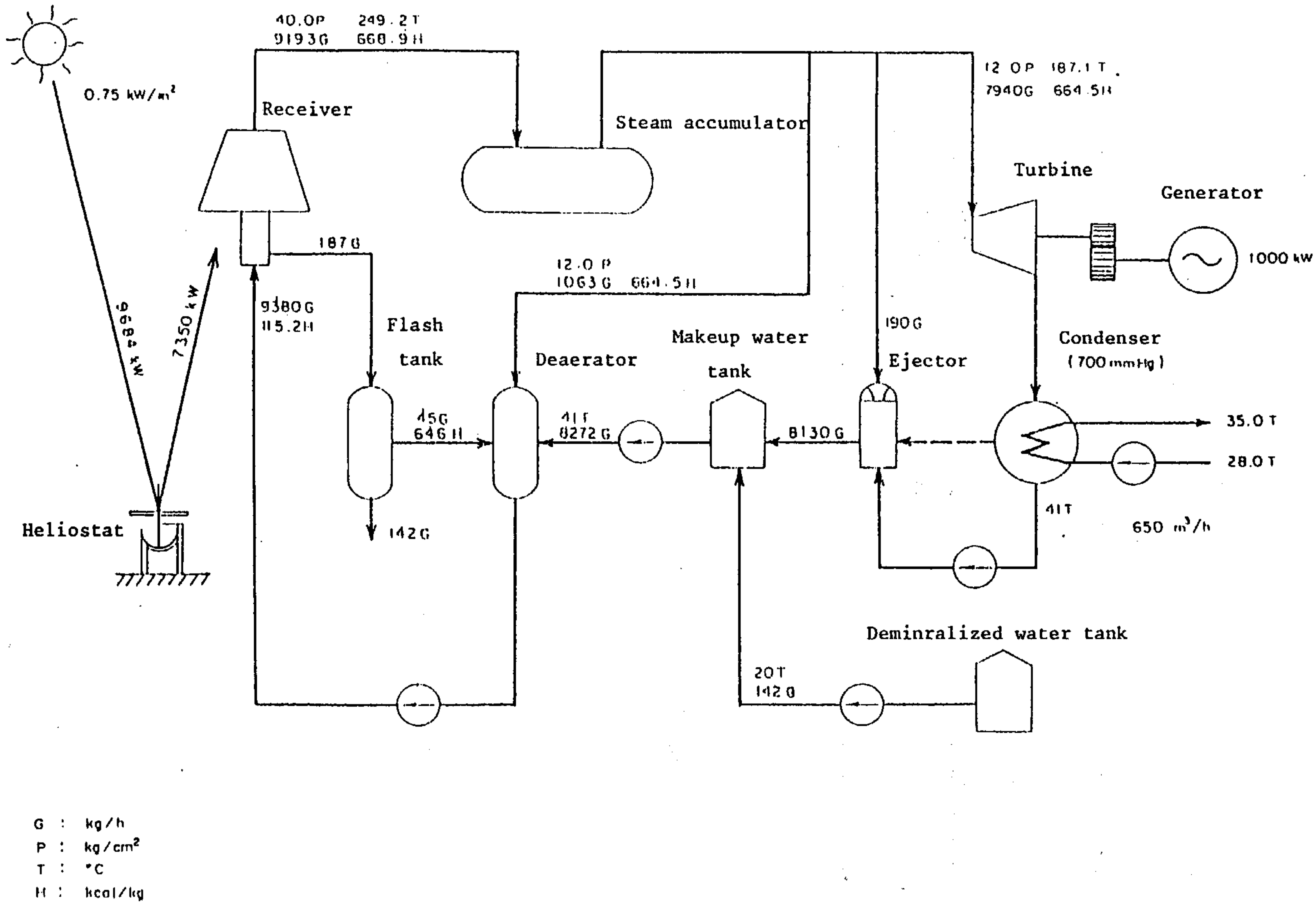


Figure 3.4 Power Conversion System

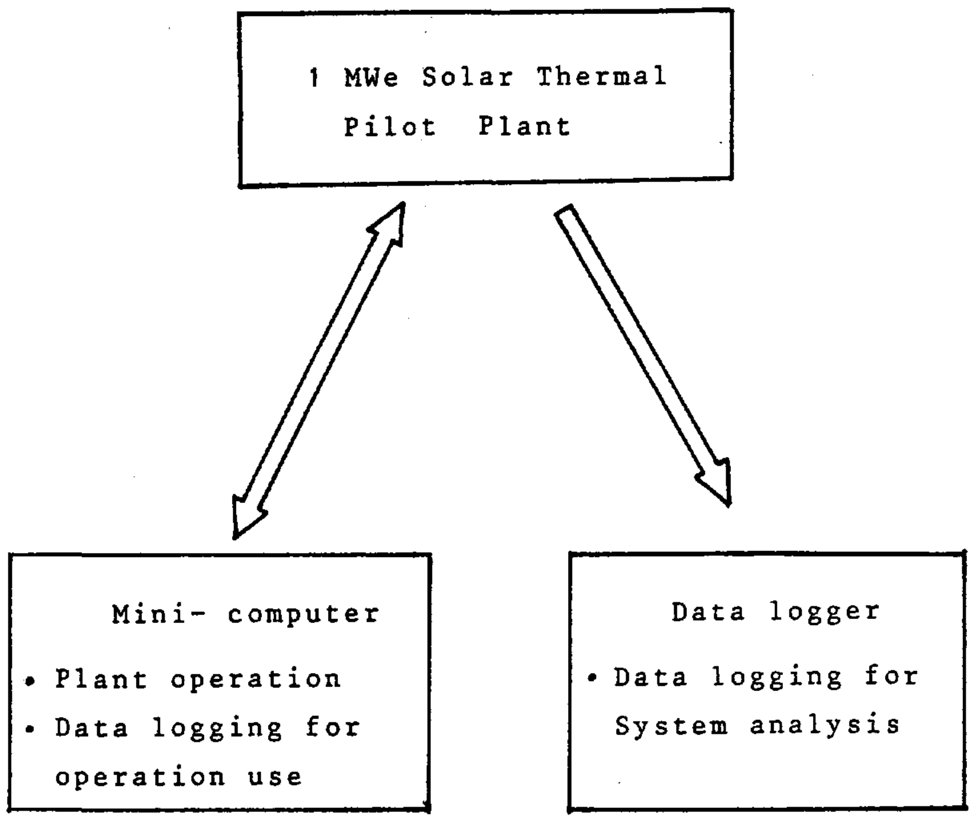


Figure 3.5 Data Acquisition System

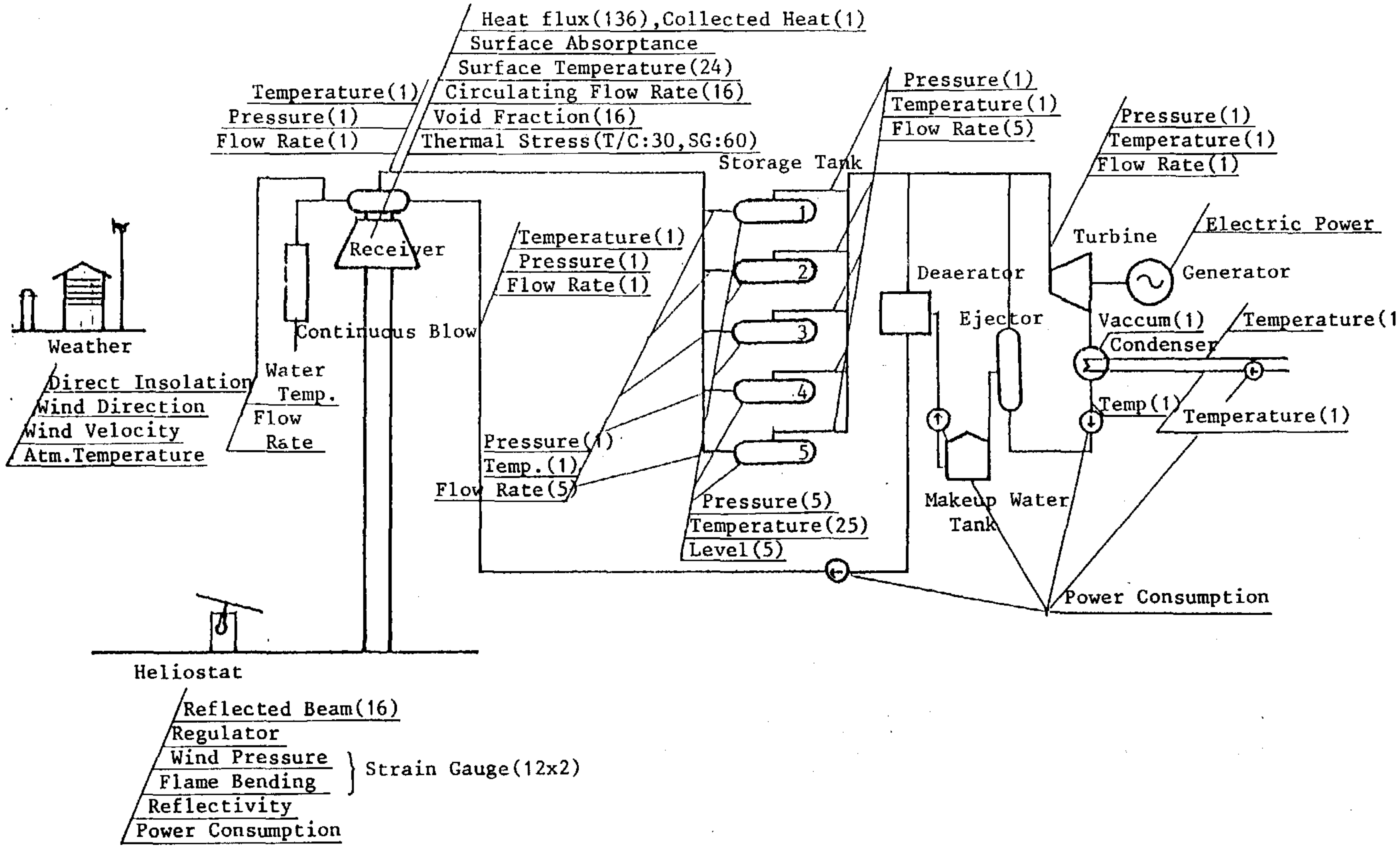


Figure 3.6 Items to be Measured

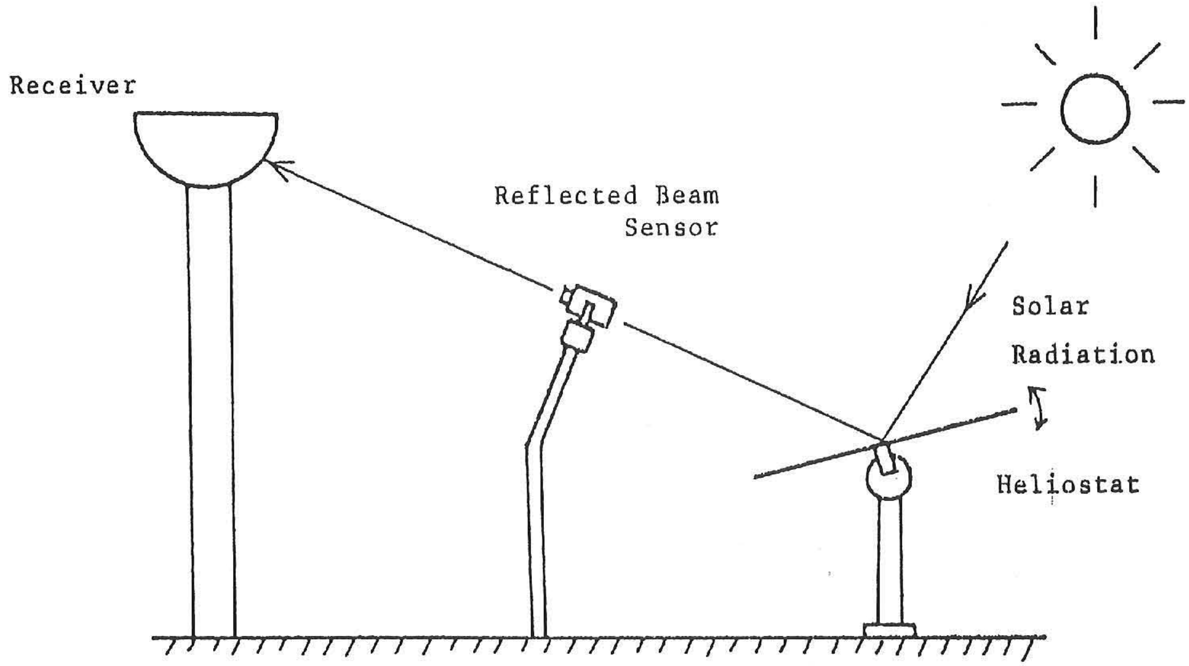


Figure 3.7(a) Reflected Beam Sensor

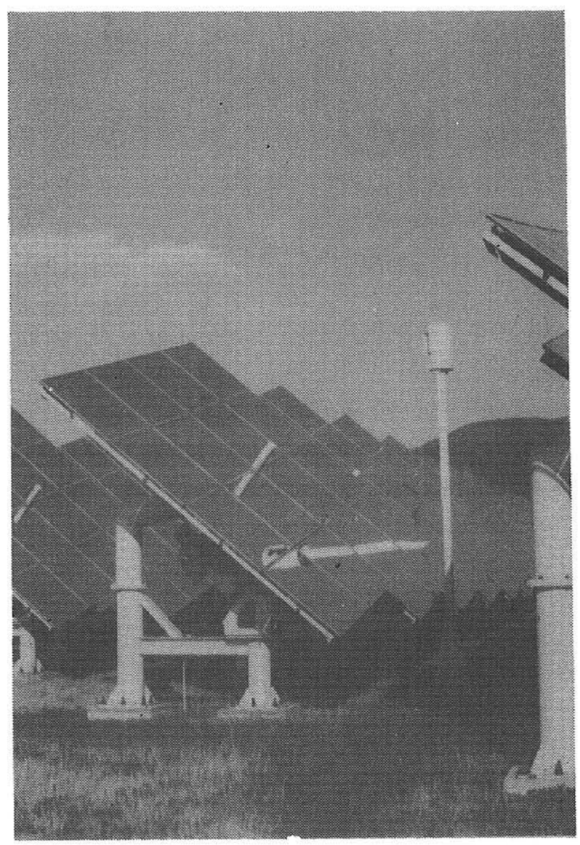


Figure 3.7(b) Reflected Beam Sensor

Table 4.1 Cost of Construction

Ttems	Cost (M¥)
Heliostat System	2200
Receiver System	400
Heat Storage System	300
Power Conversion System	400
Control and Data Acquisition System	700
Utility	1000
Total	5000

Table 5.1 Efficiency of Receiver

Feb.15,1982 Data

Time	Normal Direct Insolation	Theoretical Collected Heat (A)	Obs. Collected Heat (B)		Opt. System Efficiency (B)/(A)	Absorbed Heat		Heat Absorb. Efficiency	Wind Velocity	Air Temp.
	kWh/m^2	kWh	gross kWh	net kWh	%	gross kWh	net kWh	%	m/sec	°C
11:00	0.894	7162.7	6062.4	6003.2	83.81	5142.9	5141.4	85.64	1.8	6.4
12:00	0.910	7391.4	6203.6	6140.5	83.08	5194.2	5192.5	84.56	1.9	7.1
13:00	0.895	7394.8	6059.8	6002.3	81.17	5168.7	5166.9	86.08	1.6	8.0
14:00	0.828	6495.6	5480.7	5403.4	83.19	4262.9	4261.5	78.87	0.5	6.3
15:00	0.719	4763.8	4109.1	4021.0	84.41	2555.9	2554.3	63.52	0.7	6.3

Ave.Efficiency of Optical System 83.13%

Standrad Efficiency of Heat Absorbing at the Summer Solstce 14:00 (Design Value) 85.50%

Table 5.2 Performance of Accumulators

		No. 1	No. 2	No. 3	No. 4	No. 5	Total
Inlet	Press. (kg/cm2g)						26.8
	Temp. (°C)						230.4
	Flow rate (T/h)	0.000	0.000	4.936	0.000	4.860	
Inside	Press. (kg/cm2g)	.7	.7	26.9	.3	27.0	
	Level (m)	0.000	0.000	.670	1.499	.766	
	Temp. 1 (°C)	64.7	42.4	229.8	37.3	229.4	
	Temp. 2 (°C)	63.7	44.5	229.4	30.6	229.5	
	Temp. 3 (°C)	62.3	45.5	229.2	24.4	229.5	
	Temp. 4 (°C)	54.7	37.2	229.4	37.2	229.4	
	Temp. 5 (°C)	47.1	31.5	229.4	18.0	229.6	
	Ave. Temt. (°C)	58.5	40.2	229.4	26.1	229.5	
Outlet	Press. (kg/cm2g)						26.8
	Temp. (°C)						230.3
	Flow rate (T/h)	0.000	0.000	4.779	.229	5.370	
Heat balance	charged energy flux(kw)	0.0	0.0	3864.7	0.0	3805.4	7670.1
	discharged energy flux(kw)	0.0	0.0	3740.8	179.0	4203.7	8123.5
	storaged energy (kw·h)	2757.2	2061.1	12202.9	3528.9	12602.5	33154.5

№ 2

X − 11, Y − 13

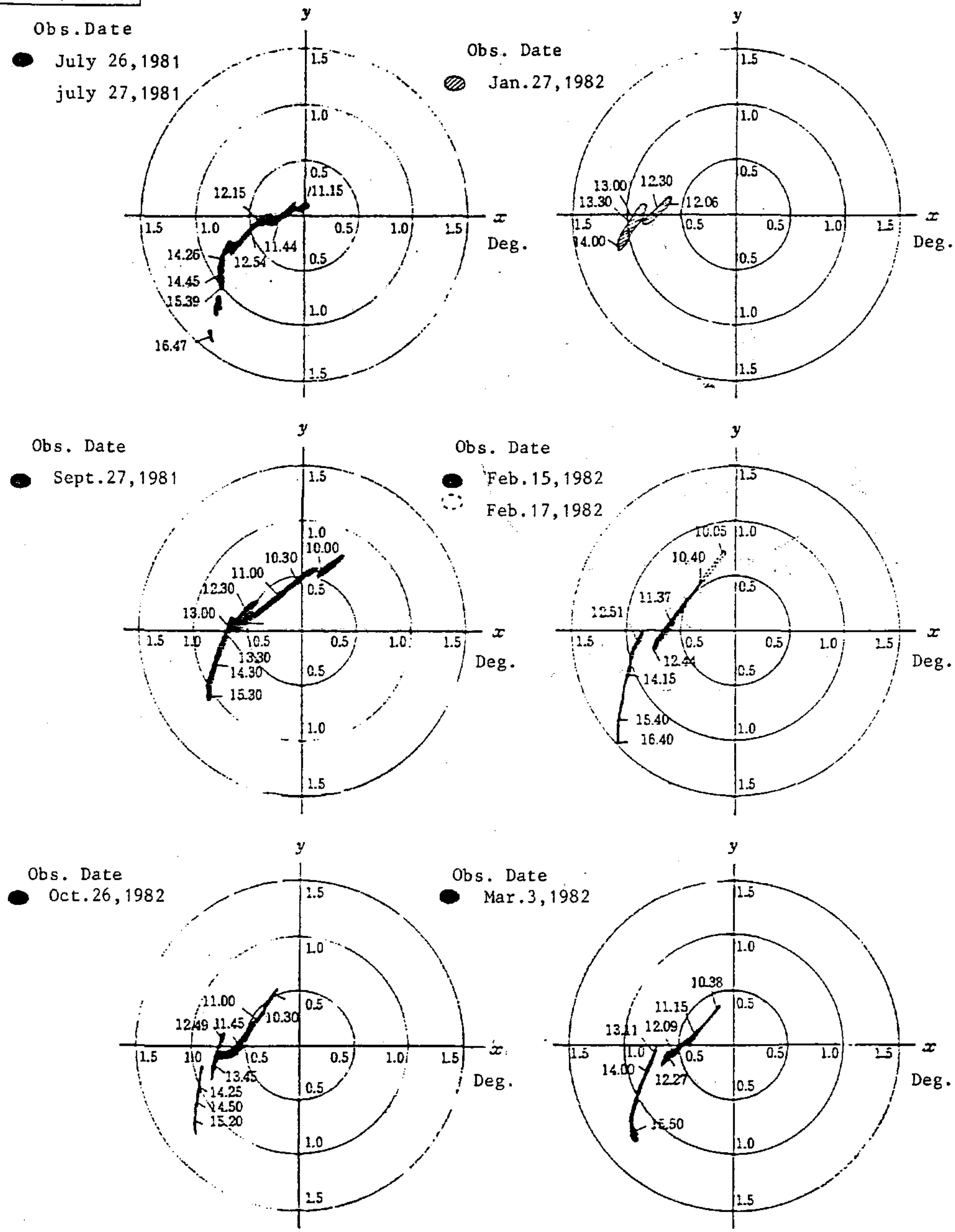


Figure 5.1 Measured Tracking Error

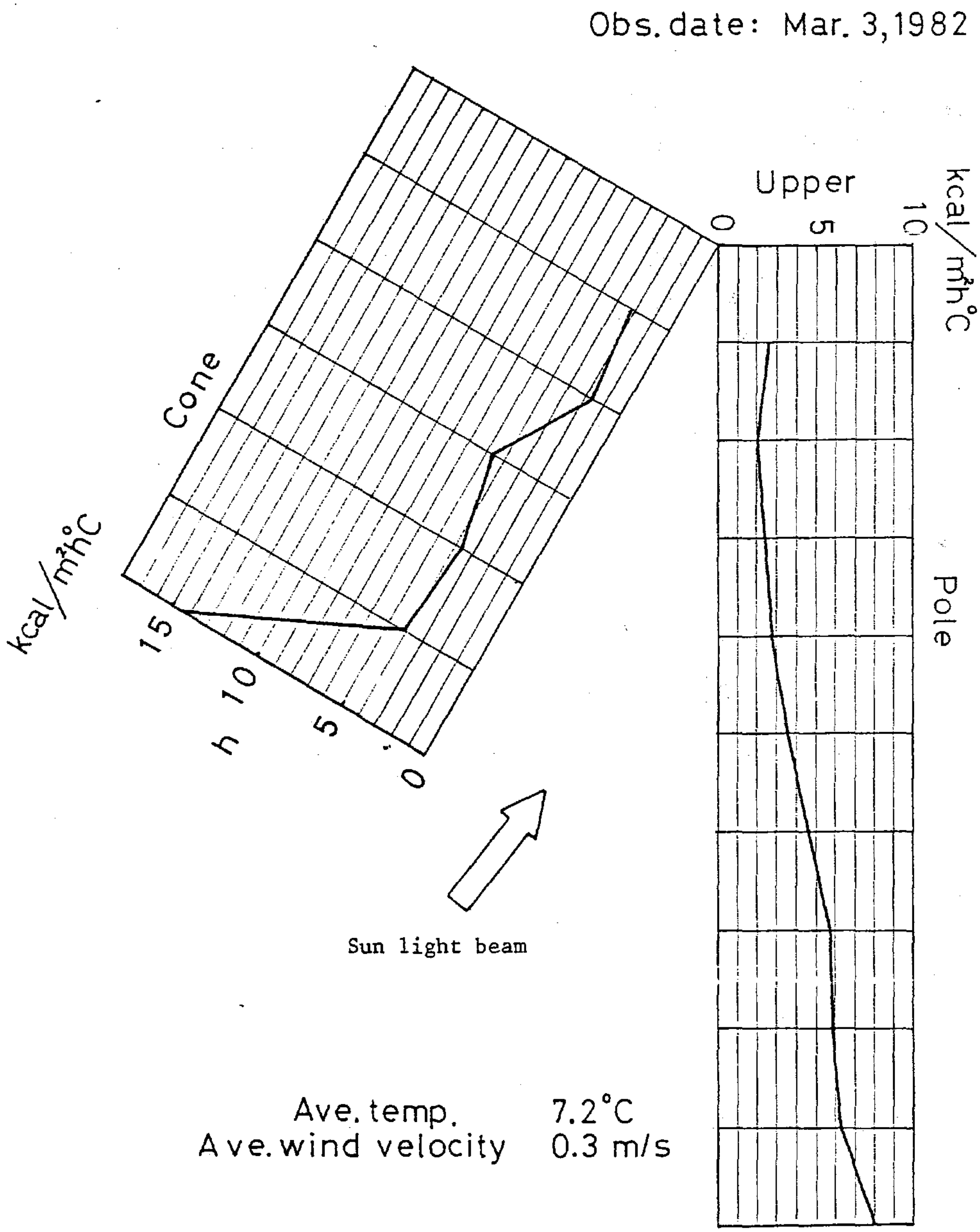


Figure 5.2 Convective Heat Transfer Coefficient on Receiver Surface

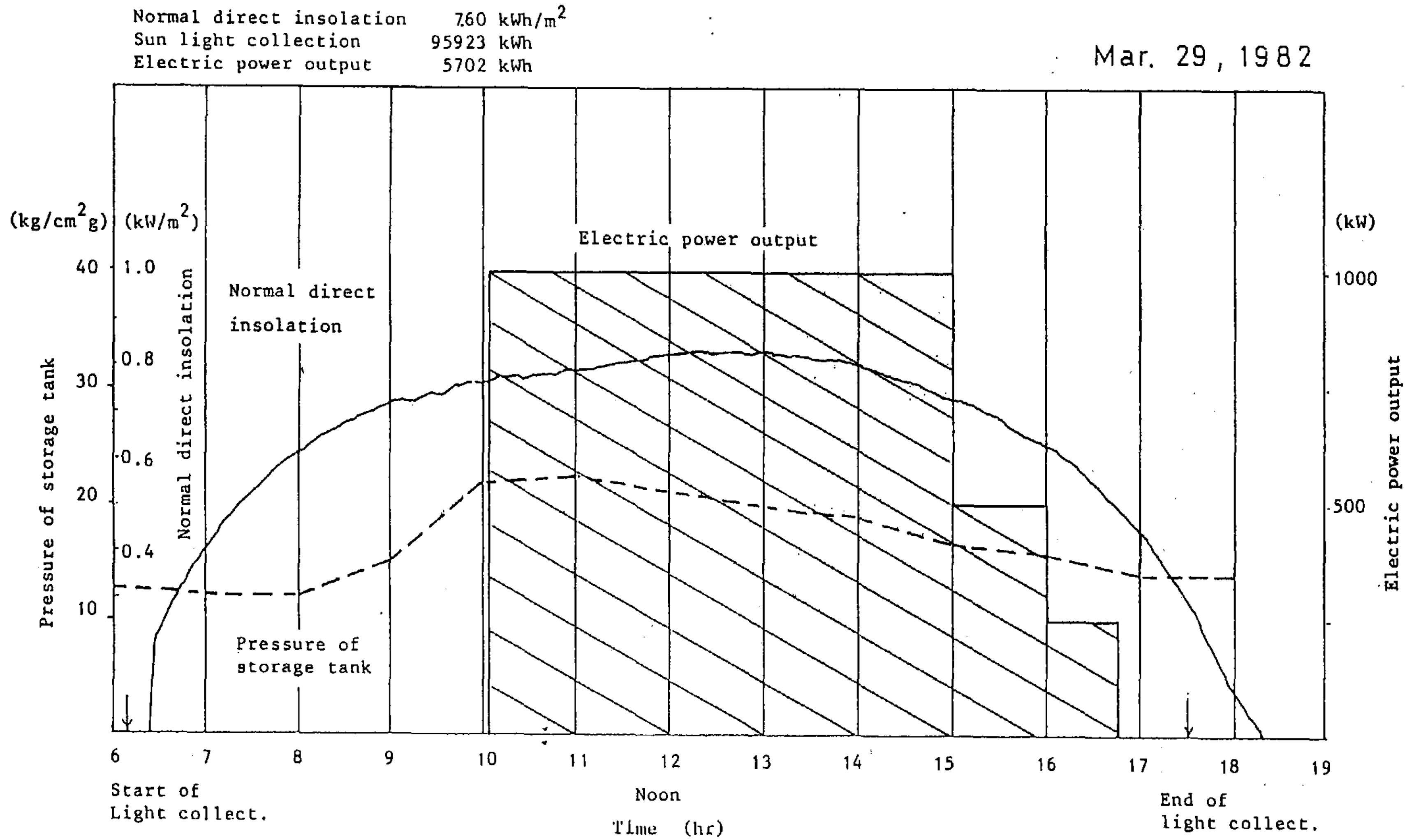


Figure 5.3(a) Operation Performance (Mar. 29, 1982)

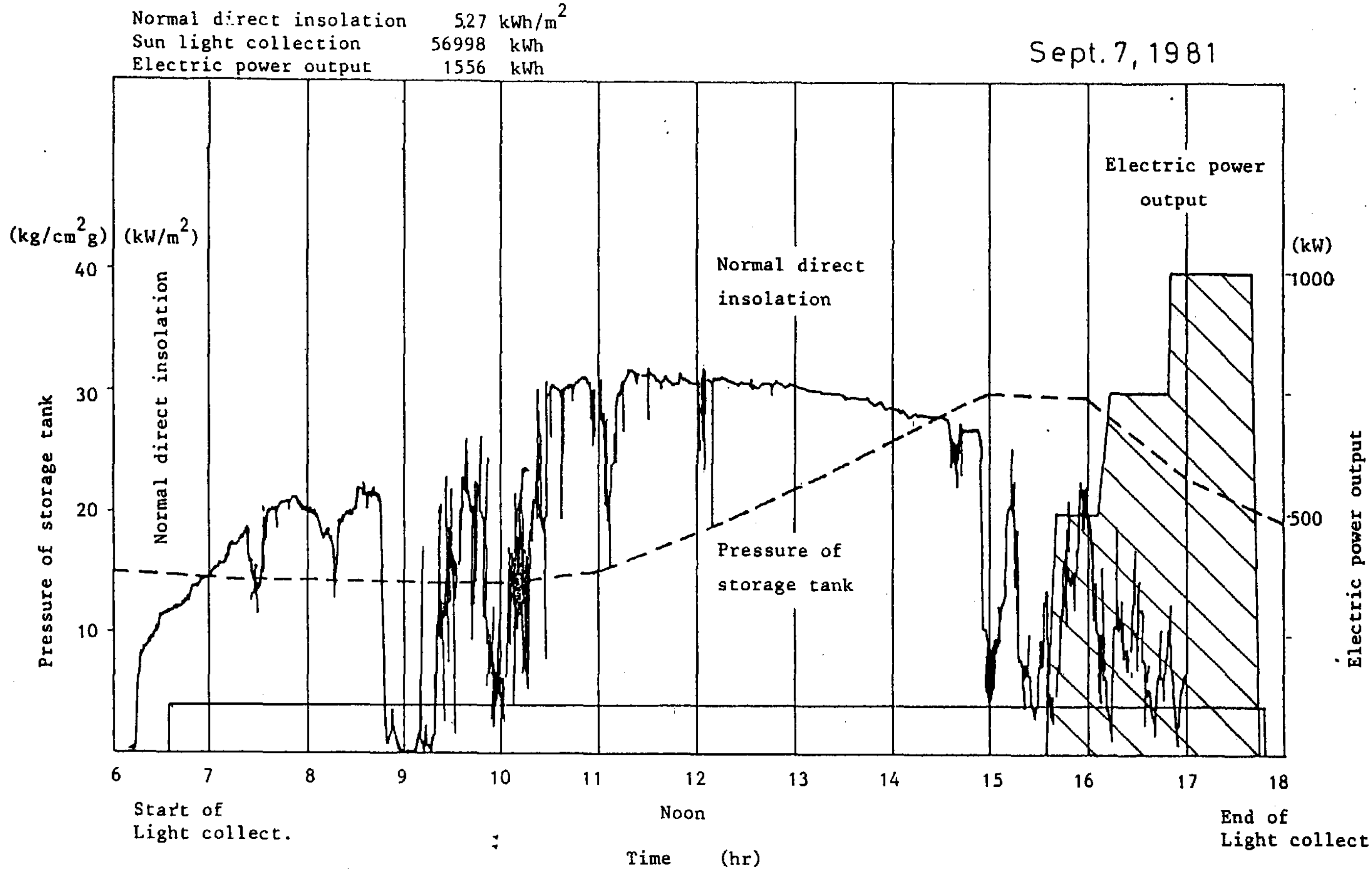


Figure 5.3(b) Operation Performance (Sept. 7, 1981)

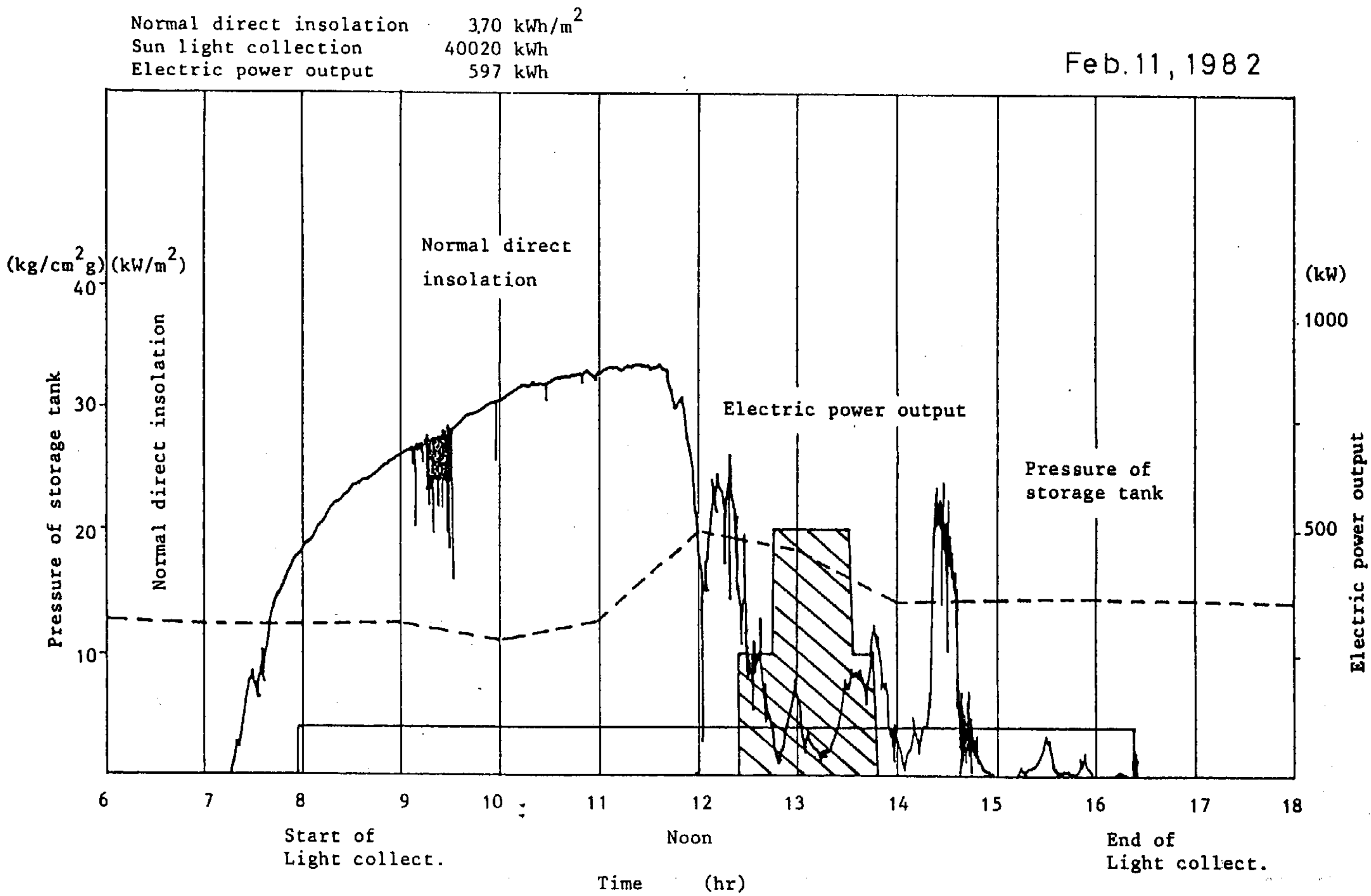


Figure 5.3(c) Operation Performance (Feb. 11, 1982)

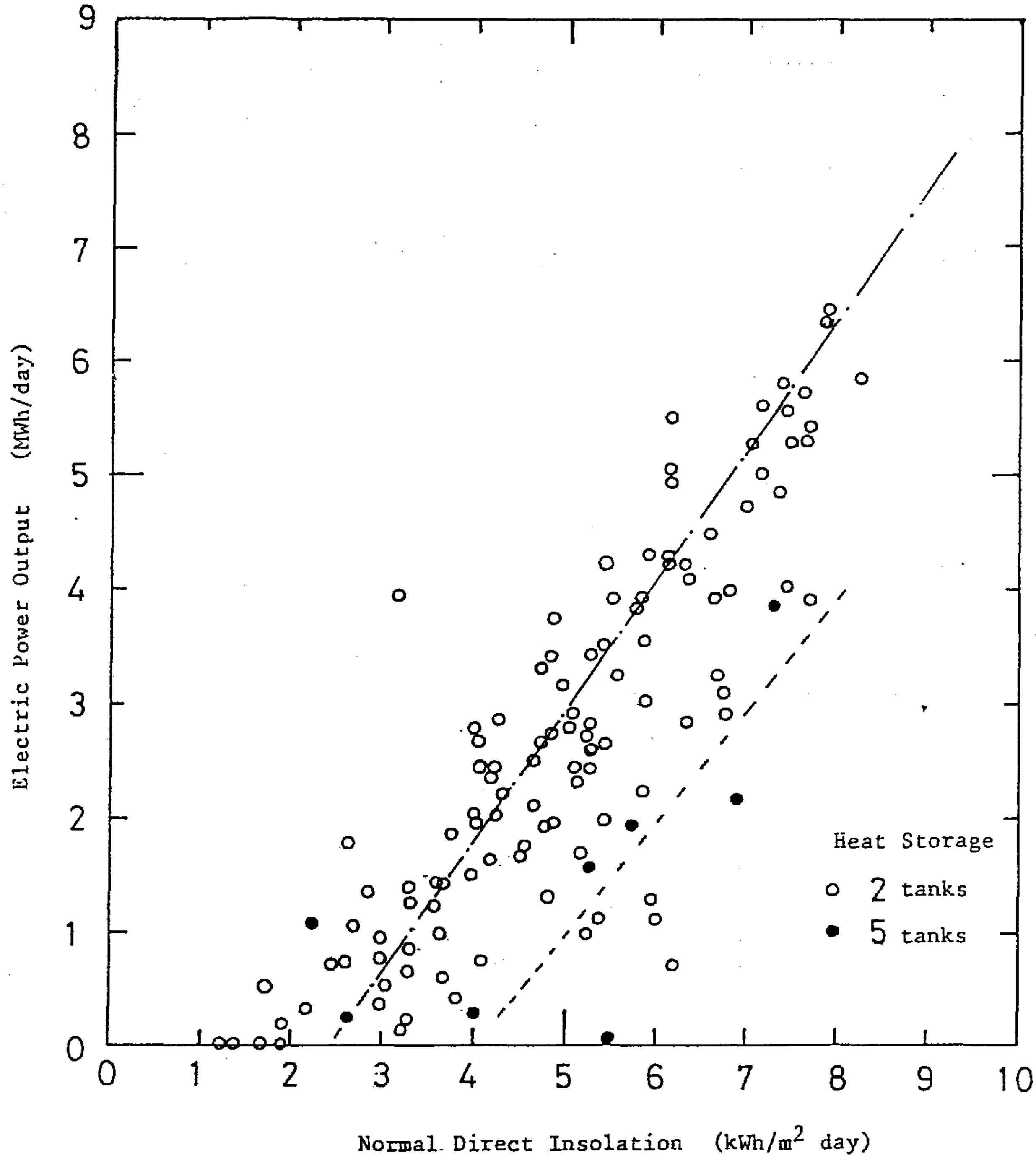


Figure 5.4 Power Output Performance

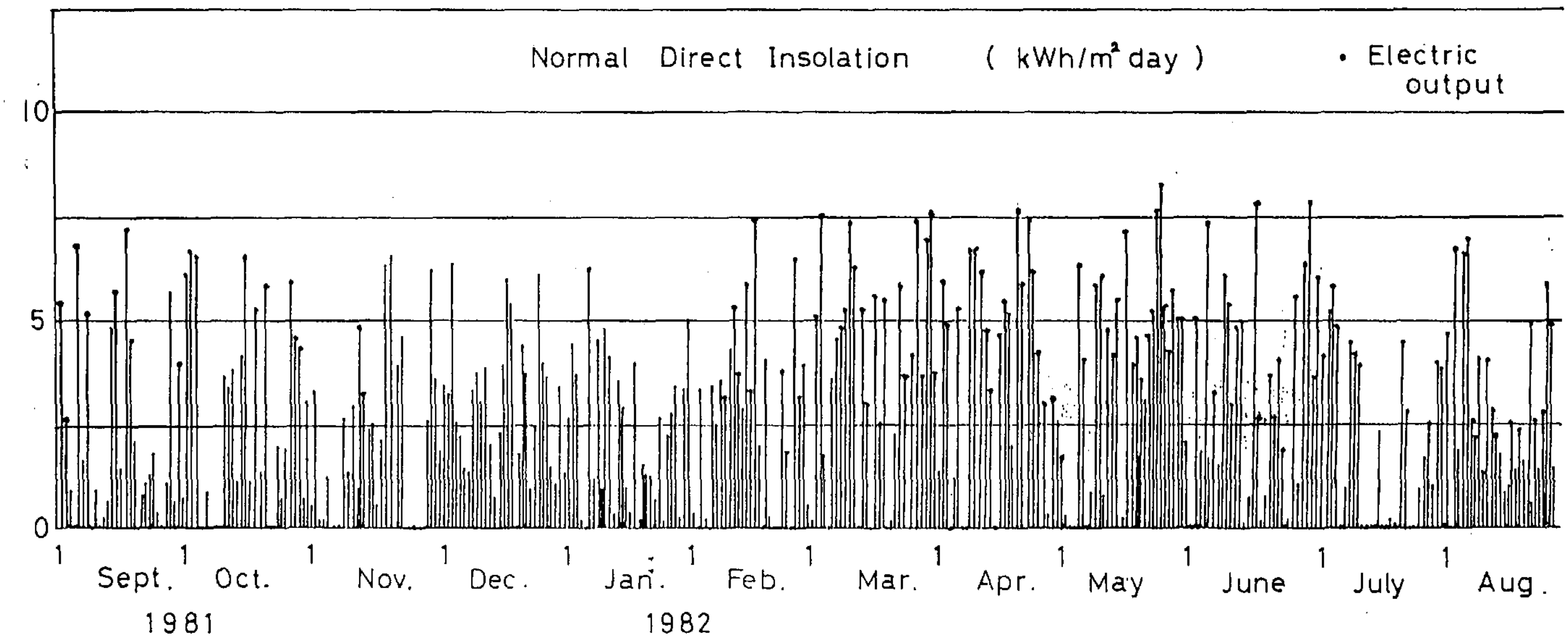


Figure 5.5 Direct Insolation Data

Table 6.1 Facility Staffing

Work shifts	7 Days per week 2 shifts per day
Administrative staff	1
Operating staff	2 (am) and 2 (pm)
Maintenance staff	4
Facility evaluation staff	n.a. (part time)
Specialized staff Security Safty	1

IEA/SSPS

CENTRAL RECEIVER SYSTEM (CRS) IN THE
SMALL SOLAR POWER SYSTEMS PROJECT (SSPS)
OF THE INTERNATIONAL ENERGY AGENCY (IEA)

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Deutsche Forschungs- und Versuchsanstalt
fur Luft- und Raumfahrt e.V.

Introduction

The Small Solar Power Systems Project (SSPS), conducted under the auspices of the International Energy Agency, consists of the design, construction, testing, operation and evaluation of two different types of solar thermal power plants.

The project objectives are to

- Demonstrate the viability of a Distributed Collector and a Central Receiver solar power plant, each with a nominal output of 500 kW electric

- Gain, over a two-year period, experience with both plants in relation to operational reliability, performance and costs

- Assess the future technical and economical developments and application of these types of plants.

Design started in early 1978, construction began in December 1979 and, after approximately a six-month period of functional testing, the local utility Sevillana started routine operation of the plants in January 1982.

Nine member countries of the IEA participate in the Project and jointly fund it with the following contributions (all phases as well as in-kind contributions included):

37.0%	German Federal Ministry of Research and Technology
18.0%	U.S. Department of Energy
16.0%	Spanish Ministry of Industry and Energy
7.0%	Italian National Research Council and Italian Industry
6.0%	Belgian Ministry of Scientific Research
5.5%	Swiss Federal Office of Energy
4.5%	Austrian Federal Ministry of Science and Research
4.0%	National Swedish Board of Energy Source Development
2.0%	Greek National Energy Council of the Ministry of Coordination

Supervision authority for the Project is vested exclusively with the SSPS Executive Committee, consisting of one member from each country. The Deutsche Forschungs- und Versuchsanstalt fur Luft- und Raumfahrt e.V. (DFVLR) acts as Operating Agent on behalf of the participating countries in that it performs all legal and contractual acts as well as is responsible for the overall management of the Project.

The Project is located on the Spanish Plataforma Solar near Almeria and forms, together with the Spanish CESA-1 plant and the German/Spanish GAST-Program, one of the most important solar thermal test facilities in the world.

In the following, only the Central Receiver System (CRS) of the Project will be described in detail.

Design Criteria

The plant was designed for the geographical conditions given in the arid environment of Tabernas near Almeria, Spain, i.e.,

Latitude	37°06' north
Longitude	2°23' west
Altitude	500 meters
Av. temperature	17°C

with an expected sunshine duration of 2900-3000 hours per year.

Design in 1978 was performed by a consortium formed by INTERATOM (Germany), Martin Marietta (USA), MAN (Germany) and CASA (Spain). It was based on the requirement that the net electric output of 500 kWe is to be delivered whenever direct normal irradiation equals or exceeds 700 W/m^2. Furthermore, a heat transfer system using liquid sodium and a power conversion system with a steam turbine were requested.

Due to a lack of funds, design changes before the start of construction became necessary:

- The design point was changed to equinox noon with 920 W/m^2, which reduced the number of heliostats from 160 to 93.

- The MAN turbine was to be replaced by a steam motor.

Furthermore, the heliostat field was provided as an in-kind contribution by the U.S. DOE in combining the manufacturing of the heliostats with those of the SOLAR-1 plant in Barstow.

The plant is to be operated in connection with the public grid or together with a substitute load in three operational modes:

- Insolation only

- Insolation and storage

- Storage only

Constraints for operation were specified as given below:

Operability		Full	Reduced	Survival
Insolation	[W/m^2]	1100		
Wind	[Km/h]	13	50	144
Earthquake	[m/s^2]	0.3	0.3	0.6
Hail Size	[mm]			19
Air Speed	[m/s]			20

Construction

Final design (as requested by the above-mentioned modifications) and construction were started in mid-1979. Mainly as a consequence of the in-kind contribution of the heliostat field, the DFVLR (Operating Agent) took over the role of the system integrator. Three main contracts were placed with:

- Interatom (Germany), for the sodium heat transfer cycle, the power conversion system and the electrical system (i.e., for the power plant as such)
- Martin Marietta (USA), for the heliostat field (under the provisions of the SOLAR-1 procurement)
- SAIT (Belgium), for the Data Acquisition System

The cost breakdown of the Central Receiver System is as follows (approximate values only, because 60% of the contracts were of the firm-fixed price type):

Heliostat Field	Approx.	7	Mio DM
Sodium Heat Transfer System and Electrical System (incl. Control)	Approx.	23	Mio DM
Power Conversion System	Approx.	3	Mio DM
Data Acquisition System	Approx.	1	Mio DM
Building and Infrastructure (50% of total)	Approx.	2.3	Mio DM
		36.3	Mio DM

All contracts, except the one with Martin-Marietta, included extensive warranty and guarantee provisions.

Subcontractors from all participating countries were involved, thus realizing to a great extent the expected "fair reflow" of financial contributions to the Project.

Acceptance of the Plant after construction and assembling was to be made according to a very detailed test plan which breaks down into:

(a) Functional Tests	without solar energy at ambient temperature and without heat transfer media for all subsystems from HFS* to DAS
(b) Functional Tests	without solar energy at elevated temperatures and with heat transfer media for SHTS*, PCS* and ES*
(c) Functional Tests	with solar energy - integrations HFS/SHTS, SHTS/PCS - component tests from SHTS to ES
(d) Acceptance Tests	plant start-up - capability of HFS/SHTS; SHTS/PCS; storage - start-ups HFS/SHTS; SHTS/PCS - shut-downs HFS/SHTS; SHTS/PCS
(e) Acceptance Tests	plant emergency - power supply failure - pump failure (sodium; feedwater) - steam motor failure

Plant Characteristics

The schematic of the CRS Plant is given in Fig. 1.

The heliostat field located north of the tower (Fig. 2) has a total reflective surface of 3655 m^2 and focuses the irradiated power to an aperture plane of 9.7 m^2 on top of the tower, the center being 43.25 m above the ground. The main heliostat field performance data are given in Fig. 3 (calculated).

The cavity-type receiver (Fig. 4) receives 2840 kW at design conditions, of which 2508 kW (88.3%) are absorbed by the liquid sodium being heated up from approximately 275°C to 530°C. The hot sodium is placed in a storage tank from where it is circulated into a sodium-water heat exchanger, generating steam at 100 bar pressure.

Design data of receiver and steam generator are:

Receiver

- Cavity receiver with north-oriented octagonal-shaped (3.4 m and 3.5 m main dimension) aperture of 9.7 m^2

*HFS = Heliostat Field System PCS = Power Conversion System
SHTS = Sodium Heat Transfer System ES = Electrical System

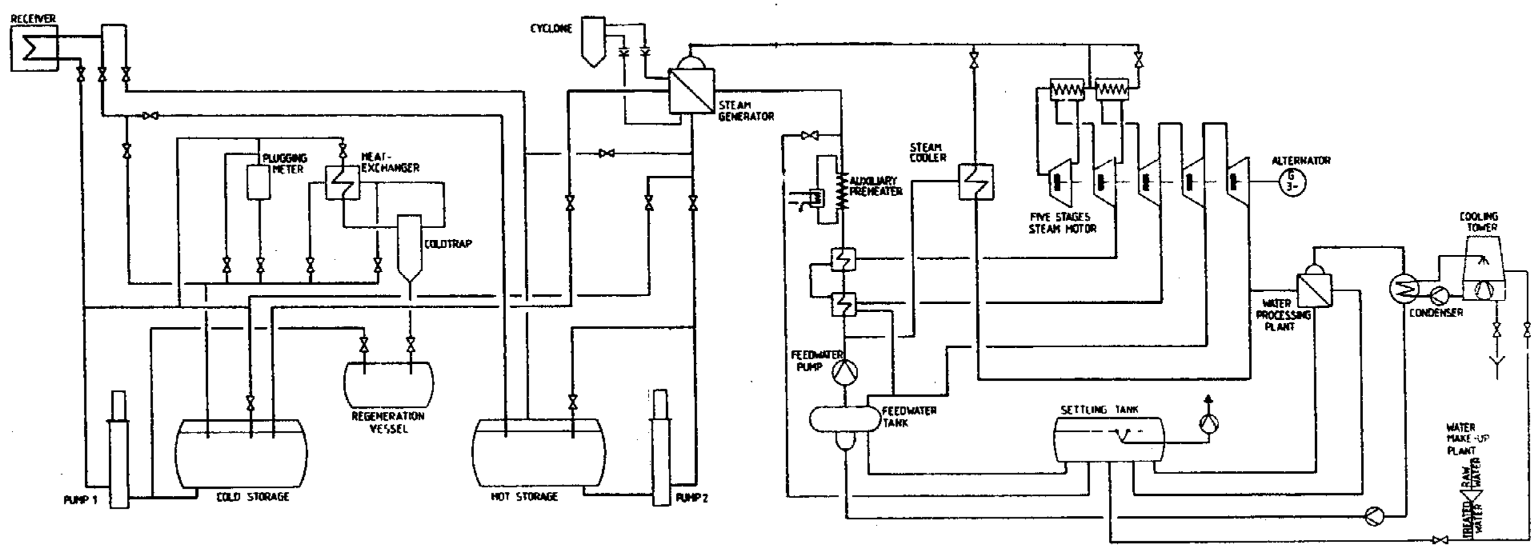
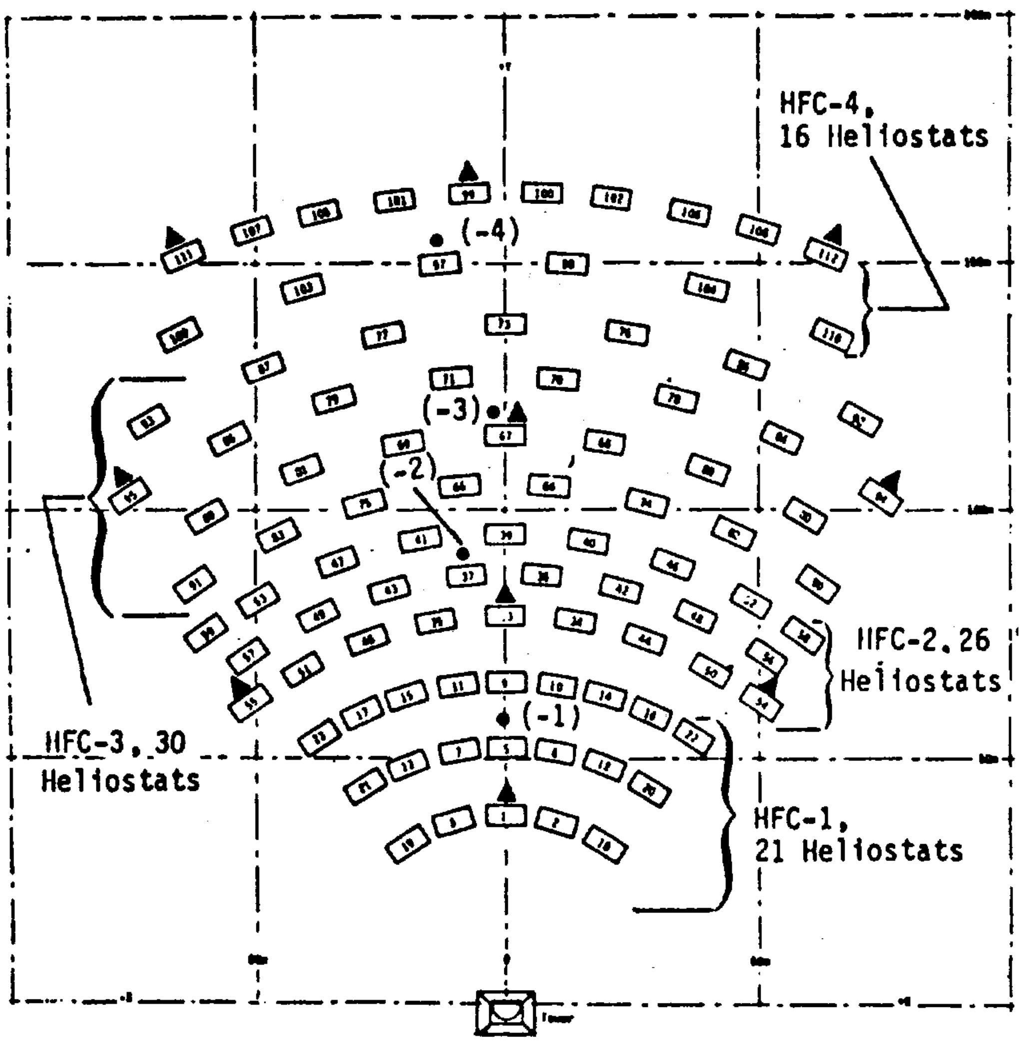


Figure 1. SSPS-CRS Schematic



• Location of Heliostat Field Controllers (4 ea)

▲ Location of Sun-Presence Sensors (10 ea)

Figure 2. Heliostat Field Plot Plan (MMC, USA)

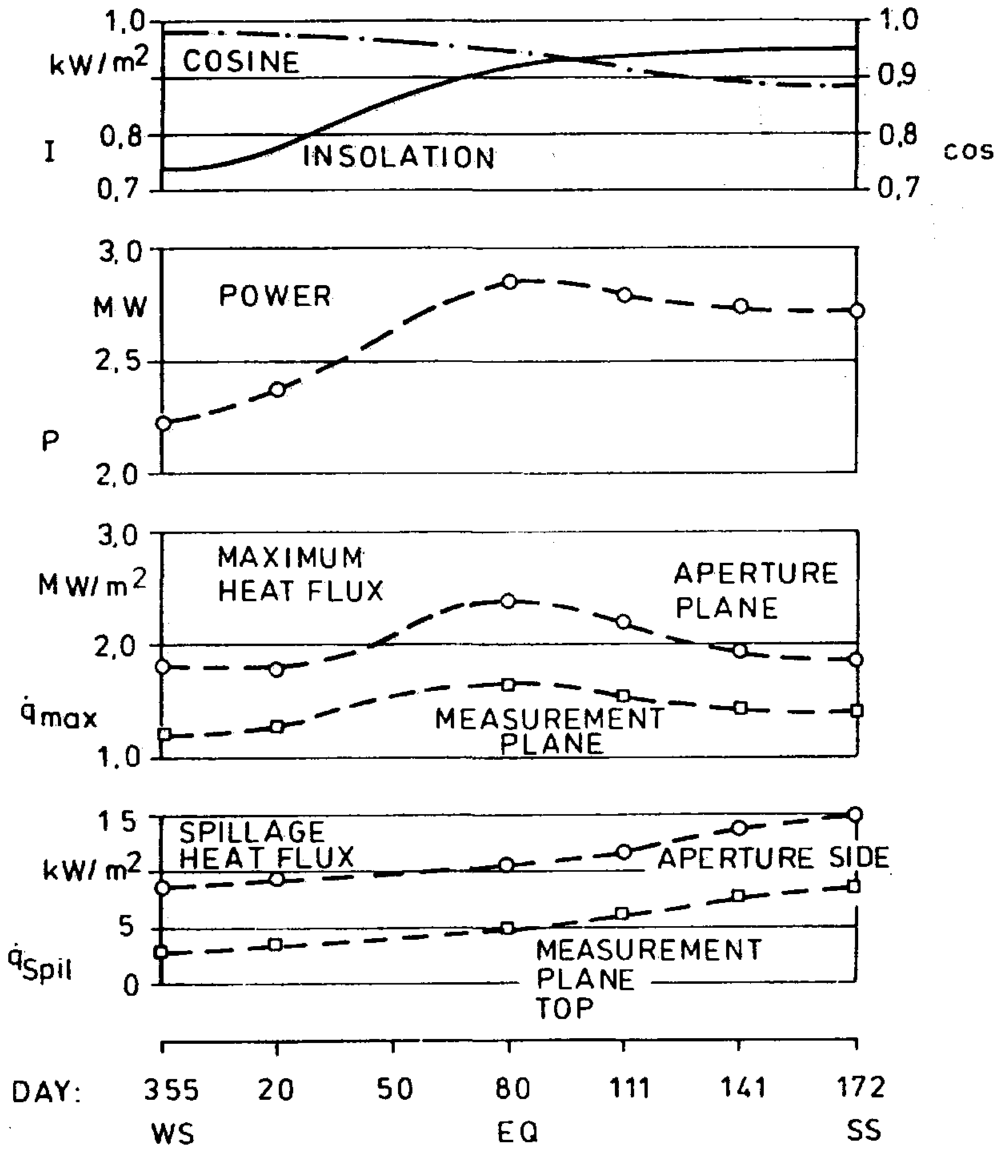


Figure 3. Heliostat Field: Insolation, Cosine, and Calculated Power Flux

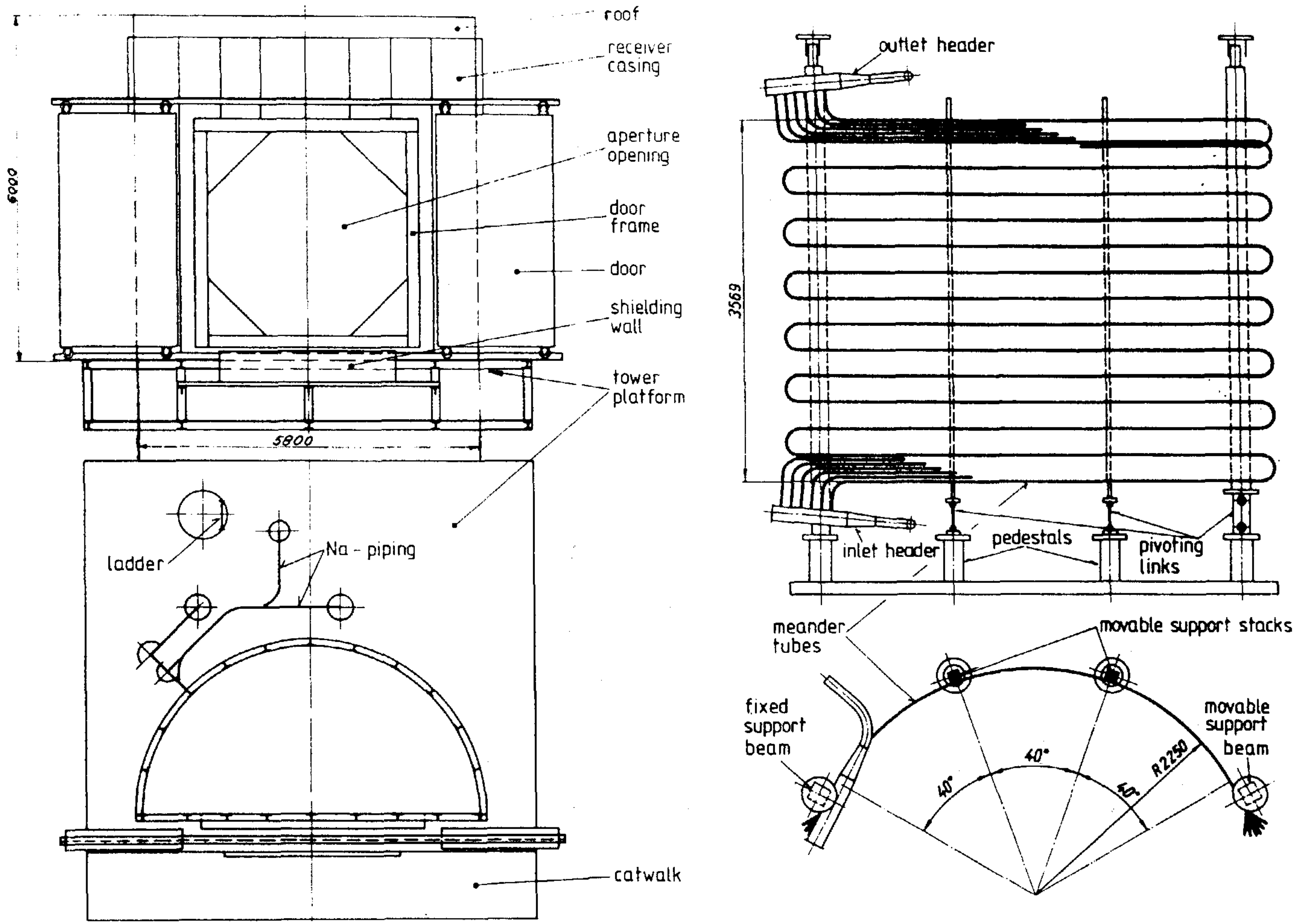


Figure 4. Sodium Receiver (Sulzer, Switzerland)

- Center located 43.25 m above ground
- Absorbing surface 17 m^2
  - 6 parallel sodium-carrying tubes directed in a serpentine way from bottom to top with 14 turns
  - Peak flux density 600 kW/m^2
  - Absorptivity of tubes 0.95
  - Design efficiency 0.883
- Ceramic back wall enables short time heat storage

Steam Generator

Design Items

- Helical tube - once through
- Coiled around central displacement tube
- Sodium flow downwards between shell and displacement around the heating tubes
- Water flow upwards
- Two rupture discs connected with cyclone

Data

- Heat transfer area	14.7 m^2
- Feedwater temperature	193° C
- Outlet steam temperature	500 to 525° C
- Outlet pressure	105 bar
- Steam mass flow	0.86 kg/s
- Sodium inlet temperature	525° C
- Sodium outlet temperature	275° C
- Maximum sodium pressure	8 bar
- Sodium mass flow	6.9 kg/s

The major part of the Rankine power conversion cycle is a 5-stage steam motor with two preheaters and a calculated efficiency of 27.2% (2203 kW live steam imput; 599 kW_e gross output). The steam delivered by the steam generator can also be expanded by a so-called by-pass line in which case, however, generation of electrical energy is not possible. A wet cooling tower completes the power conversion cycle.

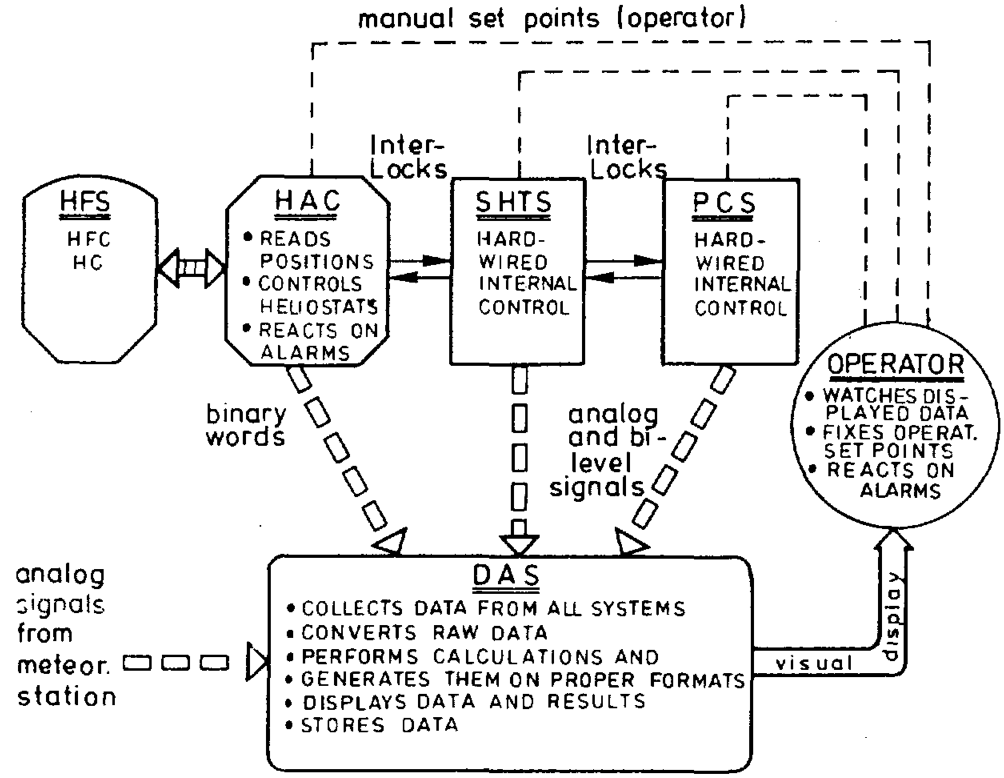
The Control and Data Acquisition System is explained in Fig. 5. Its main characteristic is the active involvement of the operator who manually adjusts the setpoints and reacts on alarms. In total, 240 analog and 1024 bilevel data are recorded. The stair-step graph in Fig. 6 shows the sequence of the subsystem's performances and pertinent efficiencies as calculated during design and construction.

Performances

With a series of graphs, preliminary performance results of the CRS plant are given as they have been obtained during the phases of:

Main Functions of CRS

Control and Data Acquisition System



HFS	Heliostat Field System	SHTS	Sodium Heat Transfer System
HFC	Heliostat Field Control	PCS	Power Conversion System
HAC	Heliostat Array Control	DAS	Data Acquisition System
HC	Heliostat Control		

Figure 5. Control and Data Acquisition System

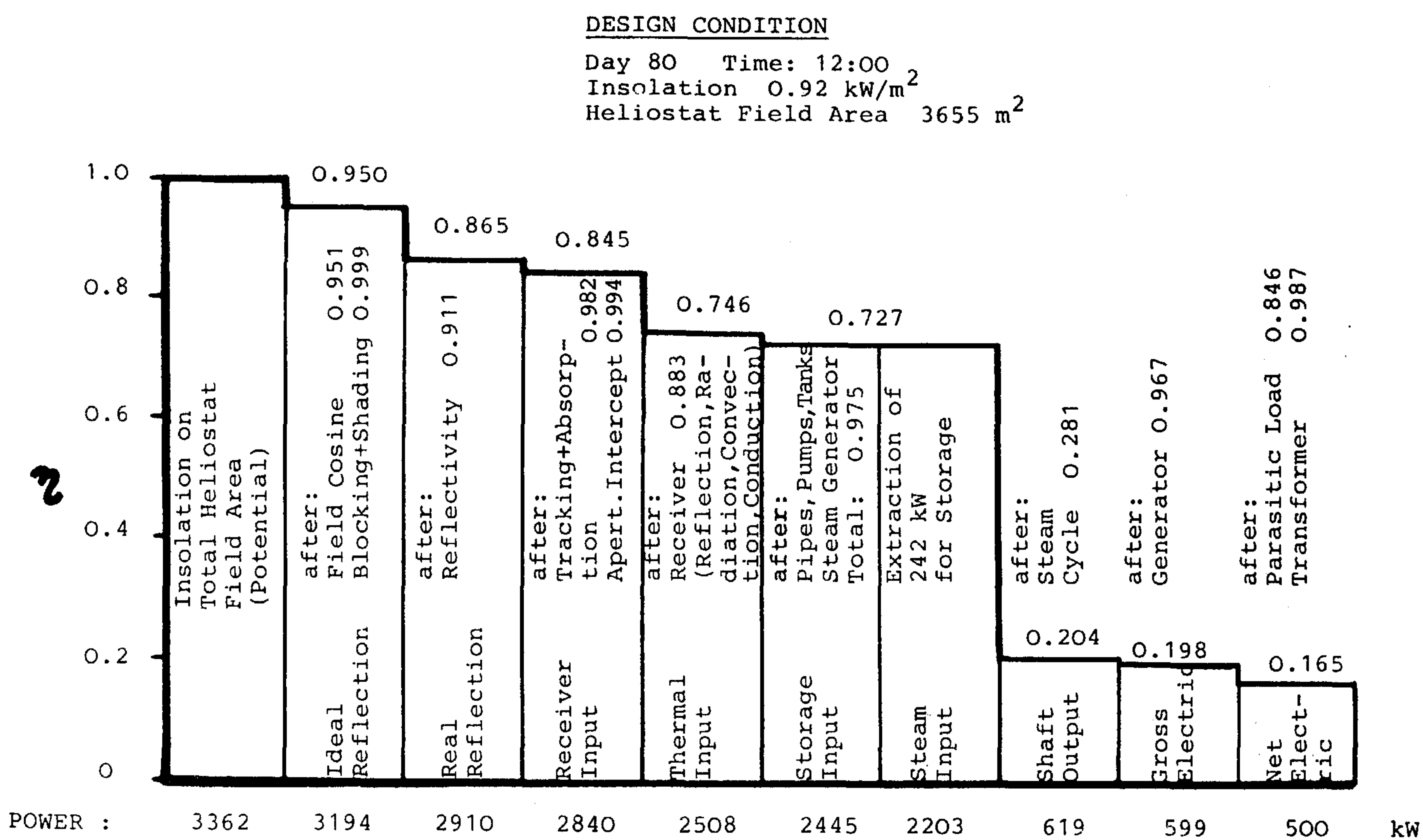


Figure 6. Power Stair-Step Calculated for Design Condition

- Functional testing (May '81 - Sept. '81)
- Acceptance testing (July '81, Dec. '81, Aug. '82)
- Plant optimization (Sept. '81 - Dec. '81)
- Routine operation (Jan. '82 - Aug. '82)
- Measurement campaign (Fall '81, Fall '82)

Figures 7 and 8 depict meteorological data in weekly summaries. It can clearly be seen that the original design (500 kW_e at 700 W/m^2) was by far more realistic than the present value of 920 W/m^2, which so far has been observed only very few hours. Accordingly, the participating countries have been asked to agree to an enlargement of the heliostat field.

Figure 9 gives the deficit in 1982 solar irradiation, compared with the design assumptions. The value of 300 W/m^2 represents the lowest limit for useful plant operation.

Figure 10 illustrates how important washing of heliostats is--at least on the Plataforma Solar de Almeria. Degradation in mirror reflectivity is mainly due to soiling and atmospheric pollution. A loss of between 0.2 to 0.6% in reflectivity per day is observed. For better understanding of the mechanisms, a soiling analysis and cleaning effectiveness program has been developed.

Figure 11 compares calculated heliostat field performances versus measured values. Measurement was done with two methods: HFD = radiometer equipped bar crossing the aperture plane, called heat flux distribution measurement; FAS = flux analyzing system with a CCD camera.

Figures 12 and 13, giving receiver performance data, show the good conformity of the calculation with the empirical measurement.

Figure 14 depicts the few measurements which could have been made for determining the power conversion efficiency. The results cannot yet be considered final. Because of various circumstances, the operational time of the steam motor was very limited:

	Average Load (kW)	Total Energy (kWh)	Grid Time (hours)
Until end July '82	166	8730	52:34
Until mid-Aug. '82 (10-days testing)	259	6855	26:25
After mid-Aug. '82 until Sept. 27, 1982	371	7055	19:01
Total	233	22640	98:00

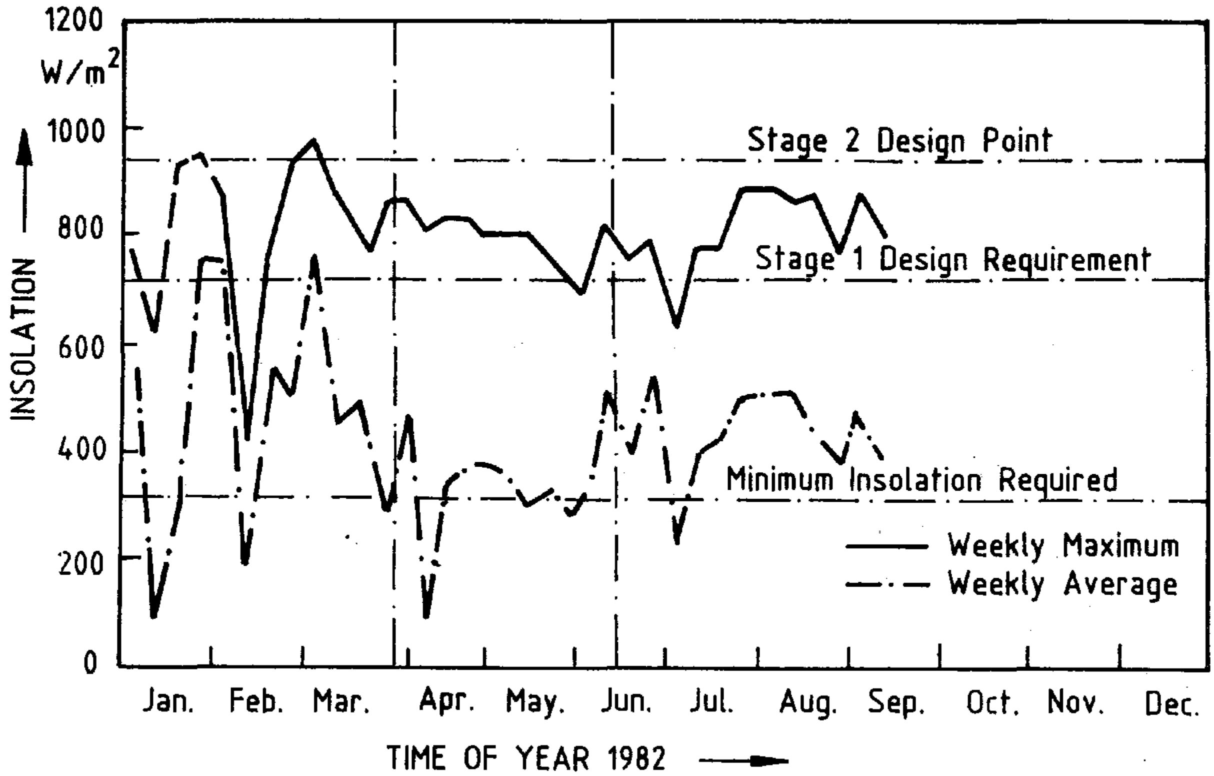


Figure 7. Meteo Data: Direct Insolation

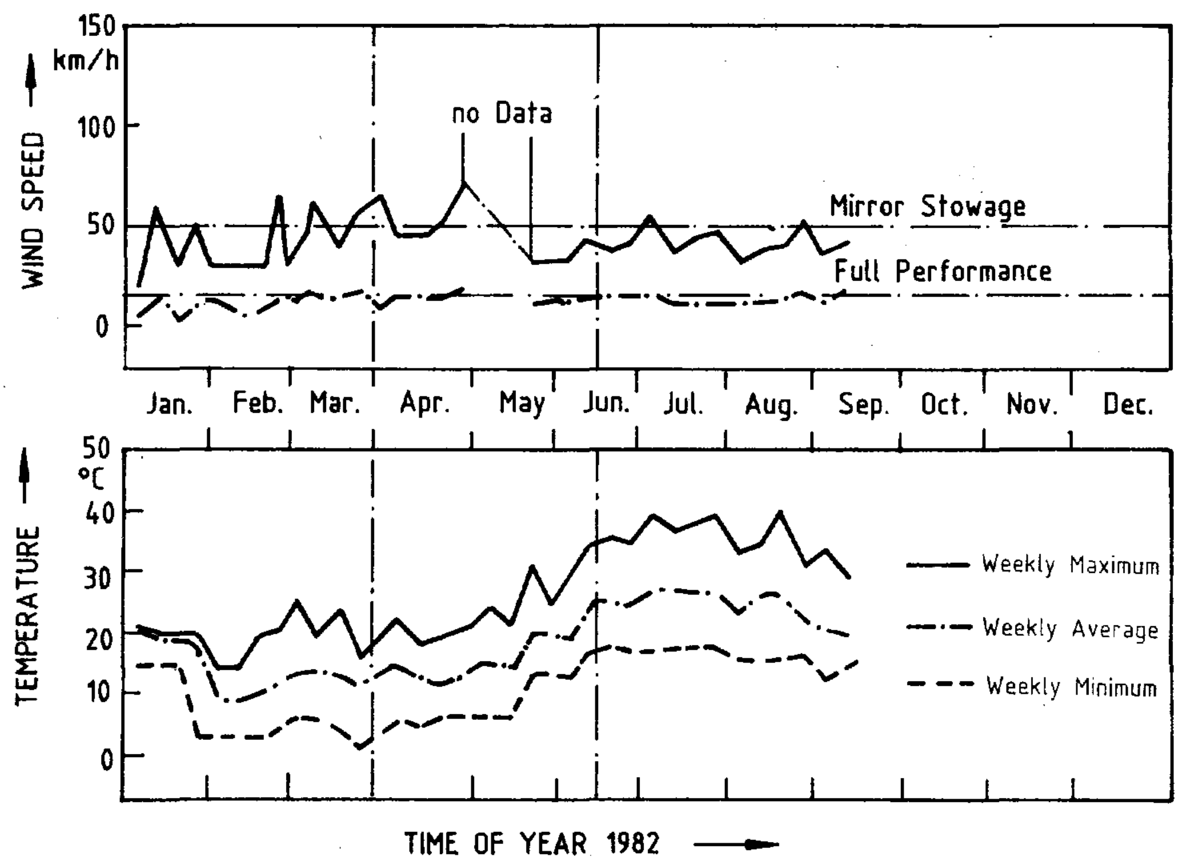


Figure 8. Meteo Data: Wind Speed and Temperature

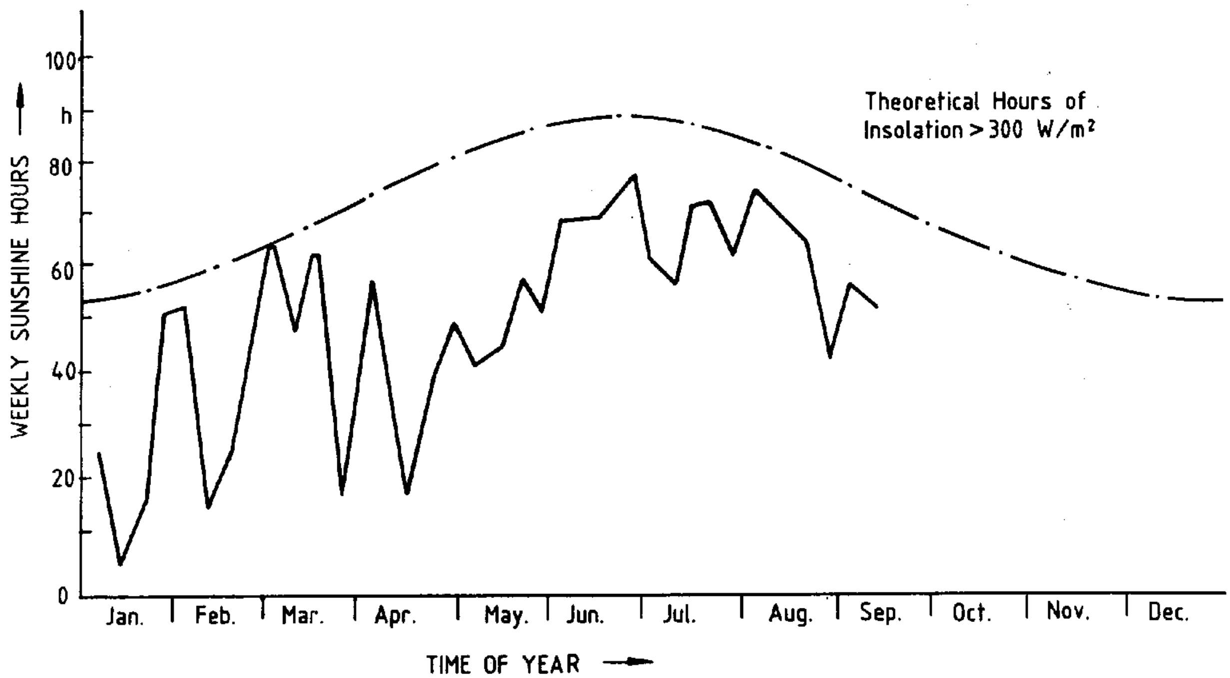


Figure 9. Meteo Data: Comparison of Measured Insolation with Clear Sky Calculated Sunshine Hours for 1982

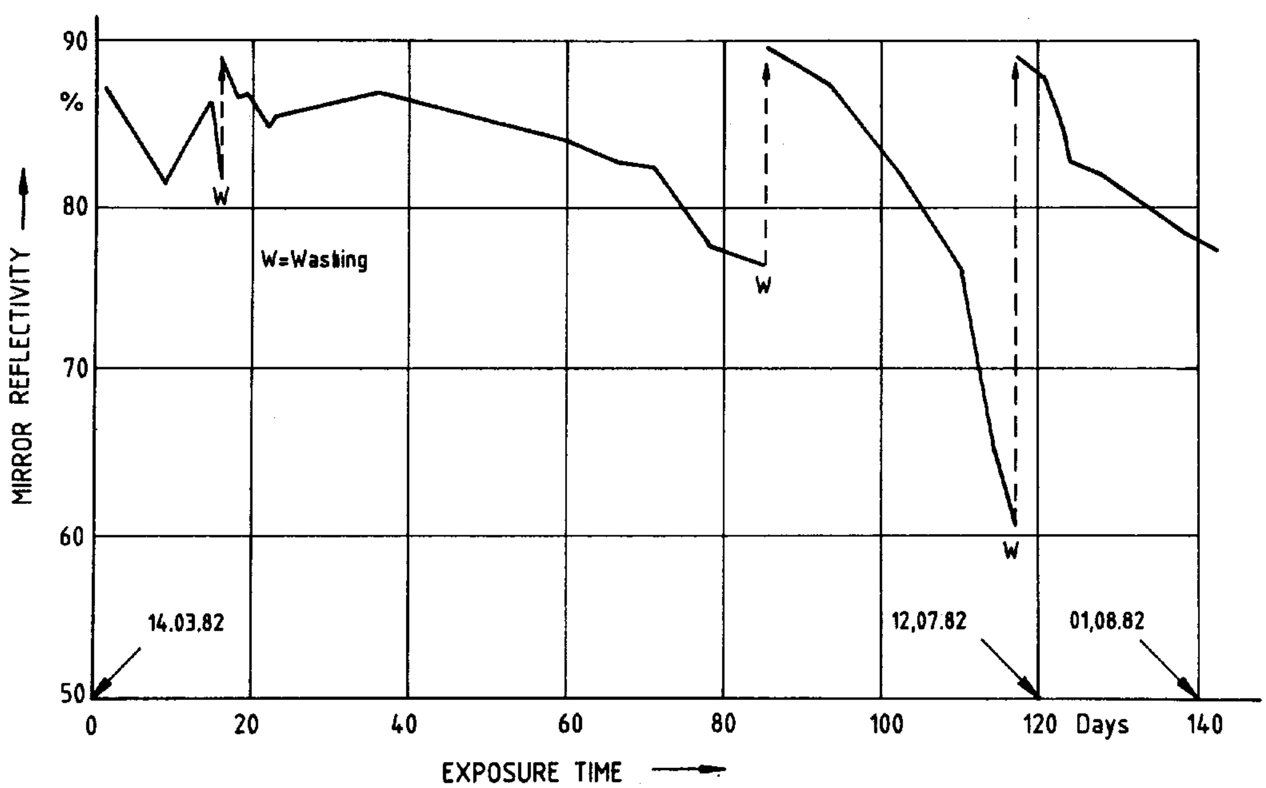


Figure 10. Heliostat Field: Averaged Reflectivities in 1982

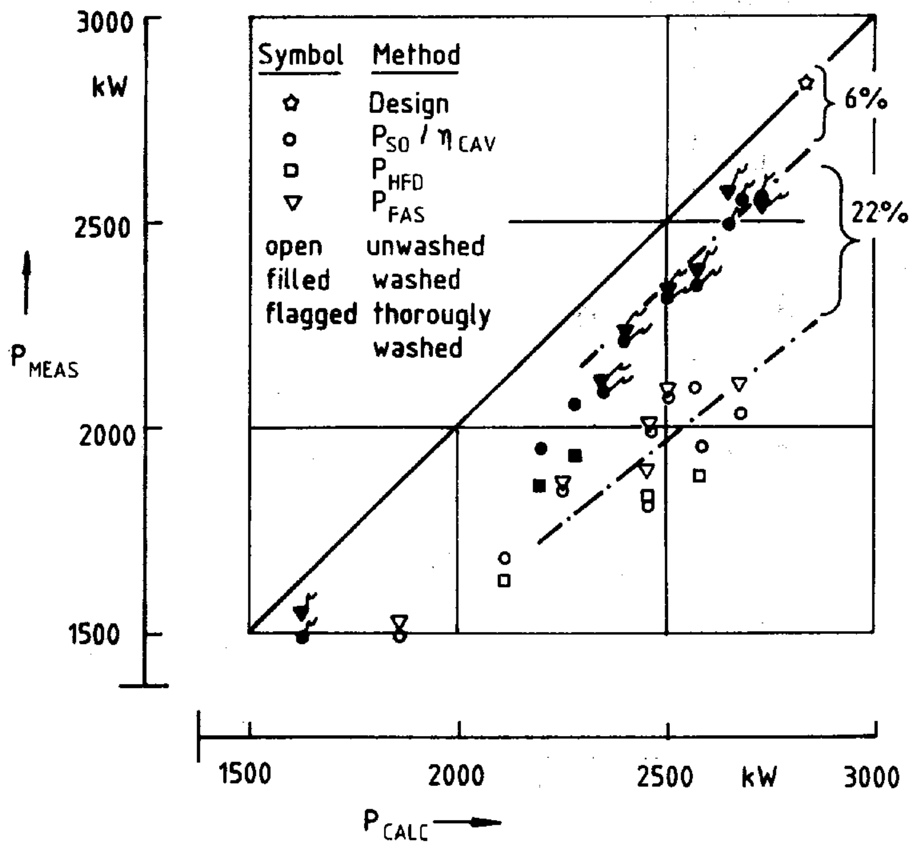


Figure 11. Heliostat Field: Power in Aperture Plane (P=power; So=sodium; Cav=cavity)

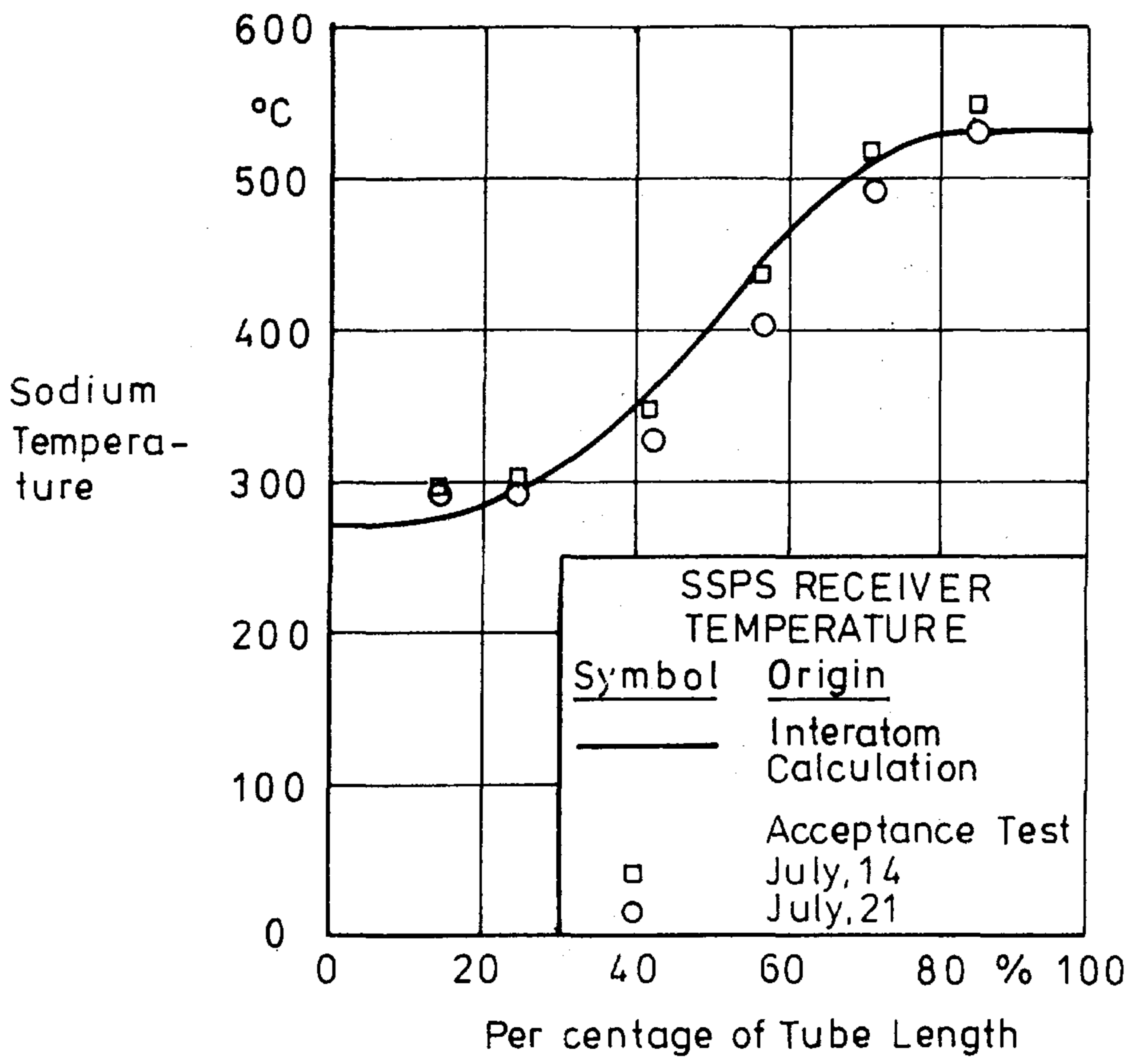


Figure 12. Sodium Heat Transfer System: Temperature in the Receiver

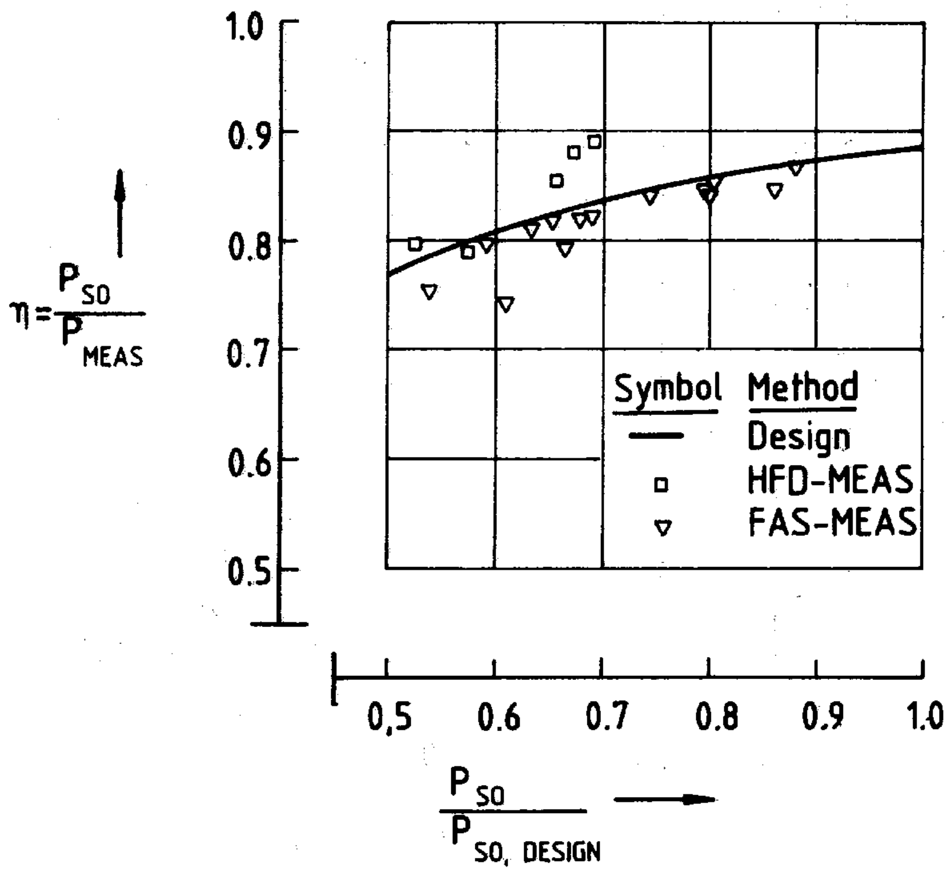


Figure 13. Sodium Heat Transfer System: Receiver Efficiency (P=power; So=sodium)

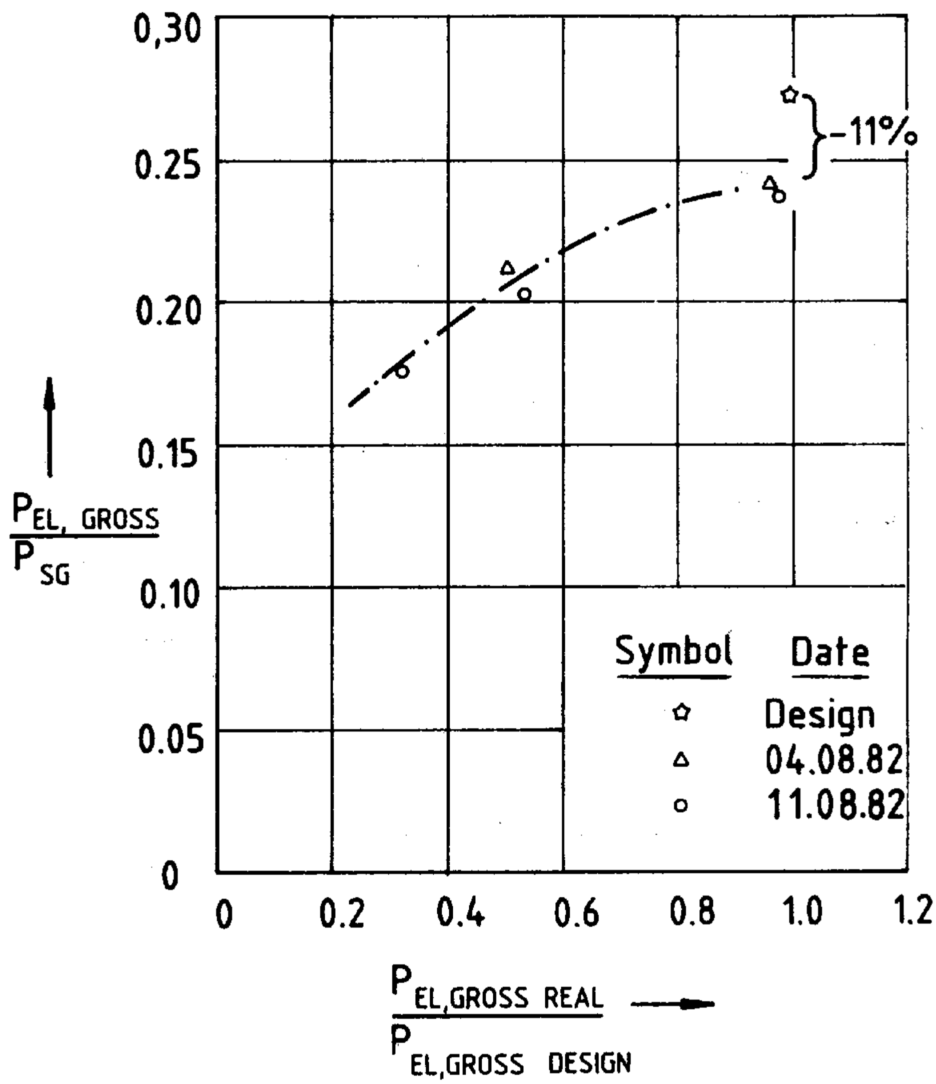


Figure 14. Power Conversion System: Efficiency (P=power; SG=steam generator)

Final determination of performances and evaluation of plant behavior require continuation of particular measurement campaigns which turned out to be the most effective way of getting together researchers from all participating countries at the same time. In the CRS plant, these efforts will be continued mainly with respect to the evaluation of:

- Concentration efficiency of heliostat field
- Cavity losses of receiver
- Power stair-step and energy production through the whole plant

This will be done with different measurement techniques (partly specifically developed for SSPS campaigns) and with analytical support from research institutes in participating countries.

Operation and Maintenance

Routine operation of the plant started on January 1, 1982. It is performed on 7 days with 2 shifts plus overnight vigilance. Its main objective is to maximize yearly electrical energy output and to minimize plant outages by adequate routine and/or preventive maintenance.

The Spanish utility, COMPAÑIA SEVILLANA DE ELECTRICIDAD, S.A., is responsible for the operation under DFVLR contract.

Parallel to this operation, Sevillana is requested to allow as much parallel testing as possible of the plant.

Again, experiences gained so far are summarized in the form of graphs and pictures.

Figure 15 lists the shift and non-shift personnel working in the framework of the contract for plant operation (for CRS totalling to 10,25).

Figure 16 includes information regarding the weekly operation hours of all CRS subsystems. It also illustrates that:

- The sodium heat transfer system (because of a leakage in the cold sodium tank) became operational only in May 1982 after it performed well during all phases of functional and acceptance testing in 1981.
- The steam motor--after a long period of various failures--is to be considered operational only since August 1982.

In total, in 1982 (until the end of August) the following operational hours were achieved and are, however, not yet to be considered representative:

SHIFT PERSONNEL	7 DAYS/WEEK
	7:00/15:00; 15:00/23:00; 23:00/7:00

2	SYSTEM ENGINEERS
4	OPERATION DEPUTIES
10	OPERATORS
10	WATCHERS
26	
13	FOR DCS
13	FOR CRS

NON SHIFT PERSONNEL	5 DAYS/WEEK
	8:30/17:30

1	PLANT OPERATION MANAGER
1	ADMINISTRATOR
1	SECRETARY
1	TELEPHONIST
1	MAINTENANCE SUPERVISOR
8	SPECIALIZED WORKERS
13	(50 % EACH FOR CRS + DCS)

JOB SHARING WITH CESA-1 PLANT (5 DAYS/WEEK)

0.5	SAFETY ENGINEER
0.5	MEDICAL ASSISTANT
0.5	CHEMIST
1.5	(50 % EACH FOR CRS + DCS)

Figure 15. Operation and Maintenance: Staff Requirements

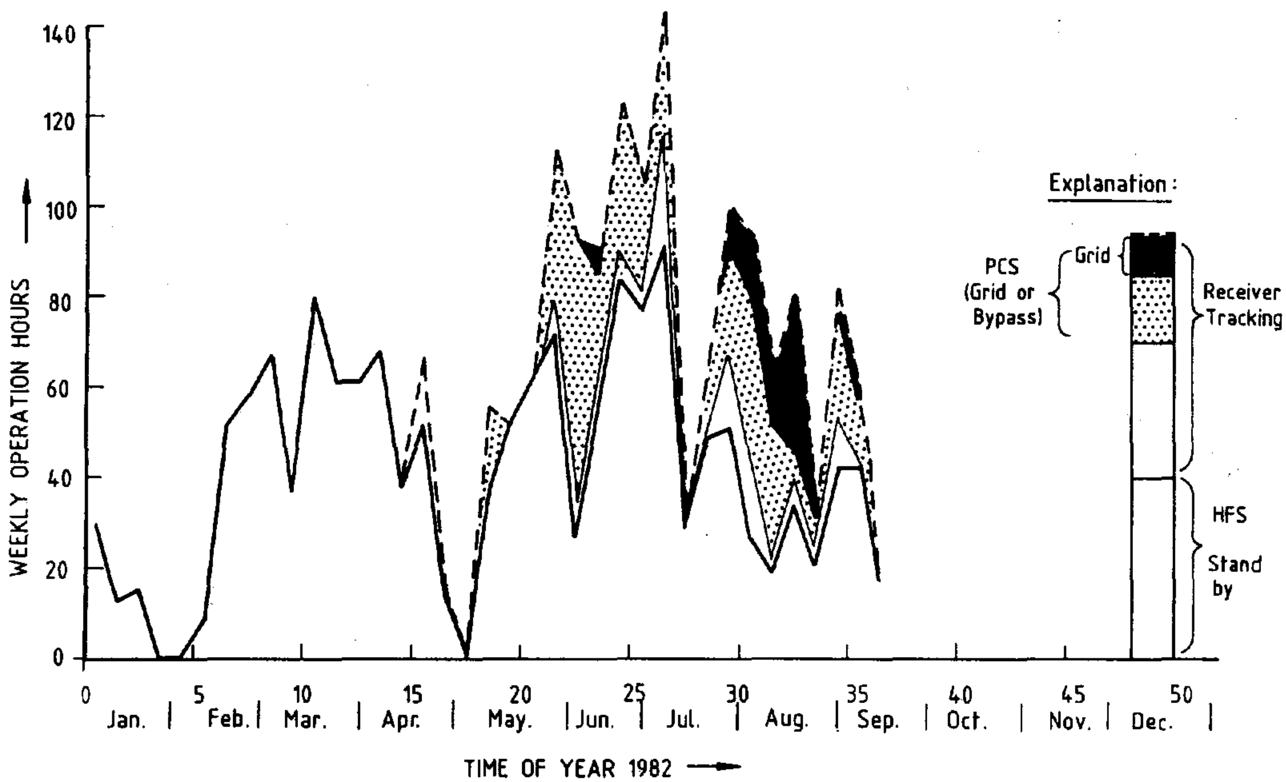


Figure 16. Plant Operation Hours in 1982
(PCS=power conversion system; HFS=heliostat field system)

Hours of insolation > 300 W/m^2	1605
Hours of heliostat field operation	1436
Hours of of energy collection	543
Hours of power conversion system operation	429
Hours of electricity production (with a total of 11800 kW_e)	40

Figure 17 analyzes the availability of the heliostat field, relative to the maximum achievable time (i.e., 24 hours per day). Irrespective of the suitability of such comparison, two conclusions are possible:

- The majority of the outages in SSPS-CRS was caused by the main computer (HAC).
- 1-shift maintenance (including washing) may unnecessarily conflict with operation.

The relative high number of heliostats out of service is due to the fact that only part of the power boxes damaged during a thunderstorm could be repaired since April 1982. This is partly because of procedural difficulties, partly caused by purchase difficulties.

Milestones and Major Events

In order to give the complete background for this first summary report regarding SSPS-CRS results and experiences, all important events are listed as follows:

1977	Spring	SSPS feasibility considerations and studies
	October	Implementing Agreement between 10 countries Invitation for tenders
1978	January	Tender evaluation and contract negotiations
	April	Design contract award
	October	Presentation design results
1979	May	Supplement to the Implementing Agreement for construction and operation
	July	Stage 2 contract
	October	Critical Design Review
	December	Heliostat procurement
1980	April	Start of Site activities
	December	Receiver on tower
1981	January	Start of heliostat installation
	February	First sodium filling
	April	DAS acceptance
	May	HFS acceptance Start of solar tests

1982	OPER.*	NON-OPER.	TRACK	STAND-BY	STOW	REASON FOR NON-OPERATION	OUT OF SERVICE (MONTHLY)
	HOURS						
JANUARY	106	638	0	52	54	1-SHIFT OPERATION (597) HAC-FAILURE (41)	3
FEBRUARY	442	230	0	115	327	HAC-FAILURE (230)	3
MARCH	718	26	0	265	453	HAC-FAILURE (26)	2
APRIL	592	128	19	206	367	HAC-FAILURE (97) MAINTENANCE (31)	11
MAY	503	241	24	161	318	HAC-FAILURE (216) MAINTENANCE (25)	31
JUNE	709	11	197	270	242	MAINTENANCE (11)	3
JULY	731	13	119	246	366	MAINTENANCE (13)	6
AUGUST	736	8	184	121	431	MAINTENANCE (8)	7
TOTAL	4537	1295	543	1436	2558		-
% of 5832 H	(78 %)		(1 %)	(25 %)	(43 %)		

* MAX. 24 HOURS PER DAY

Figure 17. Heliostat Field Operation Hours (Jan. - Aug. 1982)

	June	Provisional plant acceptance
	July	HFD acceptance/FAS operational
		Steam motor run (no load)
	September	First power to grid
		Inauguration
	October	Plant optimization
	December	Plant acceptance and repair agreement
1982	January	Routine operation start and cold sodium tank general repair
		First-stage steam motor repair
	May	Cold sodium tank operational
	June	EC decision to substitute steam engine by turbine
	September	Measurement campaign

The following gives a list of all main failures and incidents which affected construction and operation, respectively:

1980	September	Flooding of site
1981	March	Sodium fire at transport container
	April	Mirror attachments failed
		Heliostat communication problems
		Sodium Pump LK02 blockage (contamination)
	June	Sodium Pump LK02 blockage
	July	Sodium leakage at cold storage tank lower part
	August	Concentrated image eastward walk due to power failure and lack of restoration
	September	Sodium leakage at cap welding of cold storage tank manhole
		Steam engine first-stage water hammer
	November	DAS memory error, blockage of system
1982	January	HFS* inoperable (HAC* failure)
	April	HFS unsolicited interrupts
		HFS damages (HC*, HAC and HFC/HAC interface) due to lightning
	May	Sodium pump LK02 oil leak
	July	Sodium pump LK02 oil leak
	September	Cold sodium tank leakage
	October	Cold sodium tank leakage

Future Plans

Based on the experiences and results as summarized above, the following will be proposed to the SSPS Executive Committee:

- Extension of CRS operation and testing beyond December 31, 1983, (expiration date of Implementing Agreement) in order to:

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*HAC = Heliostat Array Controller
HC = Heliostat Controller
HFC = Heliostat Field Controller

- Increase operational experience and optimize operational strategies

- Complete data evaluation

- Explore operational limits for sodium as a heat transfer medium in solar power plants

- Improve insufficient hardware (storage vessel, prime mover)

- Continue measurement campaigns for evaluation of plant behavior

- Enlarge the CRS heliostat field to ensure representative operational flexibility with a solar multiple of preferably between 1.3 and 1.6

- Test the high flux sodium receiver as already contracted with the Italian companies AGIP-NUCLEARE and FRANCO TOSI

- Enhance in exchange of experience and data, in particular with respect to other high flux receivers, e.g., liquid salt receivers.

EURELIOS

EURELIOS, THE 1 MW(el) HELIOELECTRIC POWER PLANT OF THE EUROPEAN COMMUNITY PROGRAM

D. Borgese, G. Dinelli,
J. J. Faure, J. Gretz, G. Schober

Abstract

EURELIOS, the 1 MW(el) solar power plant, is a project sponsored by the Commission of the European Communities. This plant, of the mirror-field and central-receiver type, was designed and built by a Consortium of European industries. Construction of the plant was completed by the end of 1980 and it was connected to the grid of the Italian National Electricity Generating Board, ENEL, at Adrano, Sicily (Italy), in April 1981. ENEL is the operator of the plant and its co-proprietor, along with the Commission of the European Communities.

General

Within the framework of its Solar Energy R&D Programme, the Commission of the European communities decided in 1976 to build a large capacity experimental helioelectric power plant. In order to take advantage of the high exergetic potential of solar energy, it was decided to use high working fluid temperatures achieved by means of the high concentration factor available in a power-tower system. At that time, first evaluation studies indicated the investment and energy cost crossover point between distributed systems and power towers to be about 500-700 kW, and so 1 MW(el) seemed to represent a reasonable plant size.

A European Industrial Consortium consisting of

- ANSALDO SpA and ENTE NATIONALE per l'ENERGIA ELETTRICA (ENEL), Italy
- CETHEL (combining Renault, Five-Cail-Babcock, Saint-Gobain Pont-a-Mousson and Heurtey S.A.), France
- MESSERSCHMITT-BOELKOW-BLOHM (MBB), F.R. of Germany

was set up for the design and construction of the plant.

These firms completed the definition of the overall system and the engineering design specifications for all subsystems of the plant, including the construction and testing of prototype models, by November 1978. Completion of the construction of the plant was scheduled for the end of 1980; this date was maintained.

The power plant is sited at ADRANO, a village 40 km West of Catania, Sicily (Italy). It has an average elevation of 220 m, a North-South inclination of 5%, and lies near a small river. In April 1981 the plant fed electricity into the grid of ENEL, which operates the plant and is its co-proprietor together with the Commission of the European Communities (Fig. 1).

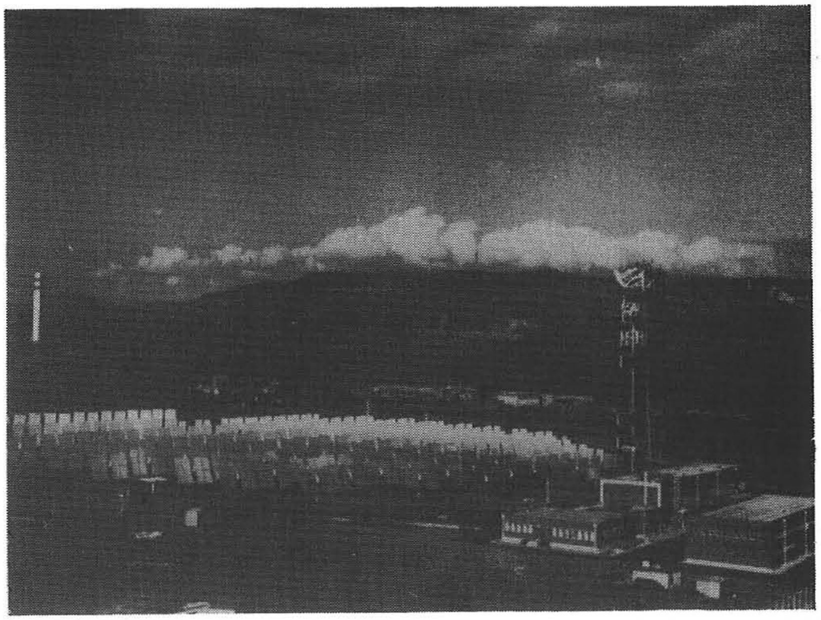


Figure 1. View of the Plant

System Concept

The plant design is based on the central receiver principle. Mirror surfaces totalling 6200 m^2, mounted on 182 heliostats, reflect direct solar radiation onto the central receiver, located on a 55 m high tower. Water is passed through the receiver where it is converted into steam to drive a turbine generator. The electrical energy generated is fed into the existing grid. A bypass is used for start-up and shut-down procedures and a thermal buffer system is provided so that the plant can continue operating without solar energy input for a period of 30 minutes.

Technical Parameters

General Characteristics

Experimental plant of the central receiver multi-heliostat type. Location 37.5°N; 15.25°E (Sicily-Italy). Design point: equinox noon, assumed insolation of 1000 W/m^2. Nominal rating: 1 MW(el). Total efficiency: 16% (from sun to grid electricity). Required land area: 35000 m^2.

Heliostat Fields: 4800 kW(th) to receiver

Heliostats: two types, two axis controlled, overall inaccuracy $\pm$ 4 mrad (1σ). CETHEL type: about 52 m^2, eight focusing modules, 70 heliostats. MBB type: about 23 m^2, 16 square elements, 112 heliostats.

Receiver/Tower

Cavity-type receiver 4.5 mϕ aperture in 55 m height, 110° inclination. Receiver outlet steam conditions: 512°C, 64 atm, 4860 kg/h (5346 kg/h possible).

Steam Cycle

Turbine directly connected to receiver (no intermediate heat exchanger). Nominal power: 1200 kW (mech) with steam of 510°C, 60 atm. Feed water temperature at receiver inlet: 36°C. Cooling water temperature: 25°C maximum.

Thermal Storage

Reduced electrical output for about 30 min. Energy storage: vapour 300 kWh; Hitec: 60 kWh. Equipment: pressurized (19 bar) water reservoir for 4300 kg; vapour produced from 19 to 7 bar. Two storage tanks containing 1600 kg Hitec (overall capacity); heat exchangers for 19 bar, 480°C and 410°C steam temperature.

Electrical System

Power generation: alternator for 1100 kW min. for about 100 kW internal power and 1000 kW for external users; transformers, emergency power supply; interface to grid: equipment to connect transformers to public grid; steam cycle control equipment; command, operation and monitoring are centralized in the control centre.

Mirror Field

There are two types of heliostats arranged in two subfields divided by a North-South line. The MBB heliostats are placed in the Eastern part, those of CETHEL are in the Western part. The aim of this is to test under field conditions the performance, behaviour, and hence the economics of heliostats of considerably different size.

The MBB Heliostat

The MBB heliostat (Fig. 2) consists of 16 mirror elements mounted on two supporting frames. These mirror elements have a fixed focal length of 190 m; their orientation can be adjusted using the fixation screws. The supporting frames are attached to the alt-azimuth drive mechanism by means of flanges. Each heliostat has a reflective surface of 23 m^2 and comprises 16 focusing square mirrors, 1.20 x 1.20 m, made of 3 mm floatglass and sandwich structure.

The CETHEL Heliostat

The CETHEL heliostat (Fig. 3) consists of 80 modules, each one being made up of 6 mirrors of 1.8 x 0.6 m, so that the total reflecting area is 52 m^2. The 48 elementary mirror stripes are flat laterally and bent vertically and arranged in such a way as to envelop a sphere of the required bending radius, focusing at $100 < L < 200$ m. The glass is 6 mm thick. Rigidity is ensured by a triangulated iron structure which guarantees, together with the very precise tracking system, better than the required 4 mrad accuracy of the reflected beam.

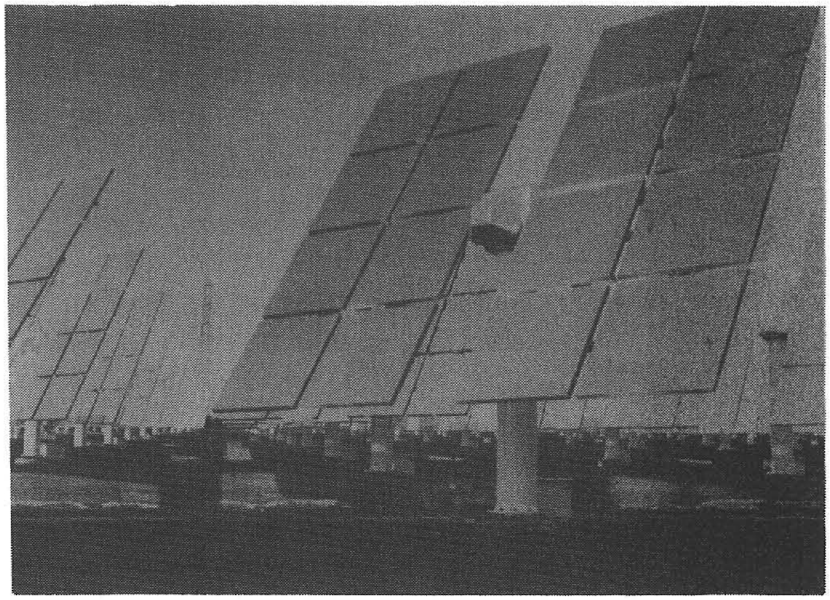


Figure 2. MBB Heliostat

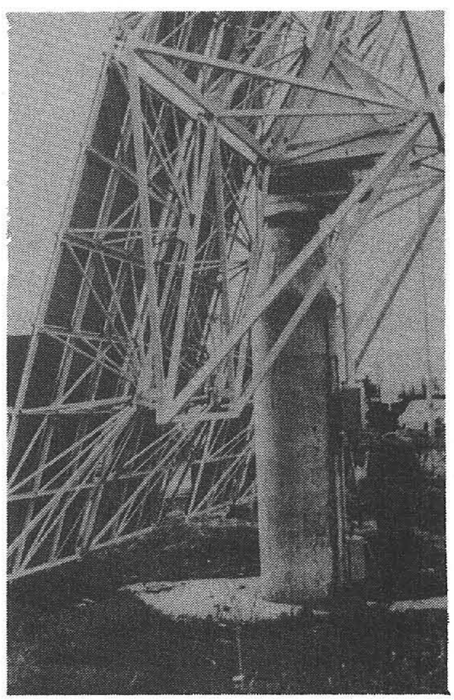


Figure 3. CETHEL Heliostat

The Receiver

The receiver, placed on the top of a 55 m high tower (Fig. 4), was constructed by ANSALDO and is based on results and experience acquired by G. Francia and ANSALDO at the S. Ilario test facility.

The once-through boiler-type receiver consists of two parallel tubes, through which pressurized water flows, rolled up in a coil to form the walls of an opened conical body (cavity-type boiler) into which the solar radiation is focused. The tubing forms a preheating zone at the lower part of the cavity where the solar fluxes are highest and an evaporating zone on the conical side walls of the receiver. The superheating zone is located in the central upper part of the boiler, which is more protected from solar radiation.

To maximize solar energy absorption, the tubes are finned, allowing the reflected rays to hit other zones of the boiler at least 2 or 3 times before being reflected outside. The tube surface is darkened by a heat treatment to approach as closely as possible black body behaviour.

In order to reduce the thermal energy loss due to radiation and convection, the receiver will ultimately be equipped with antiradiation shields composed of pyrex sheets, located on the inside over the tubes, and transparent only to the incident radiation. At first, however, the receiver will be operated without the antiradiation shields in order that their effect can be determined later.

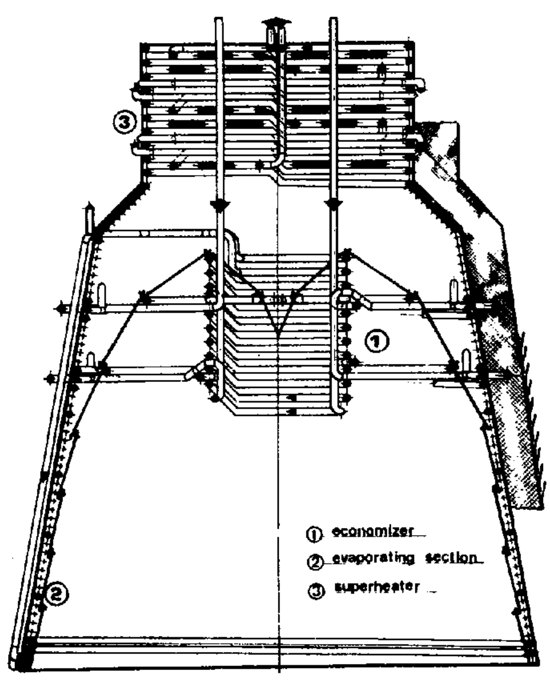


Figure 4. Receiver

The Thermal Cycle

The feed water pump system consists of a centrifugal pump and a reciprocating pump arranged in series, supplying water at 110 atm while a plenum chamber damps the peaks produced by the reciprocating pump. For reasons of safety, this system is duplicated by an identical normally unused back-up system.

The final steam temperature is constantly maintained under transient conditions by means of two direct contact attemperators on each tube. The first is located near the dryout zone of the receiver to control the termination of the boiling zone and provides up to 15-20% of the total water flowing into the receiver. The second is located near the steam outlet to ensure the correct exit temperature.

The thermal buffer allows the plant to operate for 30 mintues at derated power without insolation in order to protect the turbine against thermal shocks when clouds are passing over the heliostat field and inducing rapid variations of the incident flux on the boiler. By keeping the steam delivery temperature at the turbine at about 410°C, it will be able to start up again very quickly after a short break. The system consists of a tank of hot pressurized water at 19 bar and a molten salt system able to superheat up to 410°C the saturated steam produced by the hot water tank. The tank can produce saturated steam at pressures decreasing from 19 bar during the discharge period.

Control

The two parts of the heliostat field are controlled independently using two central units. These central units are interfaced through the Generator Control System which collects the necessary information from the whole plant, including the thermal cycle system, the electrical system, the meteorological station and both heliostat subfields. It then sends appropriate instructions to both central units.

Normally, the steam temperature at the turbine inlet will be kept constant under varying loads while allowing the pressure to vary, although operation at constant pressure is also possible. The plant control system has been set up in such a way that it can run completely in automatic mode. It is actually running under manual operation.

Literature

EURELIOS. The 1MW(el) experimental solar thermal power plant of the European Economic Community. Summary of the final report on Phase B, 15 November 1977 - 15 November 1978, EUR 6747EN.

Borgese D., Faure J.J., Gretz J., Strub A., Treiber H. and Tuardich L. (1980). EURELIOS, the 1 MW(el) solar electric power plant: A European Community Research Project in the field of new energy sources. Paper presented at the XI World Energy Conference, Munich (FRG), 8-12 September 1980.

THE EURELIOS HELIOSTAT FIELD

1.0 General

For political reasons and in order to allow comparison between different heliostat designs, two rather different approaches have been implemented: a subfield of 70 heliostats of 52 m^2 each from the French company CETHEL, and a subheliostat field of 112 heliostats of 23 m^2 each from the German company MBB.

2.0 Heliostat Field Layout and Optimization

MBB computer code "FAUST" was used with the following requirements:

a) Pure north field
b) Division into a west field with CETHEL heliostats and an east field with smaller MBB heliostats
c) Optimization for equinox noon with net power output of 1 MWe
d) Site parameters: 37.5°N; 5% N-S inclination
Direct normal insolation 1000 W/m^2 (initially 850 W/m^2)
e) Given heliostat geometry and optical characteristics

The optimized parameters are:

- Tower height
- Aperture surface and inclination
- Heliostat arrangement within the field

The following performance data were calculated:

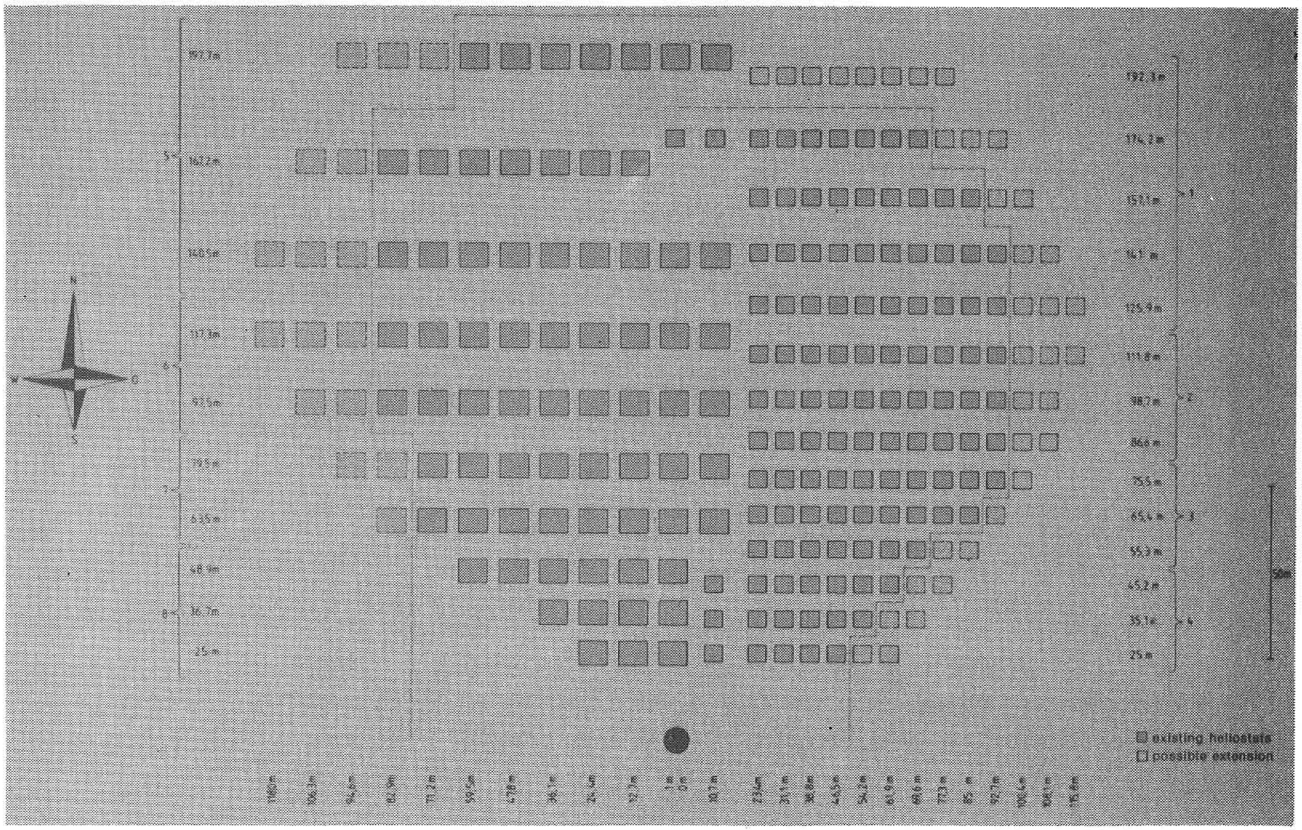
- Heliostat and field efficiencies, including shading and blocking, etc.
- Power distribution and input to the receiver
- Evolution of daily and yearly energy output from field and subfields to the receiver

3.0 Heliostat Characteristics

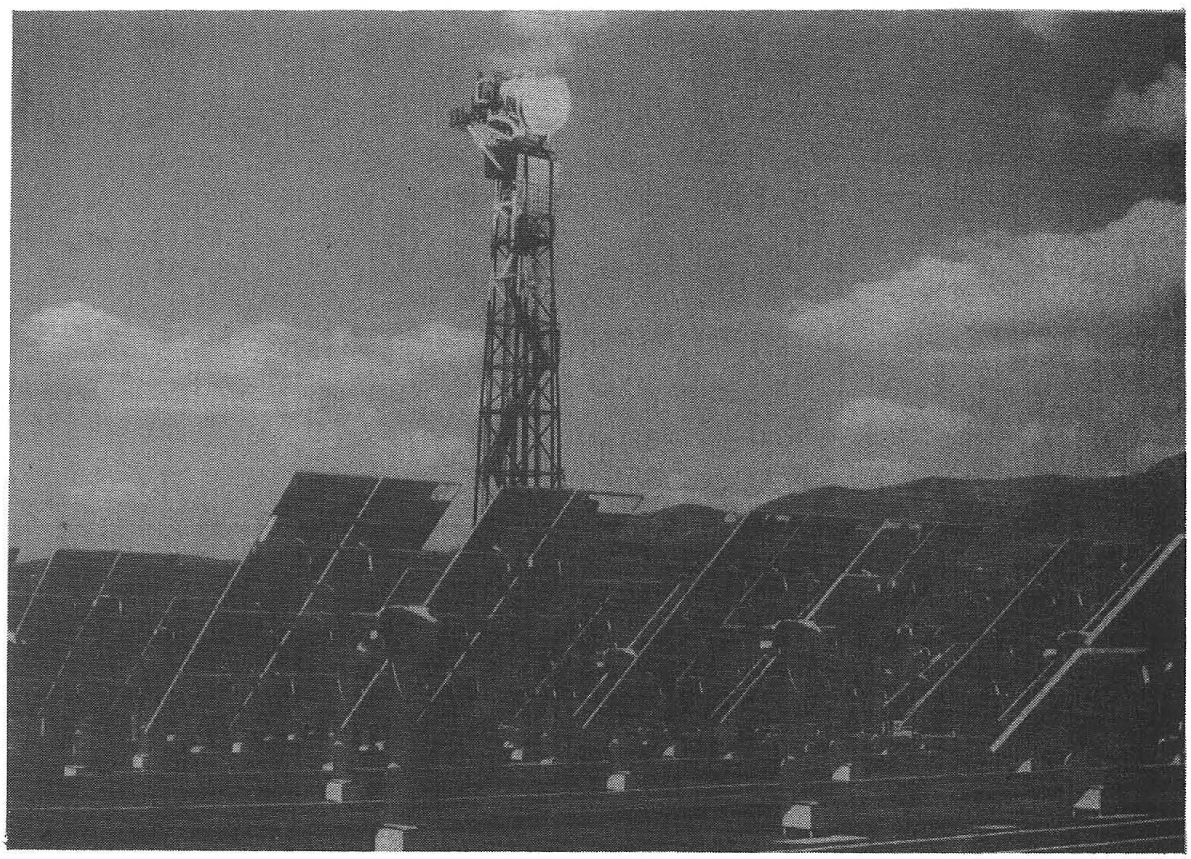
3.1 Heliostat Size
CETHEL: 52 m^2 MBB: 23 m^2

CETHEL Design and development of heliostats by CETHEL was initiated in 1975 on request of French national authority CNRS. One of the specified requirements was that the mirror surface should be around 50 m^2, which was considered as a probable optimum.

MBB Development of MBB heliostats started in 1977-78 together with the EURELIOS project. A short development time with low risk was requested. Maximum use of "off-the-shelf" components was made. Integration and mounting had to be simple and to be realized without major auxiliary devices on a remote site. Therefore, the reflecting surface and the mirror element size were kept rather small. This also was to reduce aberration losses and fluxes to the receiver rim by spillage.



Mirror Field Arrangement



3.2 Panel Construction

Mirror elements

CETHEL
- 8 modules of 6 mirrors of 1.8 x 0.6 m each, total of 51.8 m^2
- 6 mm float glass, reflecting 0.80, bent elastically and fixed in a cylindrically curved form to the pre-manufactured module structure
- Each module can be adjusted by activation of the three points of fixation.
- 4 groups of focal lengths have been realized by shaping the supporting structures correspondingly.

MMB
- 16 mirror elements of 1.2 x 1.2 m, total of 23 m^2
- 3 mm float glass, reflectivity 0.85, curved in both dimensions, forming a sandwich structure in conjunction with a 50 mm thick hard foam and a 0.6 mm thick galvanized steel cover on the back side
- Each element is individually adjusted by 3 fixation points. The focal length of all elements is 200 m.

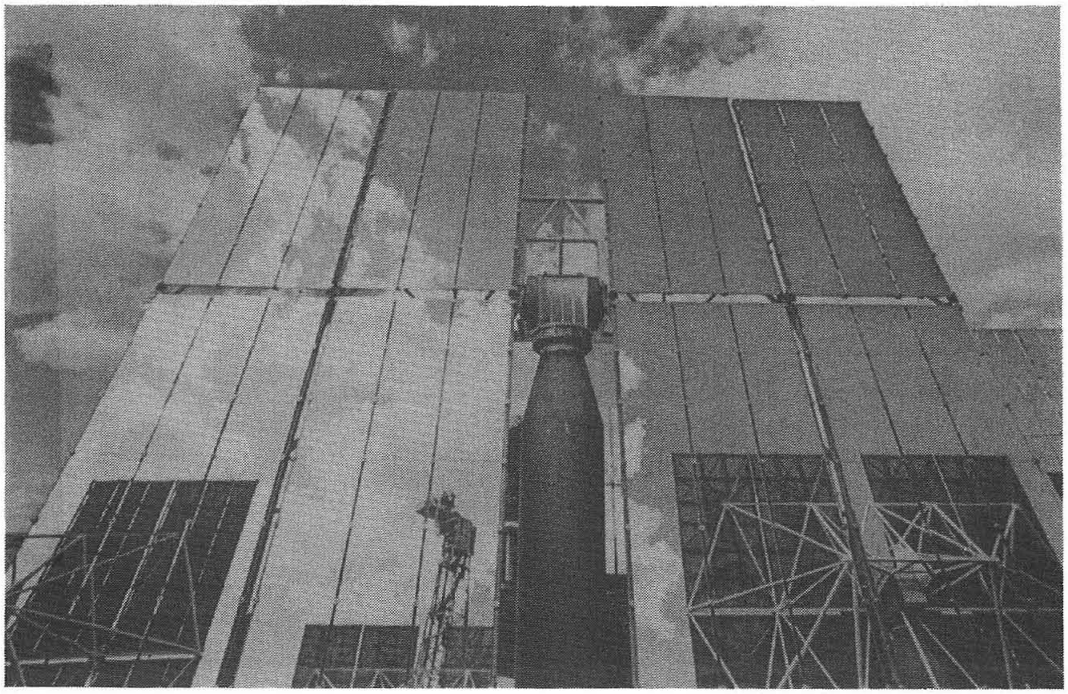
Supporting panel structures

CETHEL
- A three-dimensional braced structure has been chosen in order to provide high stiffness and relatively light weight.
- No precise cutting of the profiles is necessary and even spot welding may be used for junction.
- All design work has been done with the aim of allowing an extensive proportion of the field work by low-qualification personnel (for instance, near to the site in developing countries). Focus adjustment is done with the panel face down, at ground level, using a jig with micrometer and water levels in order to allow exact focusing independently of the sun. Prefabricated parts are galvanized, and the site finished structures are painted.

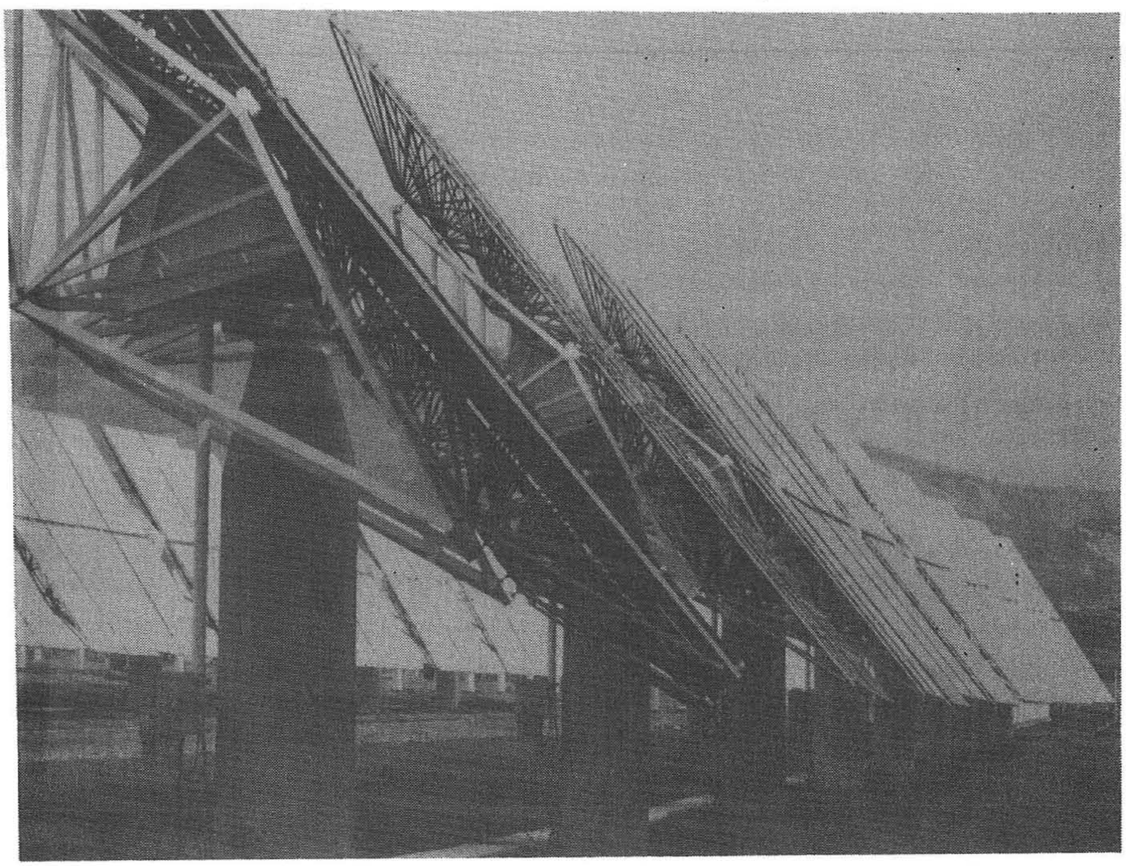
MBB
- A horizontal torque tube carries 4 vertical U-shaped cross beams (2 for each wing).
- 4 steel profiles for every wing side give support to the mirror elements. All parts are painted.
- The structure is simple and light and arrives at the site in prefabricated modular form (1 wing = unit). No welding or manufacturing at site is required.

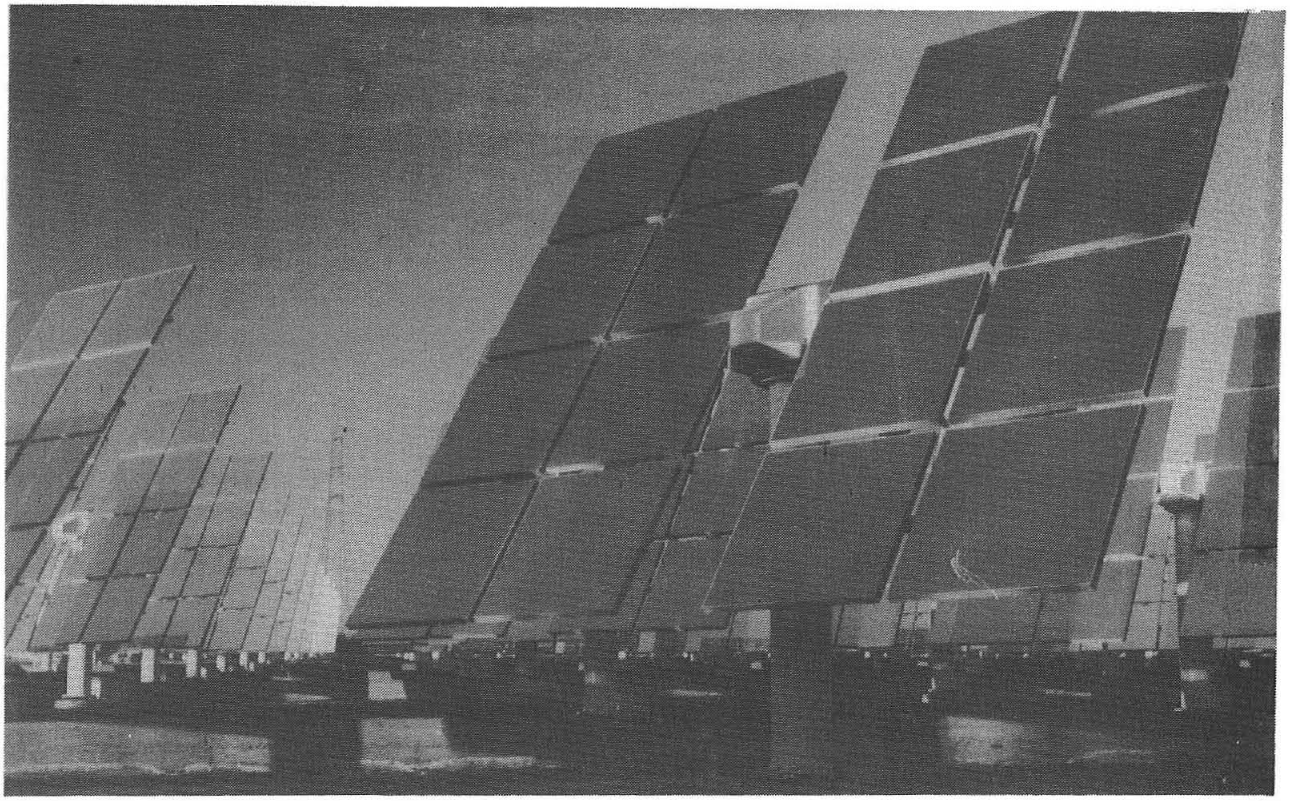
Pedestals

CETHEL chose a concrete-type pedestal, reinforced by steel, forming one piece with the foundation. On the top an iron seating is fitted and sealed after precise levelling and orientation.

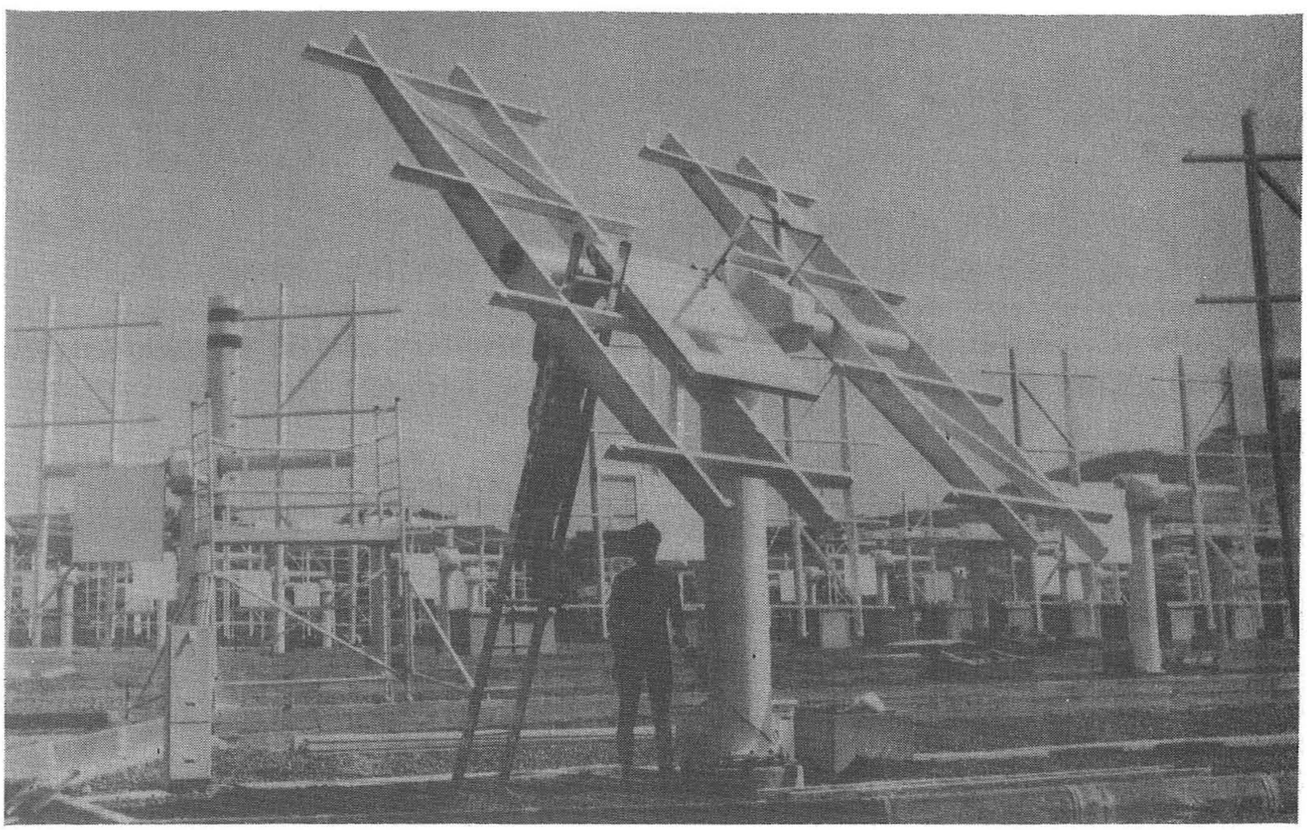


CETHEL Heliostat and Structural Layout





MBB Heliostat and Structural Layout



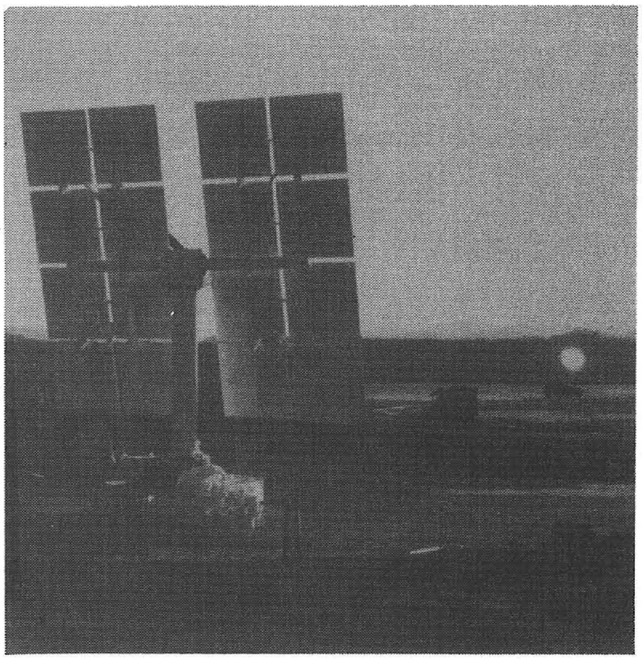
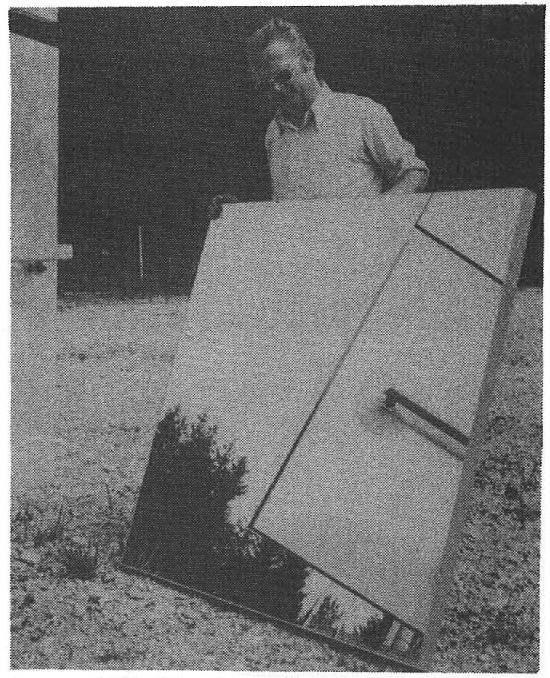
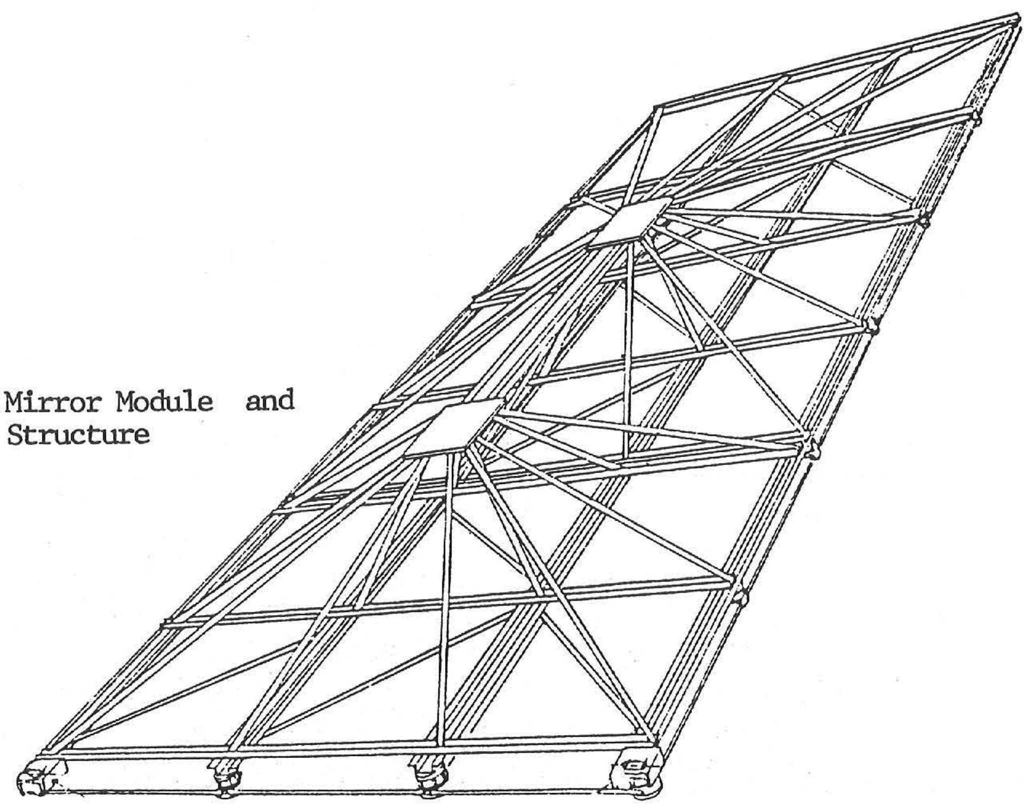


Image of Single MBB Heliostat



MBB Mirror Element



CETHEL Mirror Module and Structure

The concrete solution has been chosen as a low-cost approach wherever it can be fabricated on site and where the ground conditions are favourable. High stiffness and low temperature sensibility are to be granted by this column.

MBB has adopted a tubular steel pedestal of available mass production tubes. Low weight at reasonable costs is to be obtained by this approach, where again manufacturing at the site with its required manpower is avoided. Production in a third-world country of this kind of component could be easily realized.

Drive Units, Gears

CETHEL	24 V DC-motors, consuming 90 W at high speed and 40 W at low speed, drive the identical gears for azimuth and elevation, consisting of parallel trains of gear-wheels driven by worm gears. Reduction rate is 1: 11.200. A gear efficiency of 60% is supposed.
MBB	24 V DC-motors as well, driving identical Az and El gears consisting of a 5-stage spur gear, a 1-stage worm gear and a final spur gear. Reduction rate is 1: 225 380 in Az, and 1: 171 900 in El. Gear efficiency is close to 35%, providing self-blocking in stowage position.

3.3 Heliostat and Heliostat Field Control

CETHEL's heliostat control is more of the centralized type, i.e., functions that can be implemented reasonably in the central unit have been located there; the calculation of the required heliostat position, the control of the actual position, and the feedback to the heliostat are managed by the CU.

At the heliostat level are implemented the counters for incremental encoding, the motor control electronics, and the autonomous safety devices, as well as all interfaces for simple connection of the low-rate transmission bus to the CU.

Incremental encoding by impulsion counting was chosen, even if this requires high precision gears to avoid backlash and to maintain low power consumption. The lower cost for rather high precision seemed to CETHEL to justify the choice.

MBB has a system of highly distributed intelligence. Every heliostat controller calculates the sun's position and compares it to the requested position. Adjustment is carried out all 0.1 sec. if necessary. This also allows reaction to wind loads and to dynamic movements at a low frequency rate. Even safety trajectories are controlled individually (for instance, after emergency shutdown of the central control).

Angular position is measured by absolute encoders so that direct information on the actual position is always available. Measurement is done directly at the gear outer shaft so that all tolerances are outbalanced.

MBB's assumption was that the somehow higher cost of this method is justified by the higher performance and flexibility.

4.0 Heliostat Field Costs

CETHEL heliostat field cost breakdown is roughly as follows (70 heliostats of 51.8 m^2 each):

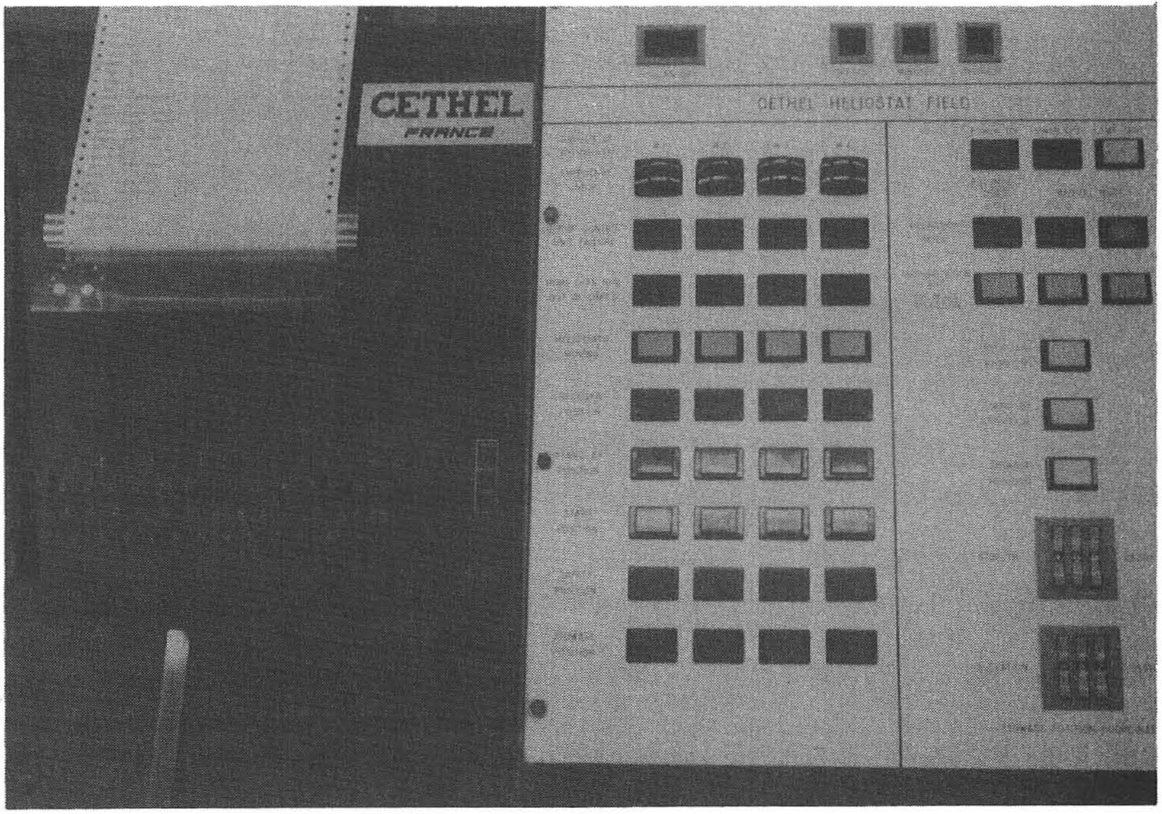
Rear structures	1 450.000,--FF
Reflecting panels and accessories	1 850.000,--FF
Mirrors	450.000,--FF
Mechanical drive units	3 600.000,--FF
Local electronic boxes	1 600.000,--FF
Central control system + cabling	1 600.000,--FF
Transportation	512.000,--FF
Work on site (including welding, painting, shaping of modules, adjustment, erection, tooling ...)	1 532.000,--FF
Foundations + pedestals	502.000,--FF
	13 096.000,--FF

Total mirror surface: 3626 (m^2)
Costs per mirror surface: 3612,--FF/m^2

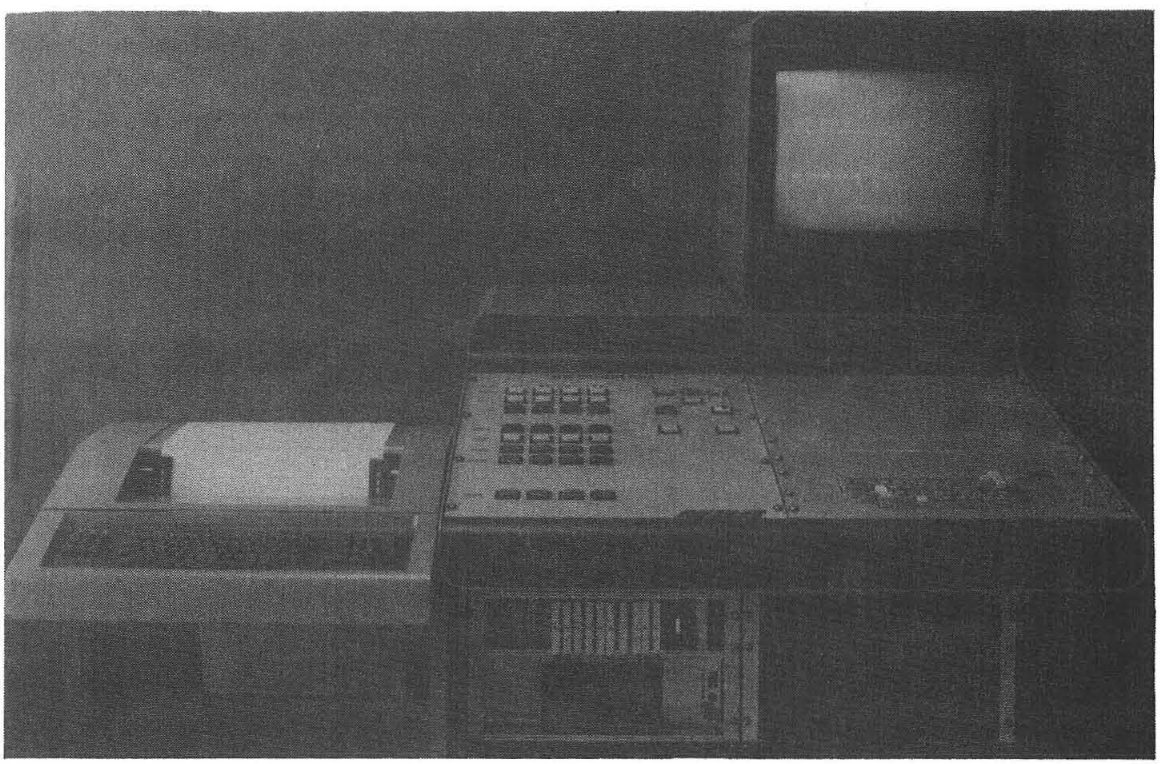
MBB rough heliostat field cost breakdown (112 heliostats of 23 m^2 each):

Rear structures	175.730,--DM
Pedestals	55.100,--DM
Mirrors (+ packaging)	504.000,--DM
Drive units	2 204.000,--DM
Local electronic box	520.000,--DM
Central control unit	250.000,--DM
Field cabling	40.000,--DM
Transportation	165.000,--DM
Work on site (incl. mounting, engineering, auxiliary devices for mounting)	443.000,--DM
3 checkout units for maintenance	90.000,--DM
Foundations	56.000,--DM
	4 239.030,--DM

Total mirror surface: 2576 m^2
Costs per mirror surface: 1650,--DM/m^2



Central Control Unit for the CETHEL Field



Central Control Unit for the MBB Field

5.0 Experience and Problems During Erection and Operation

CETHEL: In general, site work went smoothly. No major erection or assembly problem was encountered.

- The main difficulty was related to anti-corrosion treatment. Since modules are galvanized, they had to be completely welded in the factory. This led to high transportation volume and costs. The method will certainly not be applicable to far overseas sites. Therefore, other final assembly methods (e.g., rivets) or other protection should be applied.

- The focusing method has to be improved to ensure better checkout, possibly before final mounting. Mirror breakage was very limited during erection. Some later damage may be explained by excessive stress in the mirror itself.

- Initial problems with electronics have been solved rather quickly and led to modifications for the later Themis heliostats.

- Inductive sensors used for reset to zero of the encoding counters revealed temperature and adjustment errors. They should be replaced by micro-switches.

- As an average, one outage per card due to electronic component failure in the 1.5 years of operation time was noticed. Complete checkout of all individual cards and long time tests could considerably improve this failure rate.

- Signal pollution and resulting difficulties with the adjustment of interface electronics were encountered and should be improved by cabling materials of higher standards.

MBB: During assembly and erection, the rather time-consuming individual adjustment of every mirror element using the sun was a major cost factor.

- In addition, the time for adjustments was very hard to get due to other work on the tower and near the field and the non-availability of the sun. An independent quick method should be elaborated.

- In a first period, some 10% of the mirrors showed "bubbles" after high temperature exposure. Manufacturing problems could be identified as the reason: The glue had not been applied carefully enough to the supporting foam substructure. The mirrors have been provisionally repaired, and a new technology was applied to manufacture spare mirror elements for replacement.

- Failures of small lamps in the encoders were also identified as a manufacturing mistake. Unfortunately, there was no way to find where the bad lamps had been mounted, so one had to wait until failure occurred before replacement.

- Power supply units failed at high temperatures due to a non-adapted plastic cover. They had to be replaced (material cost was, as above, very low, but manpower expensive).

- Electronic components failed at a "normal" rate for low-cost (and not the expensive "high-rel") parts. The failure rate has been stabilized in the meantime.

- On the average, some 4 to 5% of the heliostats are out of service; this rate is mainly due to a very long period before the intervention. A permanent presence of a repair crew would dramatically reduce the outage periods and improve the field availability to close to 100%.

HELIOSTAT FIELD EFFICIENCY

One of the major problems to be solved in the future design of enlarged solar plants is related to the efficiency of the heliostat field in association with the receiver aperture.

The efficiency is the result of a combination of well-known factors:

- field layout, latitude and tower height combine in geometrical effects (cosine, shading, blocking)
- mirror reflectivity and its evolution with time
- heliostat performance

For the first factor, the efficiency in steady conditions is easy to compute--the correct prediction of yearly collected energy depending on the availability of appropriate meteorological data (Fig. 1).

The evolution of mirror reflectivity also depends on local conditions. At EURELIOS, an average loss of reflectivity of 7% was found, resulting from the combination of dust deposit and self cleaning by rain (Fig. 2).

Heliostat performance can be defined as the capacity of the heliostat to make all the reflected energy enter the smallest receiver aperture. It subdivides into tracking accuracy and optical quality.

Tracking errors have numerous origins, as shown in Table I. They globally result in an enlargement of approximately 2 mrad of the sun's image at the receiver aperture, with repartition among different origins varying with heliostat design.

One should notice that all systematic errors, including encoder resolution and geometrical imperfections, can be compensated by software, thus allowing less precise and cheaper construction.

The optical quality of heliostats is even more difficult to determine. It can be defined as the diameter (in mrads) of the image which contains, for example, 95% of the reflected energy. It results from:

- mirror waviness
- mirror element size and construction (plane or focusing, cylindrically or spherically curved)
- focus adjustment

Defined in such a way, it varies with the position of the heliostat relative to the receiver and with the hour of the day because of optical properties of mirrors (Fig. 3).

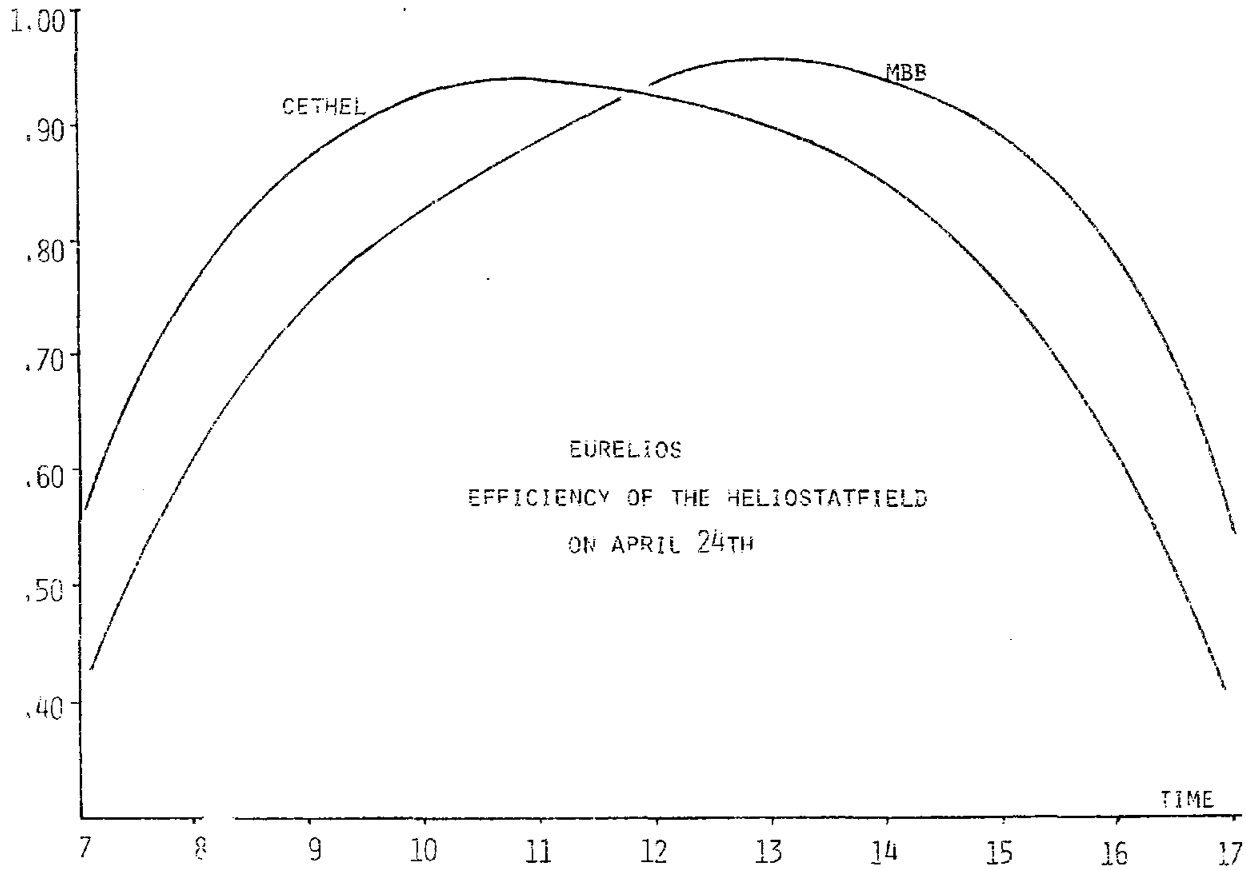
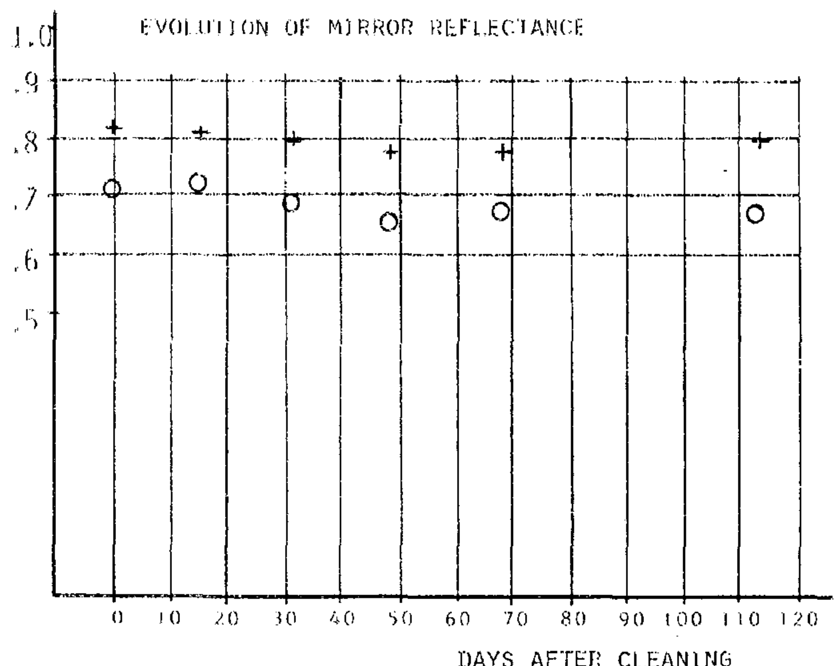


Figure 1



O Cethel
\+ MBB

Figure 2

TABLE I
Tracking Inaccuracy

	MBB	CETHEL
° Computed set point - error in computation - time inaccuracy - error on receiver and heliostat position	Can easily be as low	as necessary
° Set point updating period	0.1 s	6 s
° Encoder resolution	0.8 mrad	0.15 mrad
° Deformation of panel structure	Variable with altitu	de and wind
° Deformation and backlash of gears	Compensated by feedback control	0.4 mrad/ axis
° Origin offset	Compensated by compu	tation
° Geometrical imperfections of 2 axes	Precision construction and adjustment	Compensated by computation
° Drive mechanism, pedestal, foundation and soil deformation under temperature and wind effects		

At EURELIOS, we experienced heliostats of very different design and different methods for adjustment and checking of the focus:

- MBB heliostats are of small size and composed of small mirror elements spherically curved. The relative aperture of the mirrors is small and astigmatism aberration is almost imperceptible.

- CETHEL heliostats, on the contrary, are quite large and composed of large modules with mirror strips bent cylindrically.

Figure 3 shows the computed and measured evolution during the day of the sun's image given by a CETHEL heliostat of short focal length placed on the west border of the field.

To adjust the focus of its heliostats, MBB makes the image of each mirror element coincide with the one given by an auxiliary mirror fitted to the geometrical axis of the heliostat. This method, of course, is subject to the availability of the sun and, for good results, must be completed within precise time limits.

FLUX REPARTITION OF ONE CETHEL HELIOSTAT

F 90 M 45°

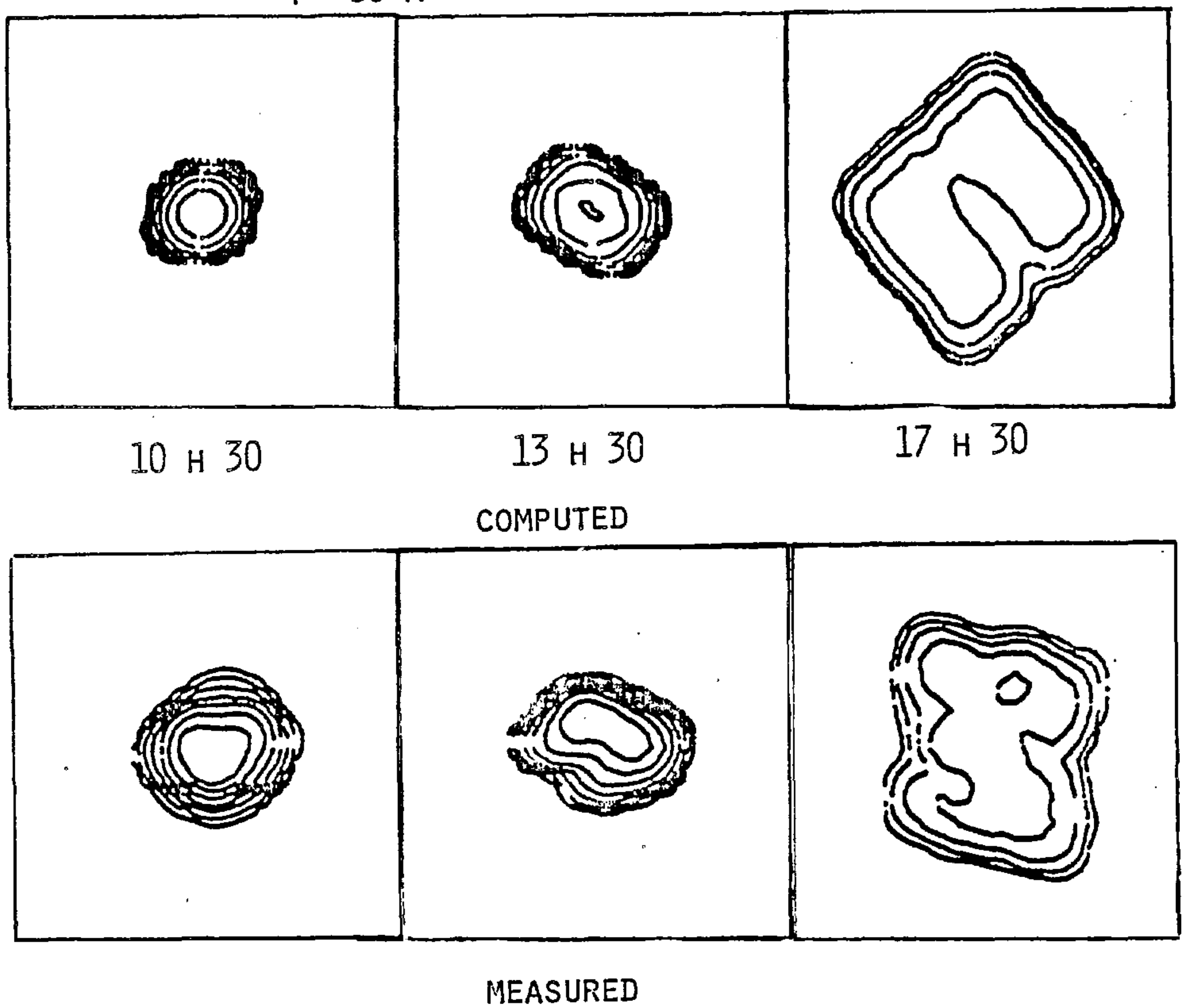


Figure 3

CETHEL, on the contrary, proceeds to a theoretical adjustment, the heliostat panel being horizontal facedown, by means of a specific tooling composed of micrometers and water levels (Fig. 4).

This method has proven susceptible to human error and to shaping imperfections of mirror elements. An average of 20% of the heliostats focused once this way had to be refocused.

For checking the correct tracking and focusing of the heliostats, 3 methods have been successively used:

- visual check auxiliary target, with its record given by photograph (Fig. 5).

- MBB also used a video camera to observe and analyze the image given by a single heliostat on the auxiliary target. The system, combined with computer analysis, allows one to determine the centre of gravity of the flux pattern as well as the relative distribution. It also permitted measurement of the deviations caused by wind and the natural frequencies of the heliostat. The quality of the results was widely subject to the poor quality of the target surface.

Such a device is anyway very useful to determine automatically and without any error the correction values to be introduced in the control software.

We at last have used the Flux Analysis System developed by the Swiss Federal Institute for Research on Reactors in Wuerenlingen which was also used in Almeria for the SSPS project.

The system basically consists of:

- a CCD camera including control electronics, temperature regulation, calibration devices and direct memory access interfaces (7)

- a PPD computer and peripherials

- a moving target. It is a strip 0.6 m large, 7 m high, of alumine coated aluminum, giving homogenous Lambertian reflectance.

The strip is moved across the receiver aperture at a speed of 0.8 m/s by an electric drive mechanism. It is radio controlled and gives to the video system synchronizing signals in order to allow the reconstitution of the whole image.

The device can be winched up on the tower and the strip folded when not in use to avoid risk of damage by the wind (Fig. 6, 7, 8, 9).

Completed with an absolute radiometer developed by the World Radiation Centre Davos, and optical device to test and calibrate camera and target reflectance, the FAS is able to give with high accuracy the relative distribution and absolute values of the energy flux at receiver aperture for single heliostats or the entire heliostat field (Fig. 10).

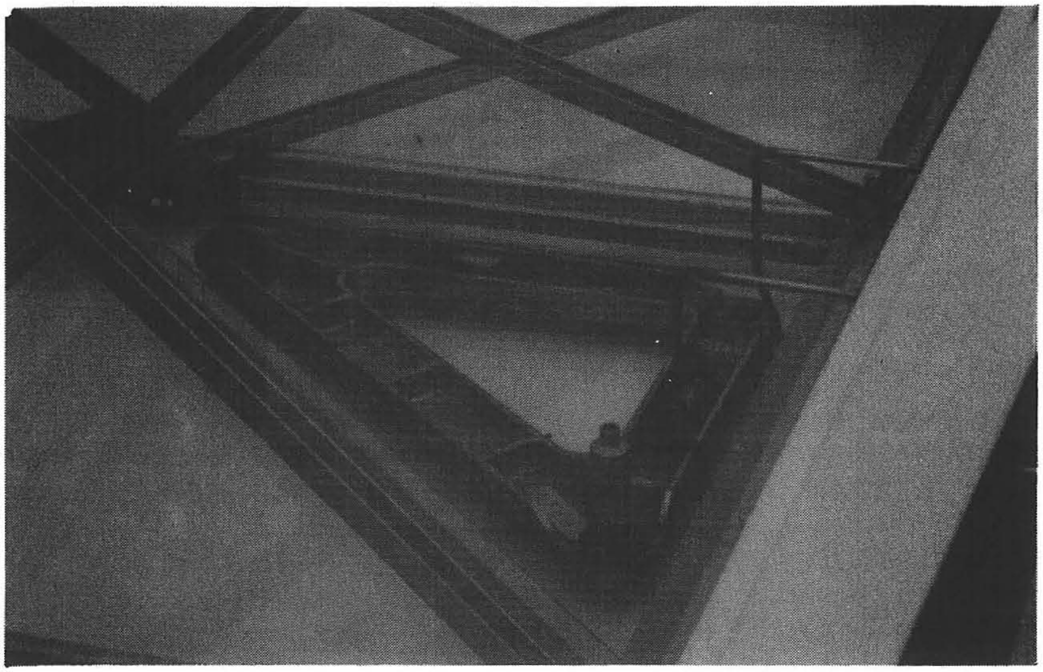


Figure 4. Tooling for Focus Adjustment

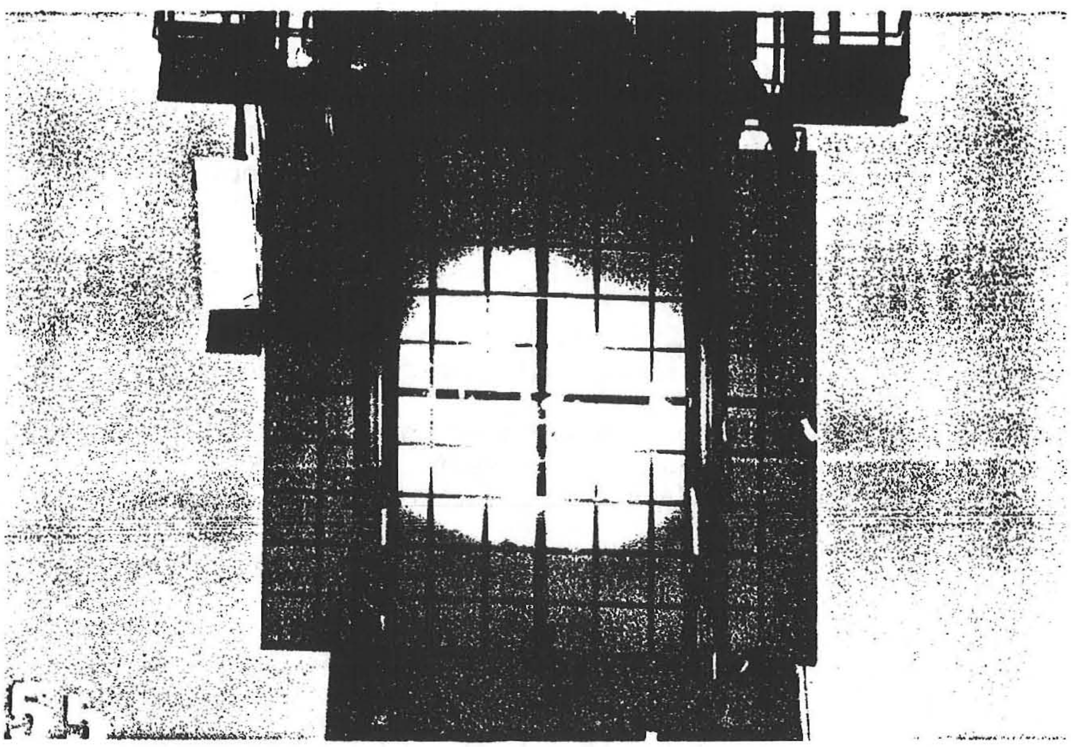


Figure 5. Checking One CETHEL Heliostat on Target

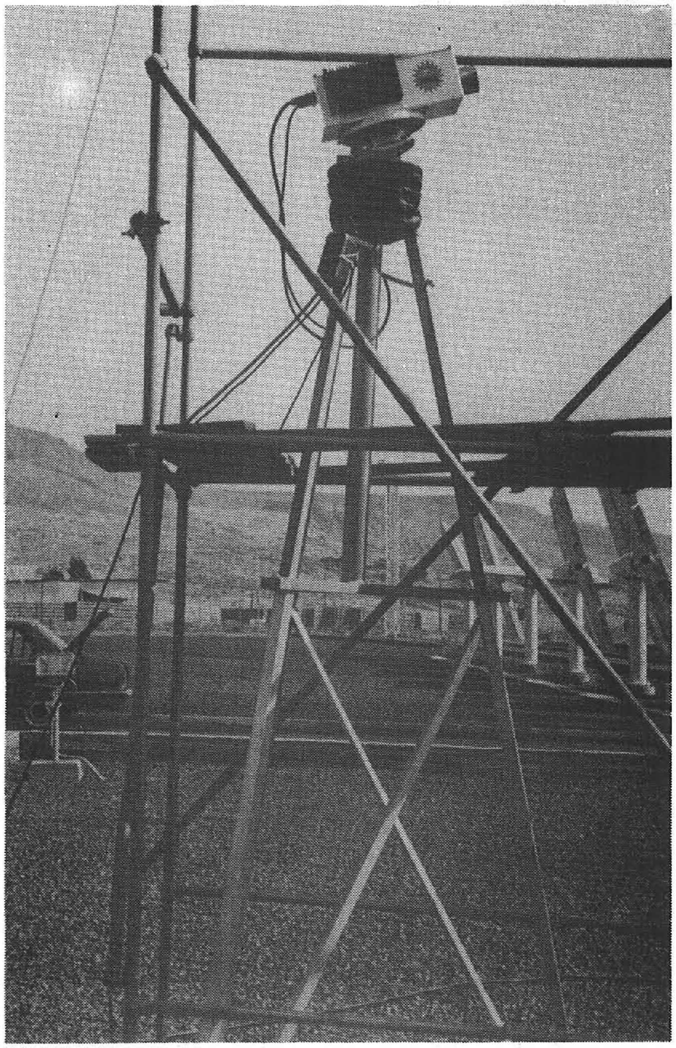


Figure 6. F.A.S. CCD Camera

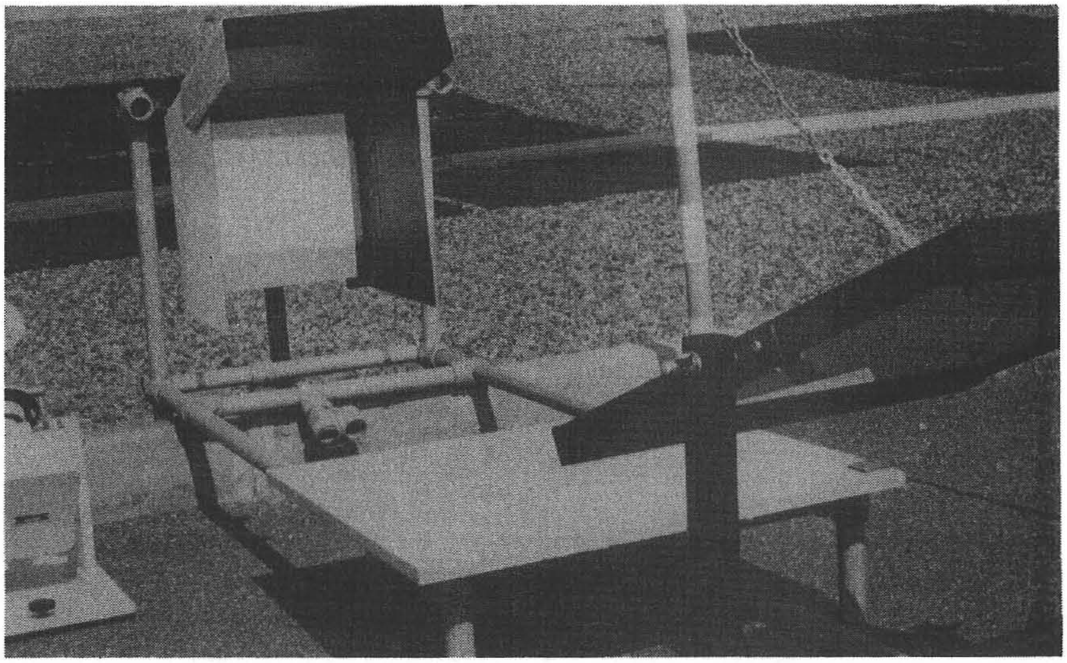


Figure 7. F.A.S. Calibration Device

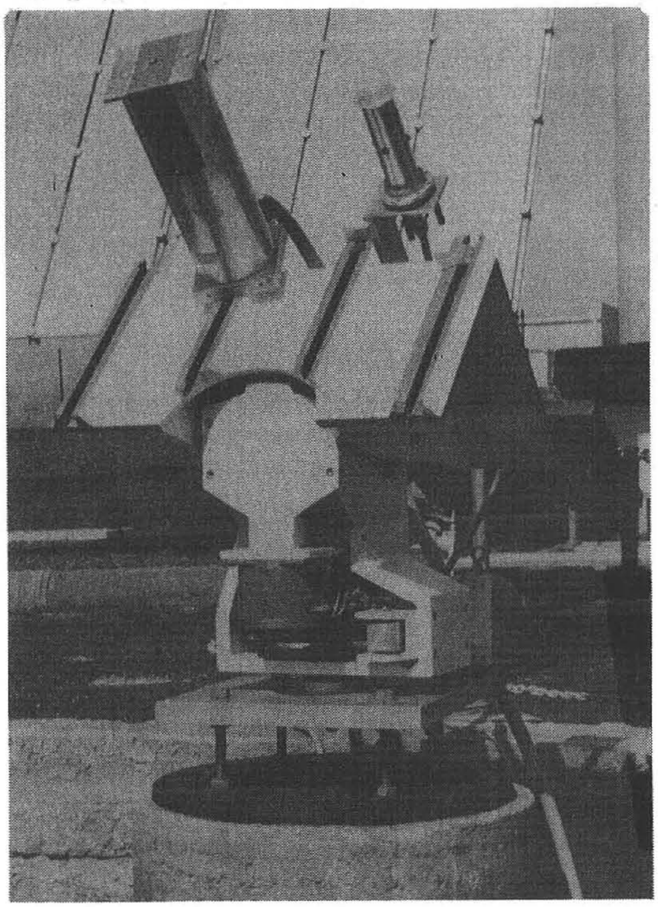


Figure 8. F.A.S. Absolute Radiometer

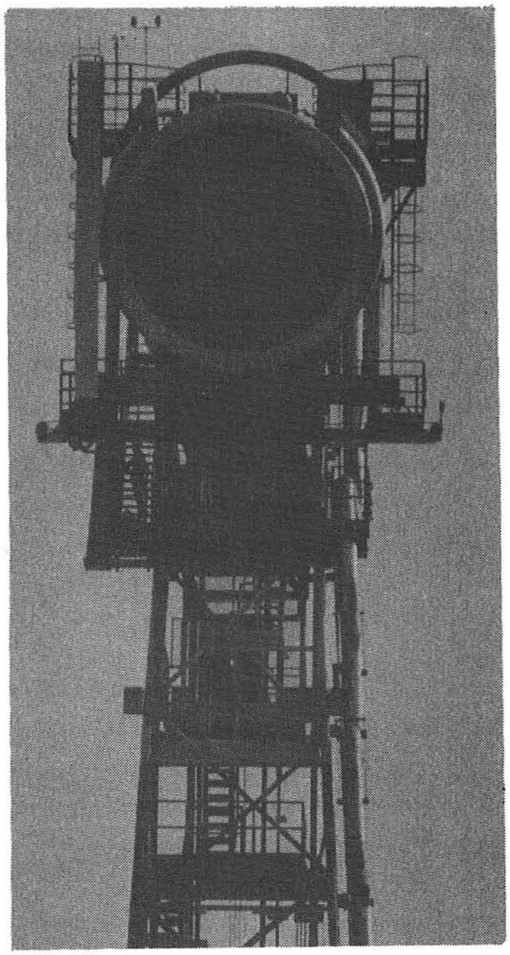


Figure 9. F.A.S. Moving Target in Standby Position, Foldable for Storage

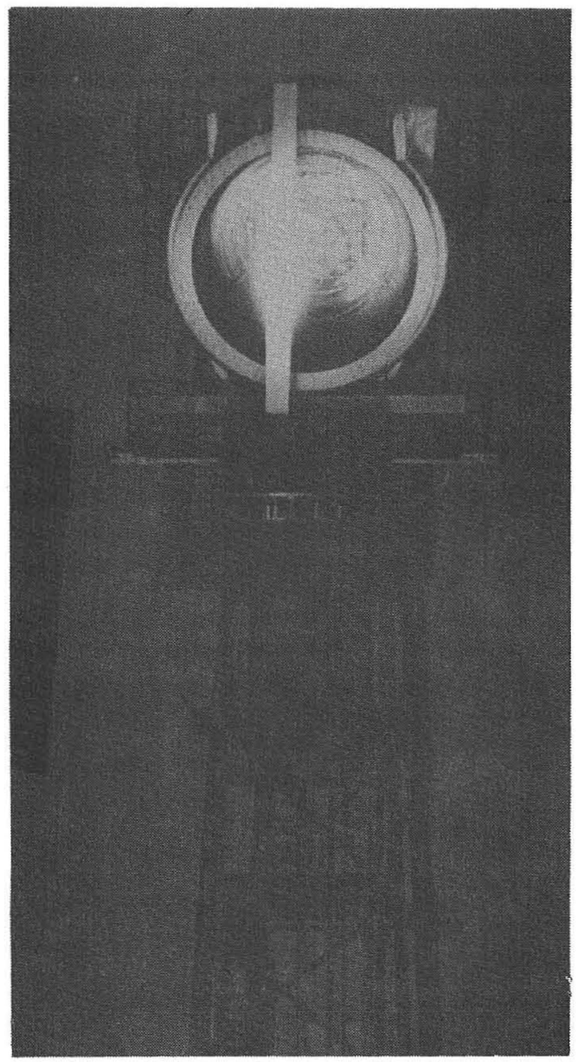


Figure 10. F.A.S. Moving Target Operating With Total Heliostat Field Illuminating the Receiver

As far as we know, this system is the most efficient and accurate for flux analysis and measurement.

The slides show samples of outputs obtained from EURELIOS' first measurement campaign in May (Fig. 11, 12, 13, 14). A second one has just ended on October 15th. It will greatly contribute to our knowledge of heliostat optical behaviour and plant efficiency.

In order to give some conclusion to this quick survey of heliostat efficiency problems, I would like to say that, in our opinion, steps still have to be made in the following directions:

- find a method to check the shape of mirror elements giving a quick and global appreciation of expectable image size
- find a method to adjust the focusing of the heliostat, not depending on sun availability and hour, but with immediate feedback through image size
- determine the best focus adjustment policy to minimize astigmatism effects
- define a universal performance criterium for heliostats.

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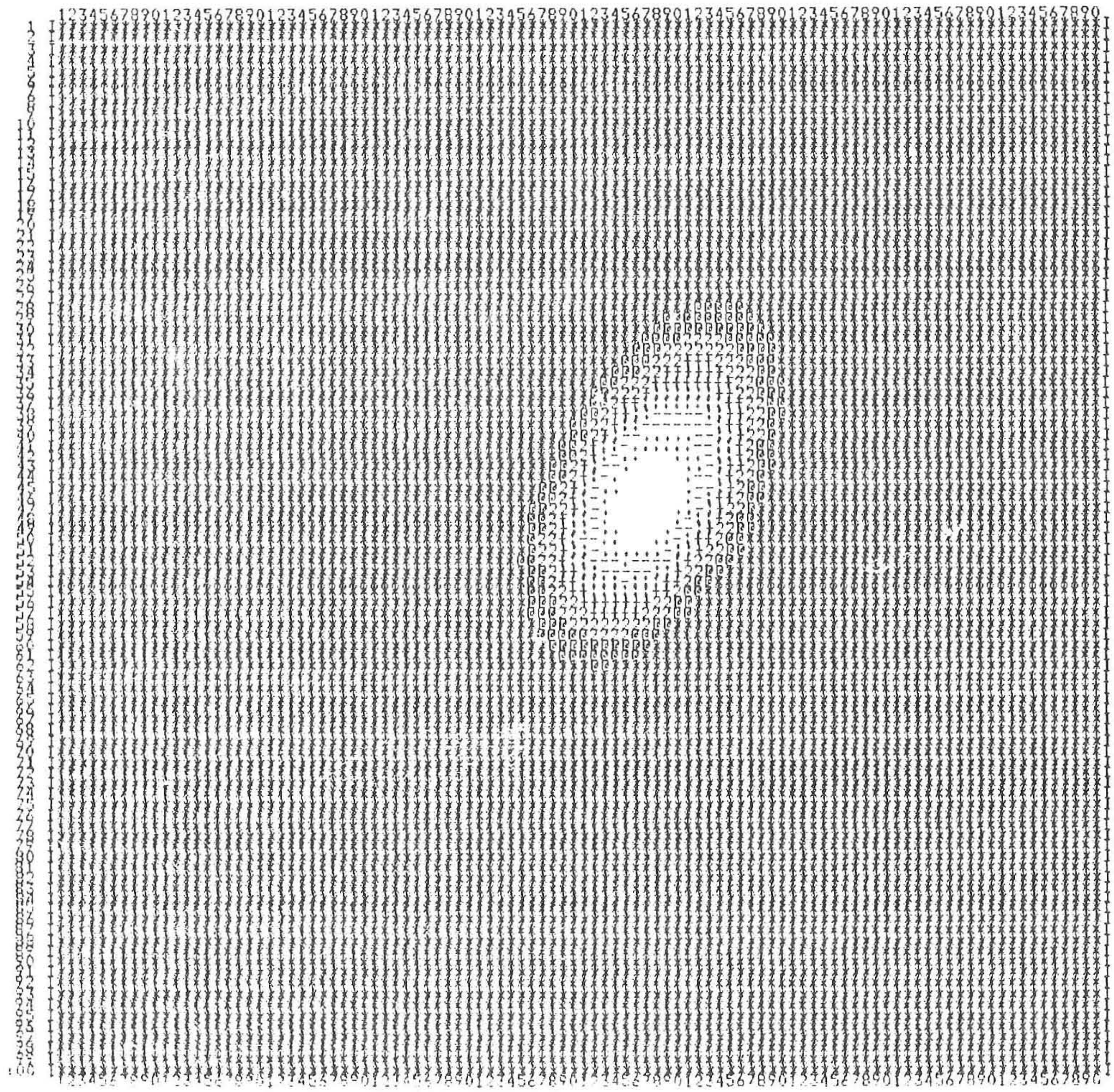

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TOTALE LEISTUNG= 39595. RELATIEF

Figure 11

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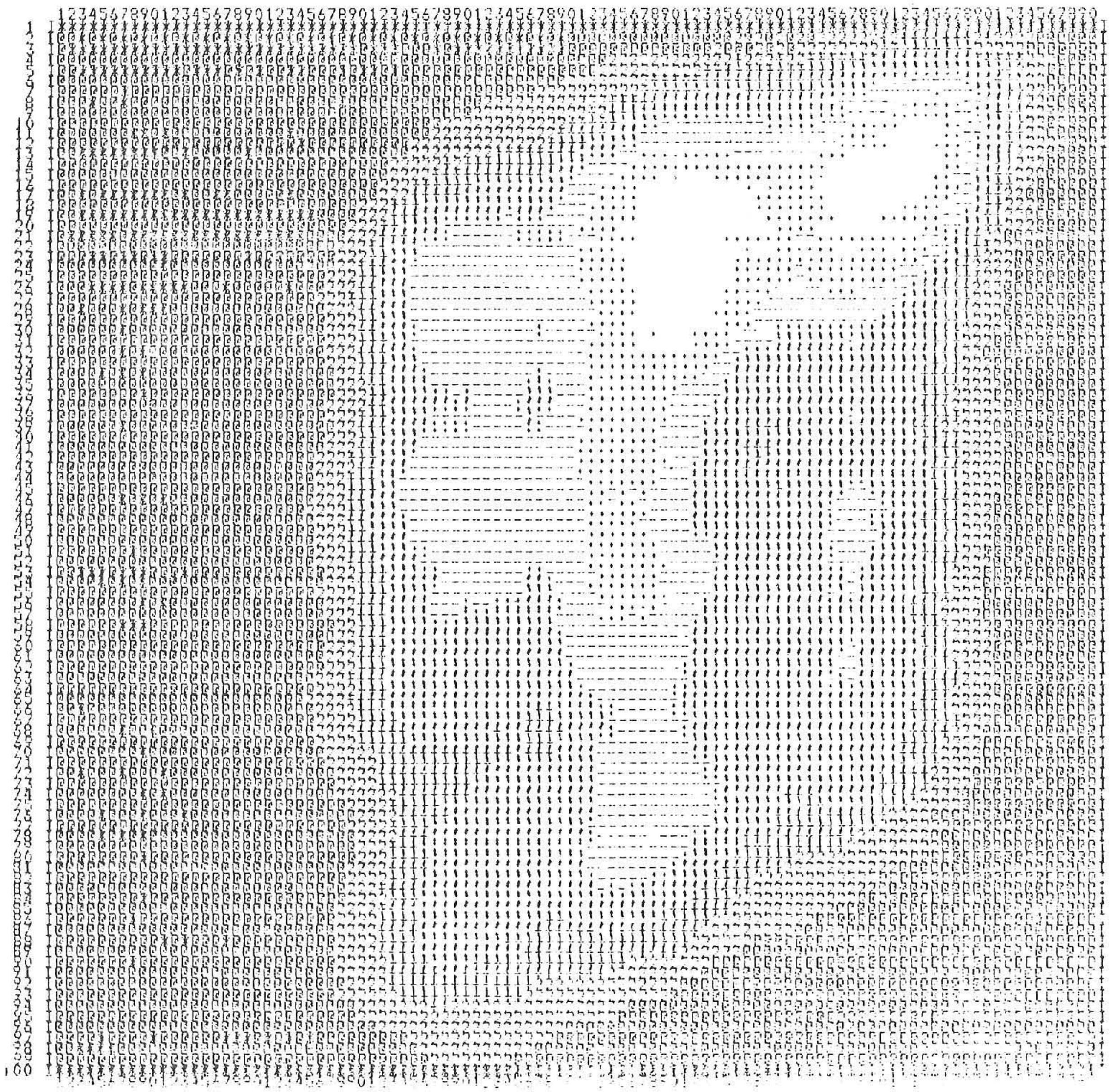

MAX.WERT(REL)= 65 KOLONNE= 61 REIHE=

Figure 12

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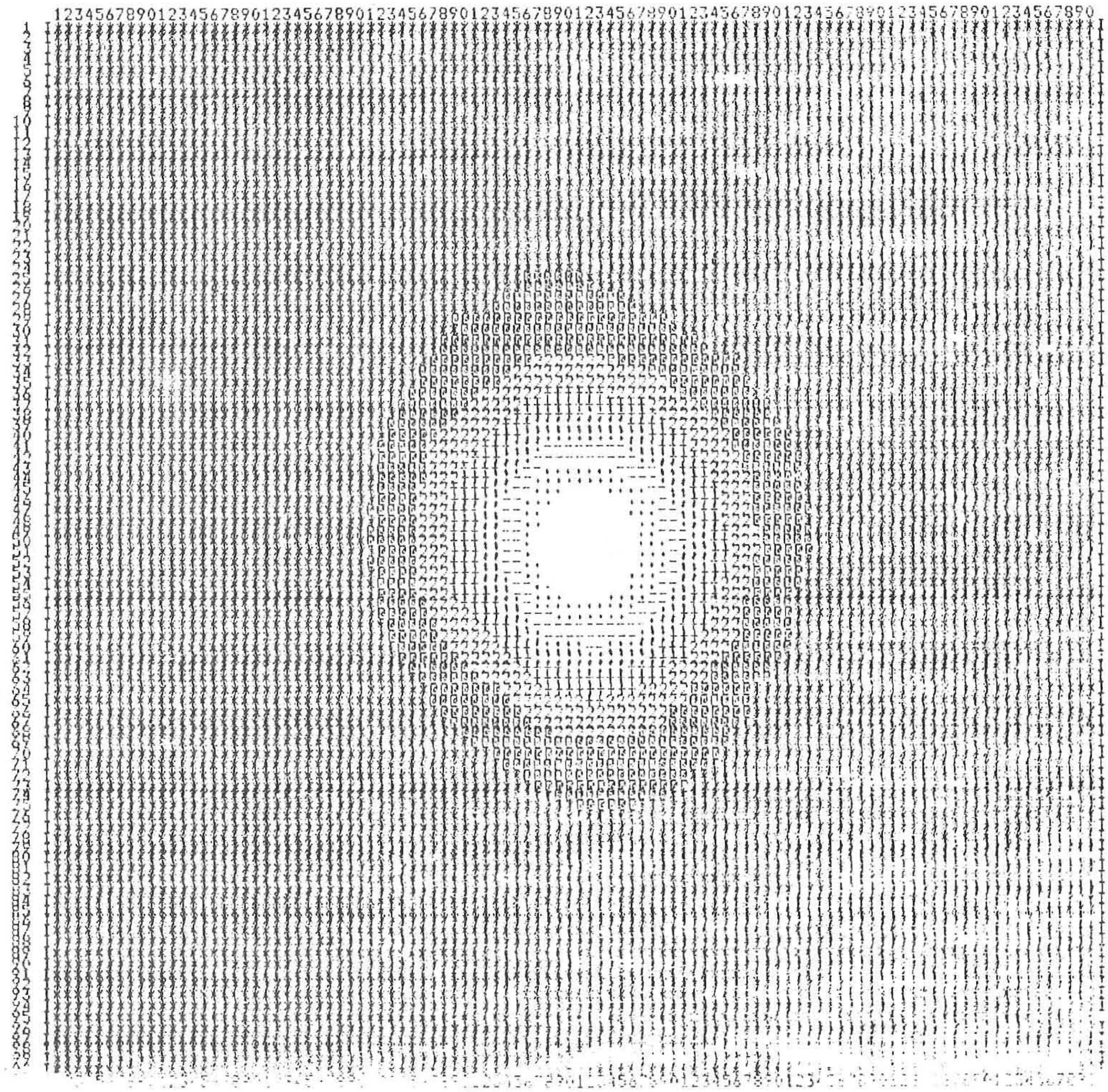

MAX.WERT(REL)= 161 KOLONNE= 52 REIHE= 50

Figure 13

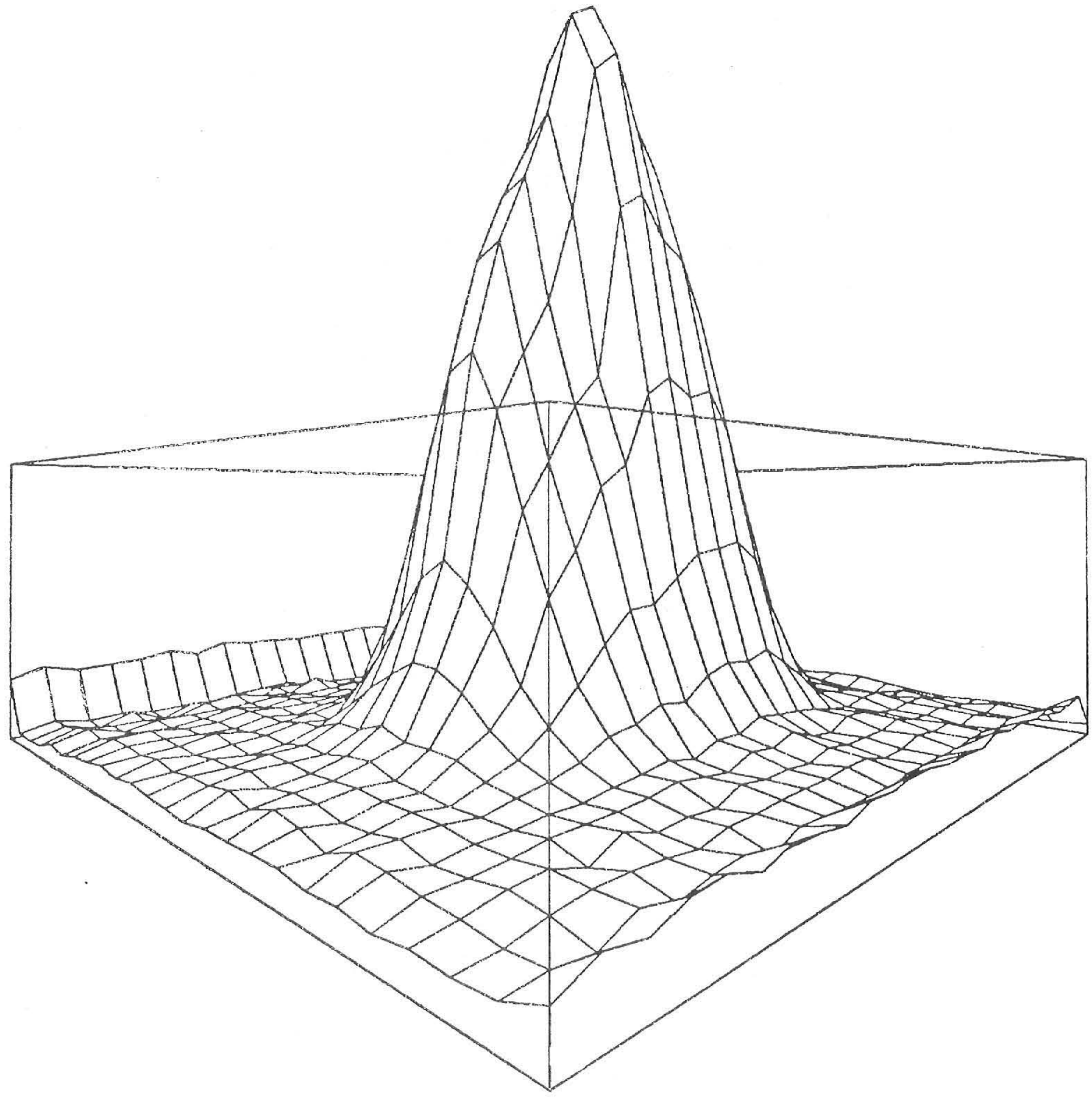

Figure 14. Tri-Dimensional Plot of One Heliostat Flux

The EURELIOS plant has been operated by ENEL since June 81. The period ending Dec. 81 was spent mainly for the final set-up of the plant. Intervention was required to some subsystems and to set up the operating procedure.

The main task consisted in putting into operation the storage system, which consists essentially in a saturated steam tank; two surface heat exchangers, one for heating the salts and one in which steam is superheated to 410°C; and two tanks for the molten salts employed to store heat at 430°C - 450°C.

At the beginning of 1982, the storage system was tested. The plant passed successfully the so-called "cloud passing" test during which the plant was maintained operating in connection to the grid for about 30 minutes. At that point, the plant had passed all the specific tests scheduled to check the process against the expected theoretical performance.

It seems worth noting that, whenever applicable, the plant has passed the functional tests of a conventional thermal power plant such as the "load rejection" test.

The specific service to be expected from a central receiver heliothermoelectric plant has been verified.

To start with, the thermal load into the receiver varies continuously, also during a sunny day, under the influence of shadowing and blocking effects which modify the effective mirror surface. Furthermore, the maximum insolation varies according to the sun's altitude, haze, and sky conditions. This requires a receiver that is flexible and at the same time stable at different loads and an adjustment of the set-points of the process according to the actual level of energy flow.

The expected electric power production at the summer solstice under a direct solar insolation of 800 W/m^2, average measured value for the site of ADRANO, is plotted in Fig. A with reference to a mirror reflectivity R in the range of 70%-80% and a heliostat outage F of 0 and 5%. As an example, the direct solar radiation, the qualitative variation of the heat flux to the receiver, and the electric power to the grid for a reference day are shown in Figs. B and C.

The morning start-up operation may become critical in absence of an auxiliary thermal power source, since to heat up the boiler and thermal cycle requires a substantial thermal input at a time when the mirror field has a lower efficiency.

A low-cost auxiliary power source would certainly make the storage system more attractive. At present, the salts are heated to 450°C with live steam from the receiver in about 45 mintues.

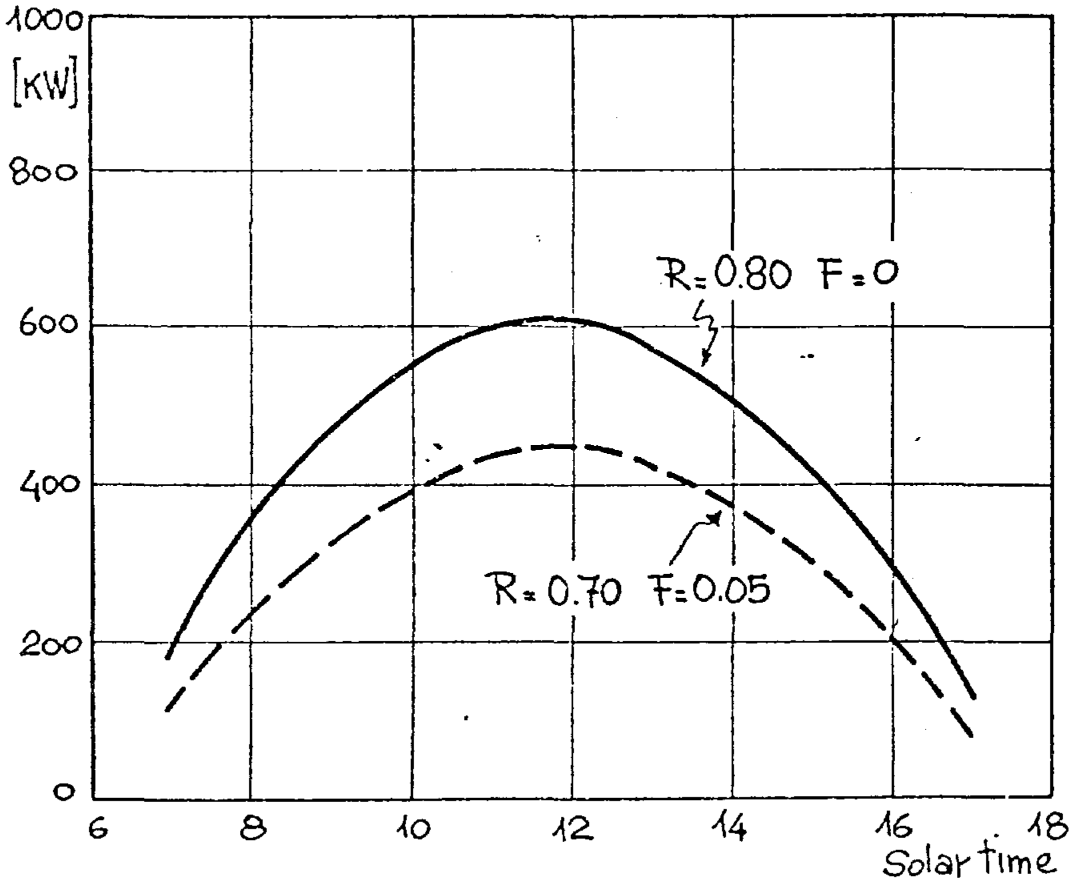

Figure A. Expected Electric Power at Summer Solstice

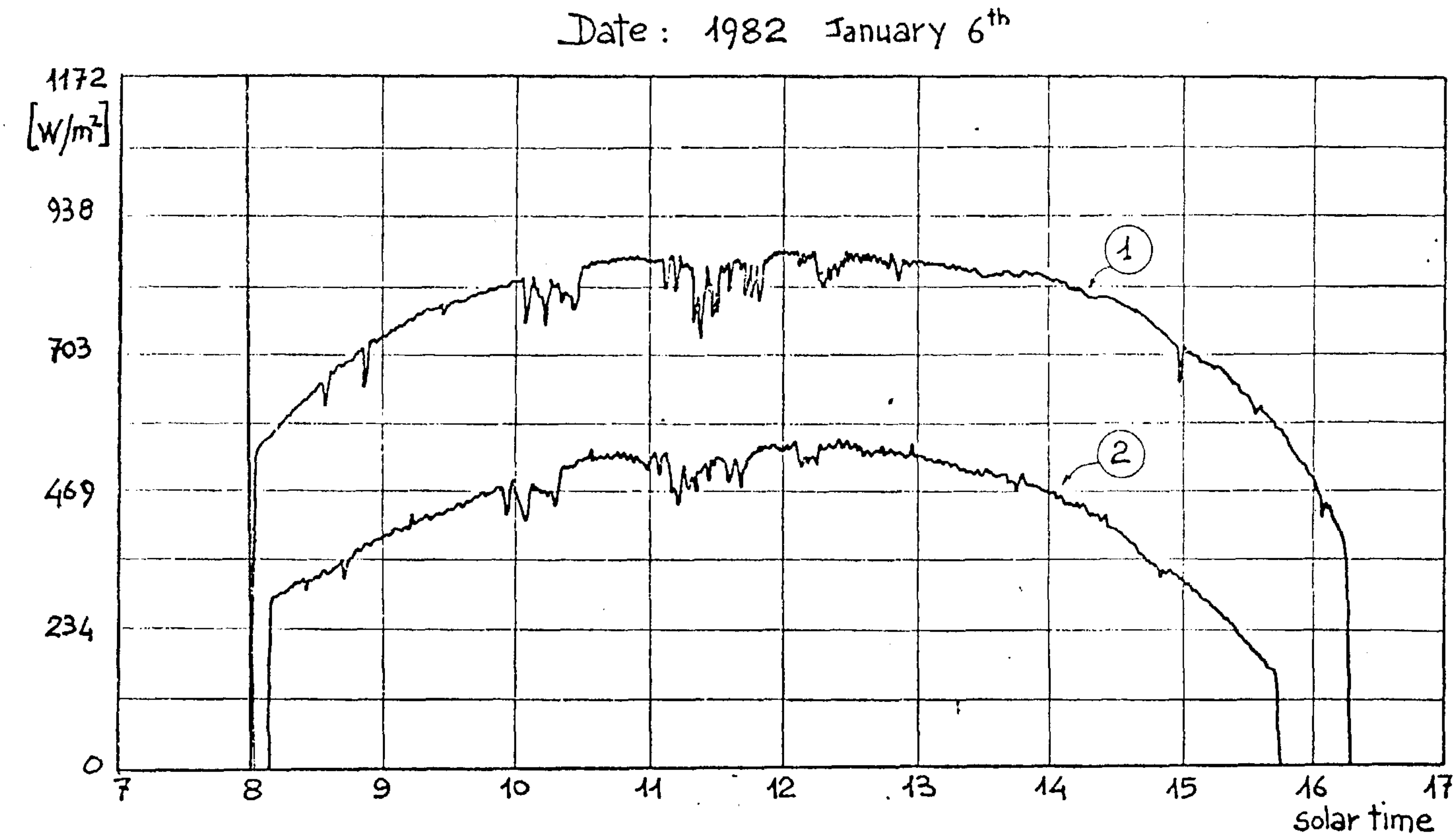

Figure B. 1. Sun Radiation; 2. Qualitative Trend of Heat Flux to the Receiver

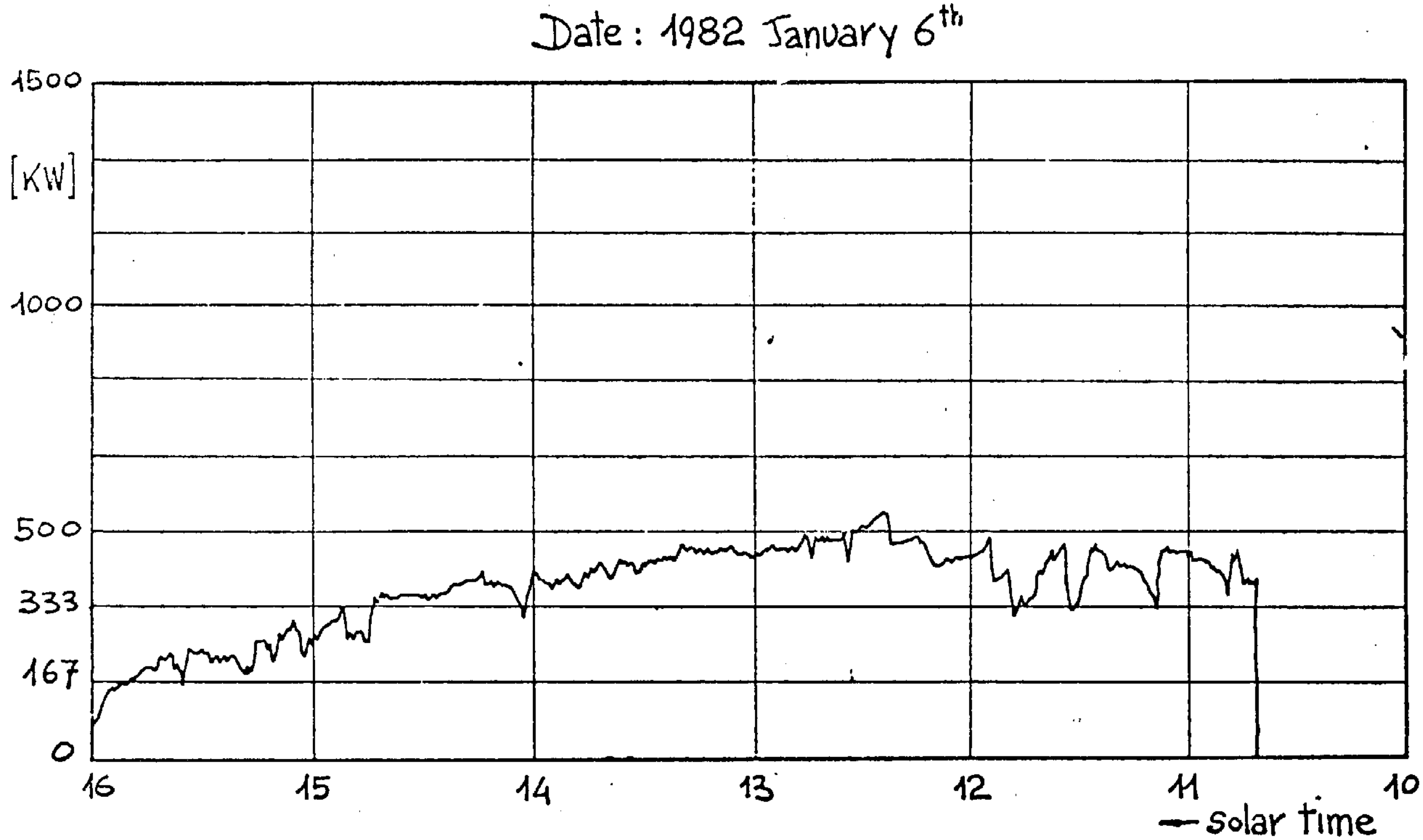

Figure C. Generated Electrical Energy: 1980 kWh

The overall efficiency of the plant will vary as the power level changes following the variation of the solar thermal power into the receiver. To maintain the overall efficiency of the plant close to its optimum value, it may be necessary to modify the set points of some parameters of the process such as the pressure in the receiver. It is clear that in order to reduce to a minimum the operating cost, a suitable control and supervision system must be envisaged in a heliothermoelectric plant.

The current research activity is performed under five working groups.

WORKING GROUP N. 1 is concerned with the operation of the plant and the evaluation of its dynamic behavior.

Under this working group, performance tests are performed at component, subsystem, and system level.

Modification works were done to improve the operation of the plant, and some procedures were accordingly modified.

WORKING GROUP N. 2 deals with the instrumentation and data acquisition system.

The process instrumentation is checked periodically, and process variables are recorded compared to the design value.

A calibrated set of sensors and transducers has been installed in support of the plant performance evaluation task.

WORKING GROUP N. 3 is engaged with the evaluation of the heat flux into the receiver.

Computer codes are available at ENEL and MBB.

An experimental campaign is planned to check the image quality of single heliostats and the global flux into the receiver.

WORKING GROUP N. 4 deals with monitoring of the behaviour of the mirror field.

Under this task, the optical properties of single heliostats or group of heliostats, the optical degradation due to deposits, and the cleaning effects of rain are investigated.

Concerning the mirror reflectivity, the design values were substantially confirmed by measurements performed under clean conditions; reflectivity degradation with time due to the atmospheric deposit was experienced to be about 10%.

WORKING GROUP N. 5 is concerned with the analysis of plant performance.

The plant and subsystems performances are analyzed and the possibilities to improve the energy production are investigated.

The following general considerations can be drawn:

- the plant operation under standard procedures has been established; that means that specialist assistance is not required to operate the plant in connection to the grid;
- in order to improve the energy output of the plant, a fully automatic procedure should be implemented also for the (morning) start-up operation;
- an improved operation is expected from a recirculation (drum) boiler to ensure a shorter start-up time and better stability of the process.

CESA-1

A SPANISH "POWER TOWER" SOLAR SYSTEM
THE PROJECT CESA-1

A. Munoz Torralbo*, C. Hernandez Gonzalvez**
C. Ortiz Roses***, J. Avellaner Lacal***, F. Sanchez***

Introduction

Like many other countries and organizations, Spain has been developing an investigation program into the economic viability of new sources of energy, among these, it should be pointed out, the large solar power systems.

Within this investigation program, "Centro de Estudios de la Energia," an organization dependent on "Ministerio de Industria y Energia," is carrying out the CESA-1 Project, which consists of design, construction, start-up and operation of a 1.2 MW Pilot Solar Power Plant.

If the current technical uncertainties are removed and the power tower concept demonstrates its economical viability, Spain will be one of the most appropriate countries in the world for a full-scale implementation of this technology.

For this reason, the "Ministerio de Industria y Energia" reached the conclusion in mid-1977 that it would be of interest to explore this technology using the domestic industrial potential. The project was approved by the Council of Ministers in June 1977 and the project begun in early 1978. The management of the Project is the direct reponsibility of "El Centro de Estudios de la Energia" and was helped by the engineering firms INITEC and SENER to attain the adequate organization to carry out the project.

Objectives

The CESA-1 Project will cover the following main objectives:

- To study and demonstrate the feasibility of this type of plant.
- To develop the specific technology.
- Industrial development of solar power plant components.
- To acquire the necessary experience to develop, construct, and operate commercial plants that could help to cover the national energy demand.
- To encourage the use of solar energy for electric power generation.

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**SENER, S.A., Sor Angela de la Cruz, 6, Madrid-20, Spain
***INITEC, Padilla, 17, Madrid, Spain

Planning

If the general CESA-1 Program (Fig. 1) is analyzed, four important phases of its development can be observed.

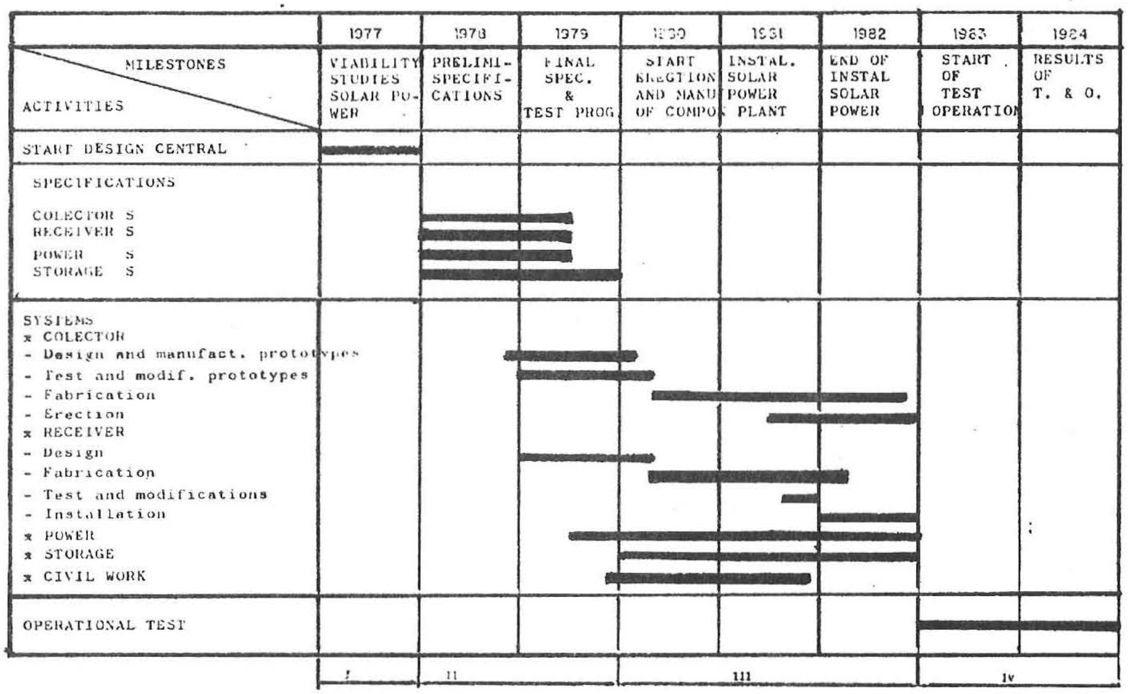


Fig. 1. General CESA-1 Program

Phase I - During 1977, the preliminary studies were carried out to see the viability of Solar Power Plants; the conclusions reached led to the approval of the CESA-1 Project.

Phase II - In the period between 1978 and 1979, the preliminary and final specifications of the different systems were defined, as well as the test program of the less well-known components (heliostats) was carried out.

Phase III - In the period 1980/81/82, the civil work and the manufacture of the components of the systems were carried out as was the assembly of the solar power plant.

Phase IV - At the beginning of 1983, a plan to evaluate and operate the solar power plant will be put into action.

Cost of Project

Fig. 2 describes the estimated percentages of the total cost of the project and the actual ones so far. In order to be able to calculate the running cost, the Management Project Office made a preestimated control of the different components of the Solar Power Pilot Plant.

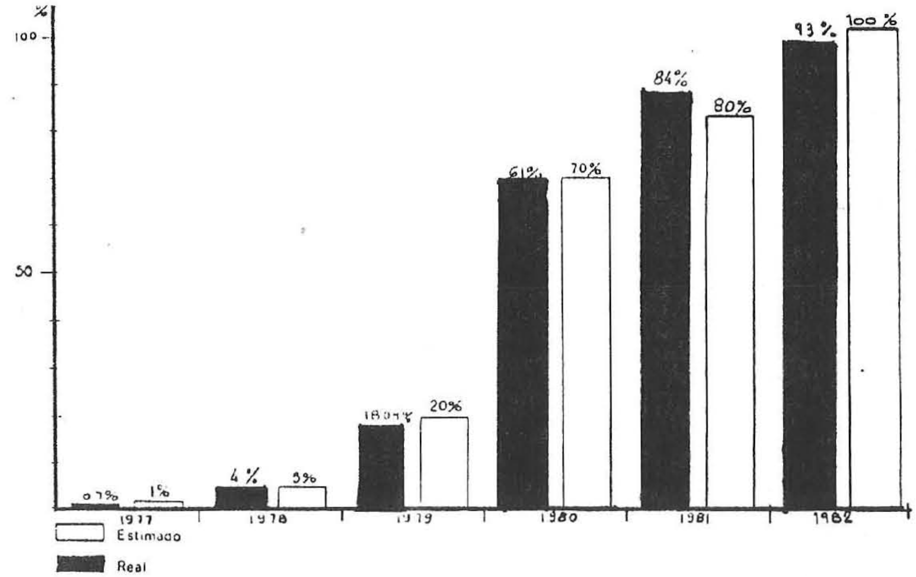
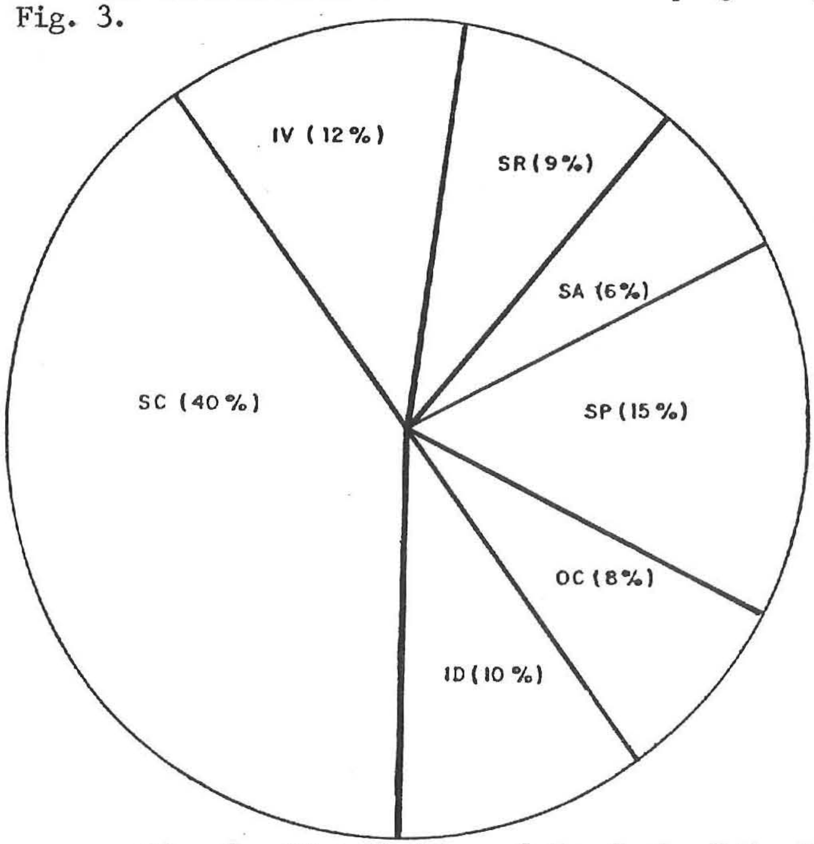


Fig. 2. Estimated Percentages of the Total Cost of the Project and the Actual Ones

The overall cost of the project was estimated in 1200 million pesetas (1977) and, as can be seen from Fig. 2, the deviation found until now has been minimum.

The distribution of the cost of the project by systems can be seen in Fig. 3.



S.A. = Storage System
S.P. = Power System
S.R. = Receiver System
S.C. = Collector System
O.C. = Civil Work
I.D. = Detail Engineering
I.V. = Investigation

Fig. 3. Distribution of the Cost of the Project (Systems)

Location

The site selected for the construction of the Pilot Power Plant is near the town of Tabernas, in the province of Almeria. The site was given by "Diputacion Provincial" and has an area of 1.000.000 m2 and is large enough for possible expansion of the CESA-1 Project. Two 0.5 MW power plants are built; each one consists of projects of the A.I.E. in which Spain participates (Fig. 4).

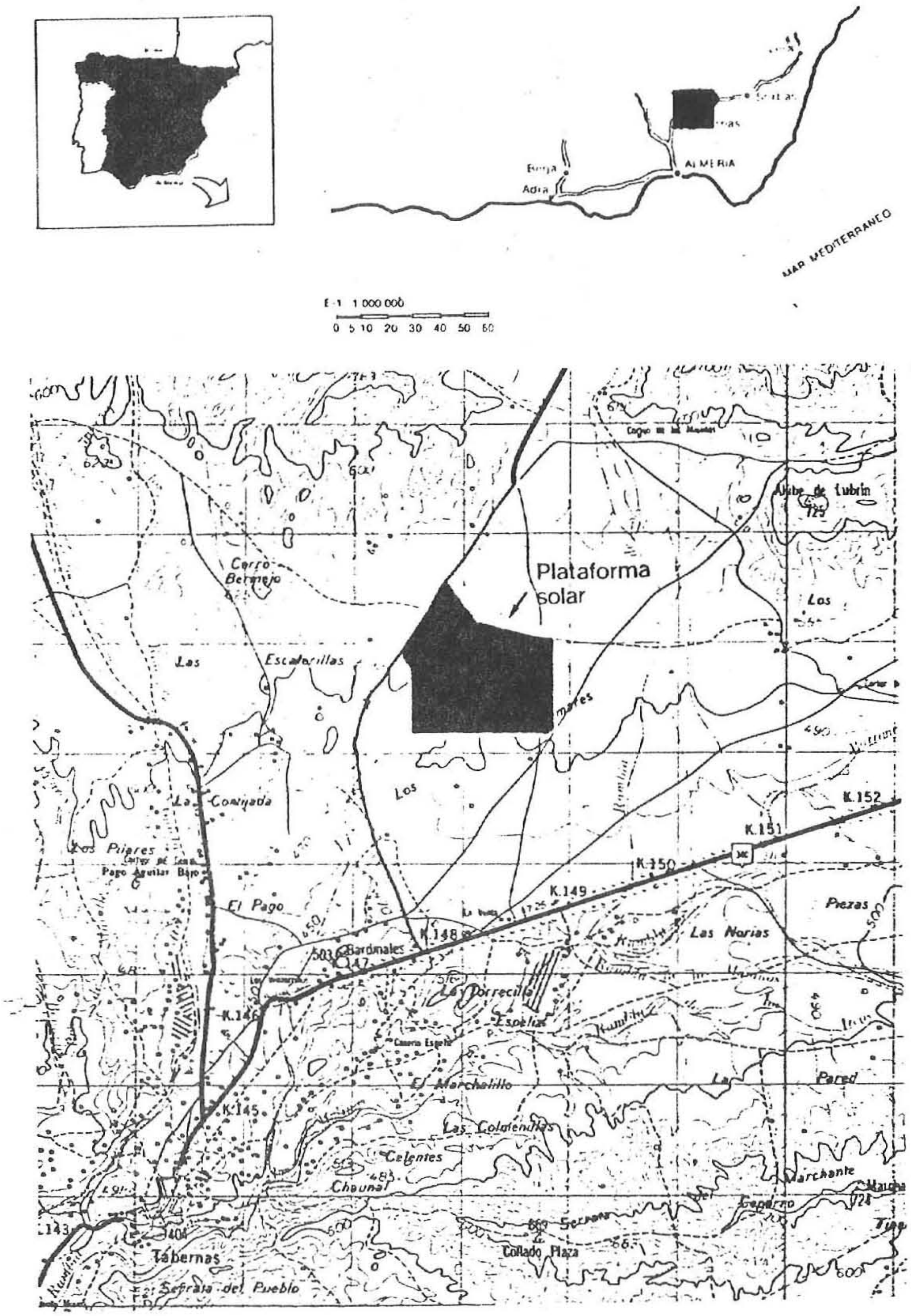


Fig. 4. Solar Platform Almeria

Technical Description

The technical concept selected for the CESA-1 Project is a central receiver power plant with a water/steam cooled receiver, molten salts thermal storage and water/steam Rankine cycle, according to the basic scheme included in Fig. 5.

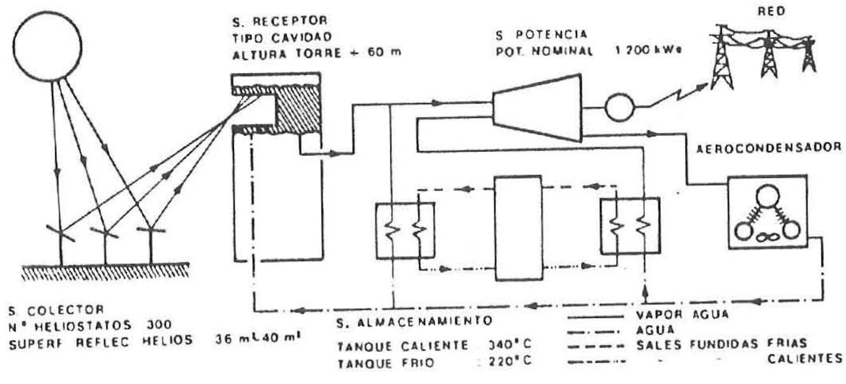


Fig. 5. CESA-1 Basic Scheme

The power plant has the following systems:

1. Collector System

This system includes three hundred heliostats of two different types, CASA-II (see Fig. 6) and SENER (see Fig. 7), distributed in sixteen rows of a north field (see Fig. 8) and their associated control system.

Table 1 shows the main characteristics of the collector system.

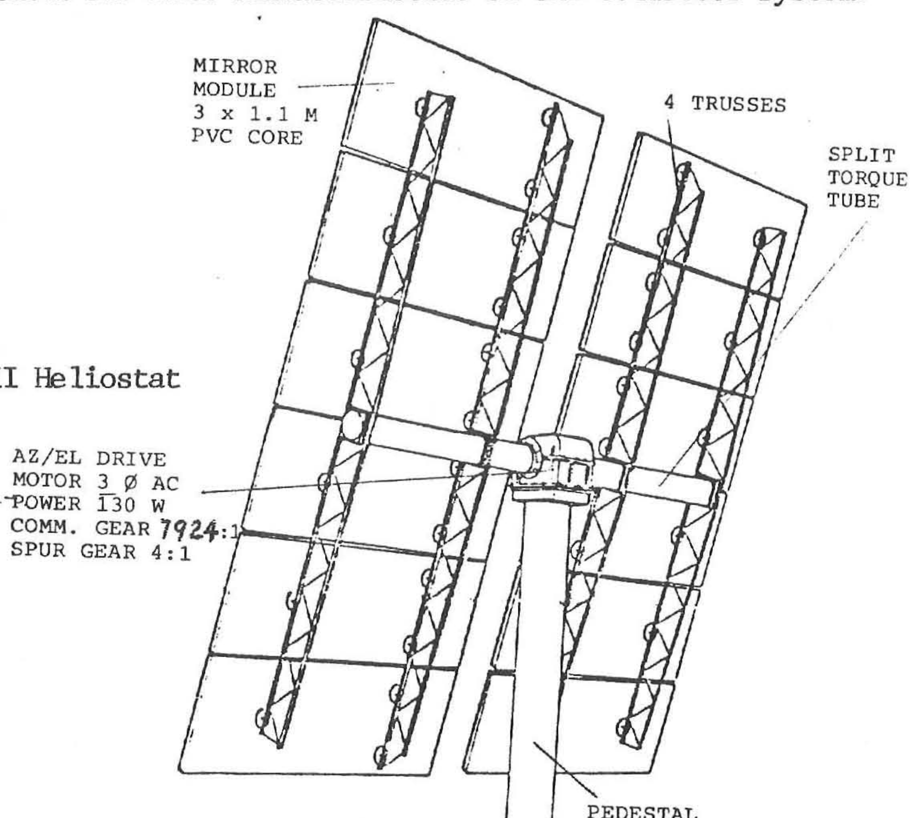


Fig. 6. CASA II Heliostat

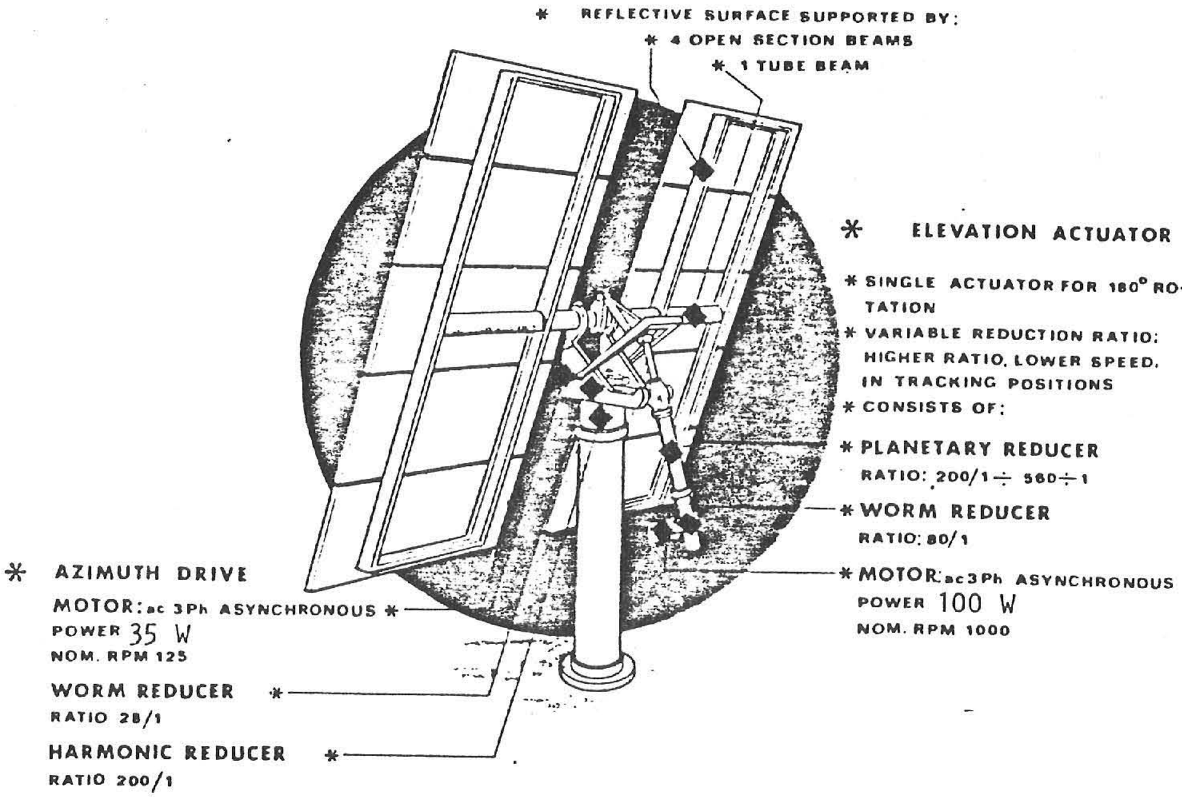


Figure 7. SENER Heliostat

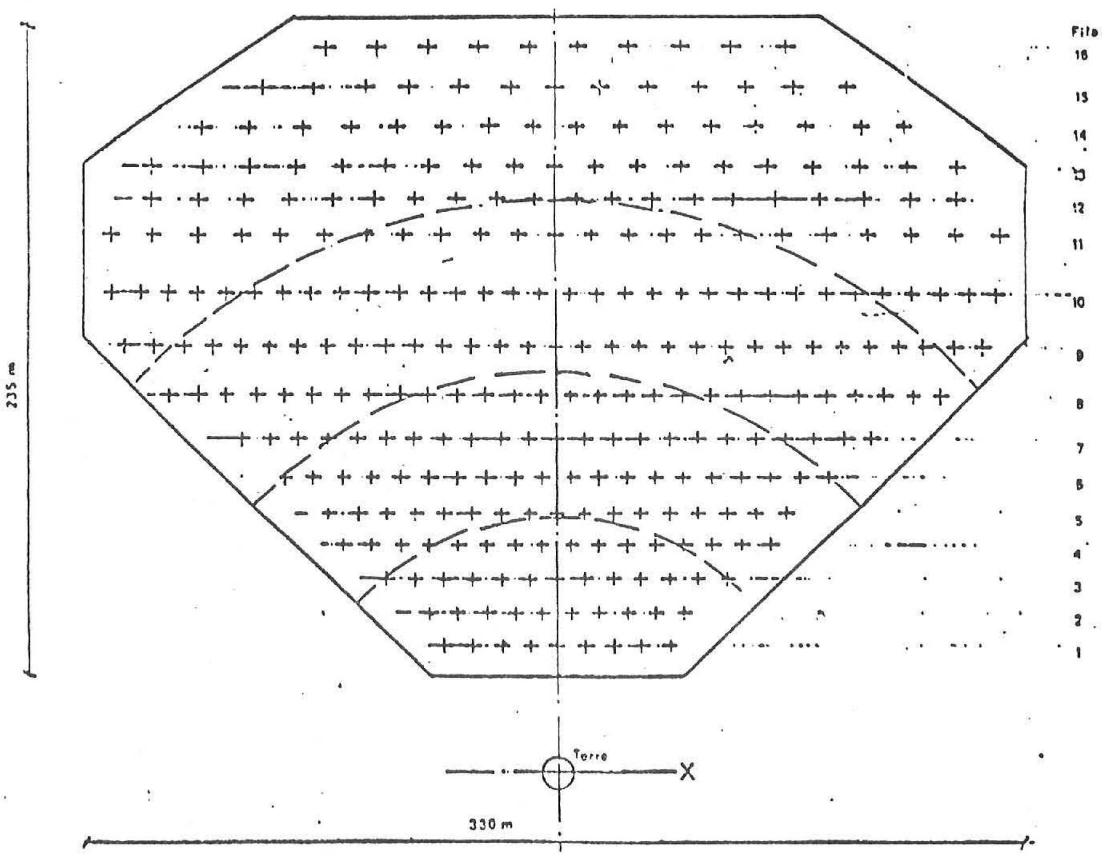


Figure 8. Heliostat Distribution

Technical Description

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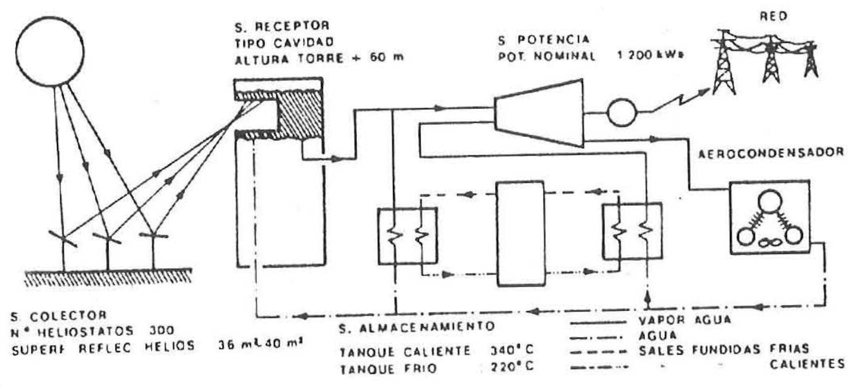

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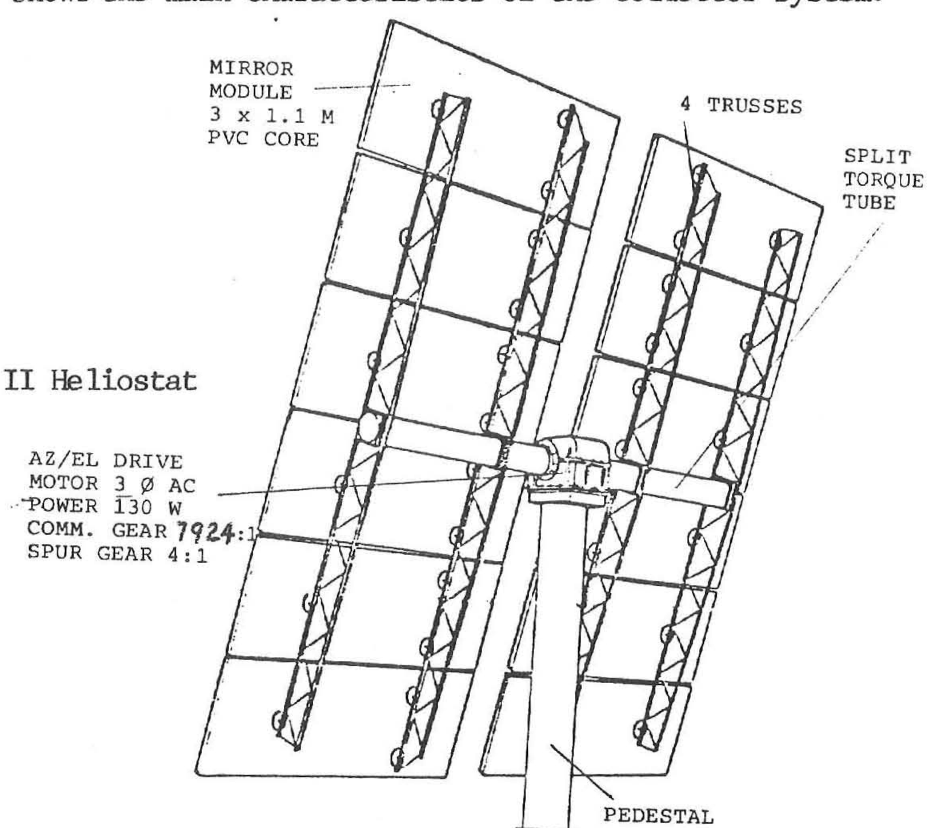

Fig. 6. CASA II Heliostat

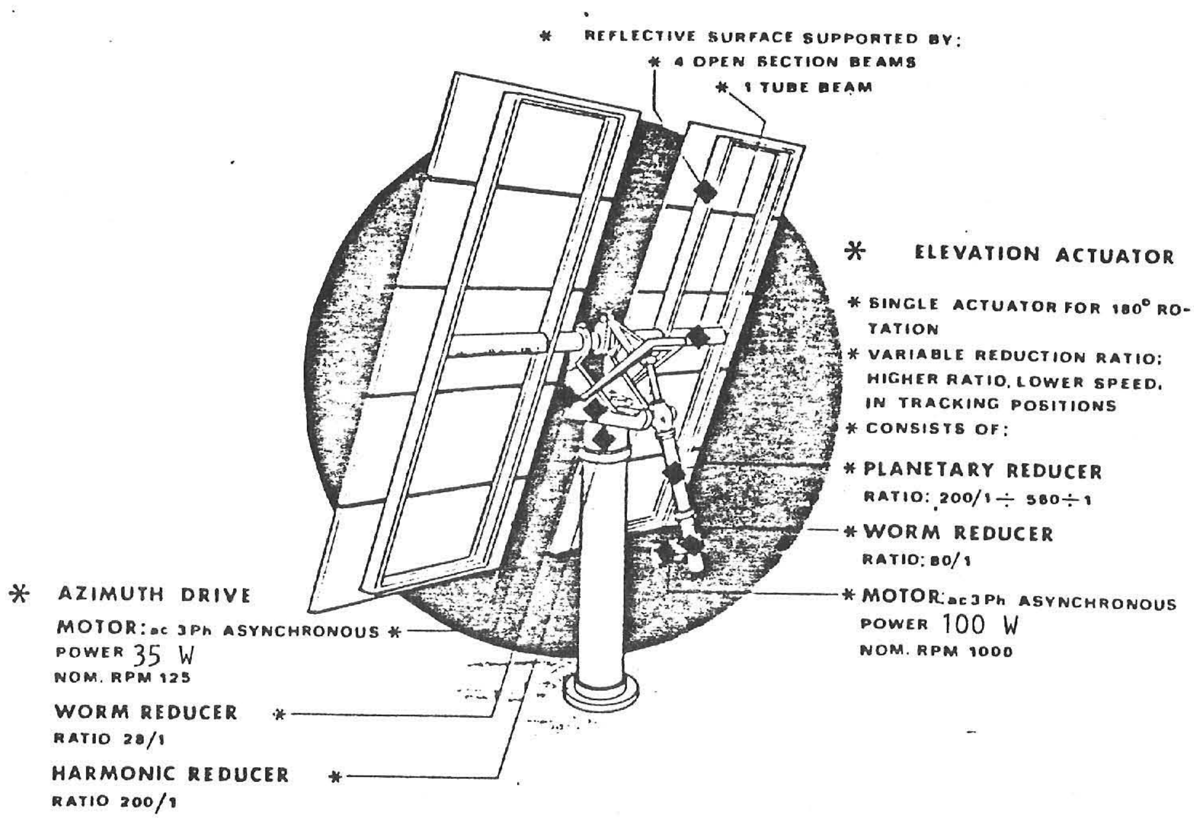

Figure 7. SENER Heliostat

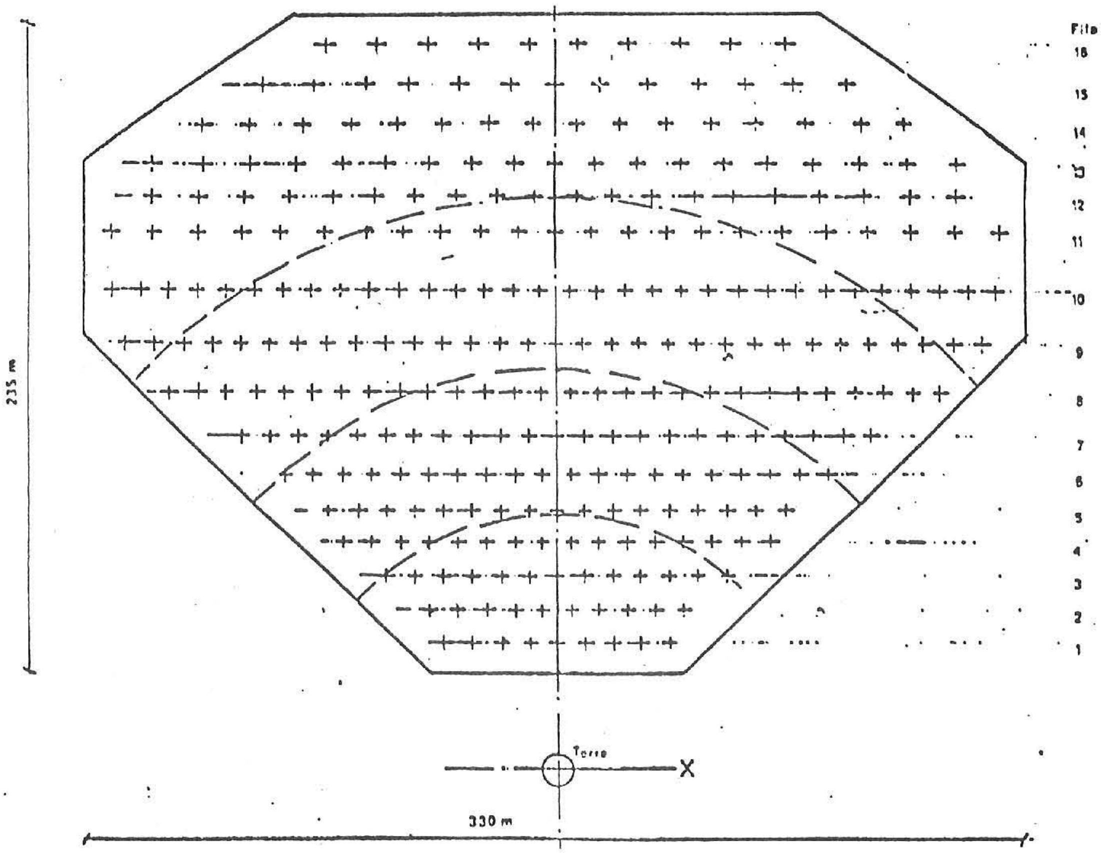

Figure 8. Heliostat Distribution

Table 1 - Collector System Main Characteristics

General	
Number of heliostats.	300
- CASA II (150)	
- SENER (150)	
North field (rectangular distribution in 16 rows)	
Field dimensions (m x m).	320 x 250
Four focal lengths (90, 140, 200, 250 m)	
Land use factor	21%
Maximum reflected power (Kw).	7,677
Design reflected power (Kw)	5,576
Overall collector field efficiency (D. point)	67.1
Heliostats	
- Reflective surace (m^2).	39.6
- Structure	T
- Mirror module	rectangular
- Single curvature	
- Number of mirror modules	12
- Type of mirror module	
3 mm float glass - PVC foam core - Steel sheet	
- Reflectivity (%).	86.5
- Azimuth motor (W)	
CASA II	130
SENER MONOPODE.	35
- Elevation motor (W)	
CASA II	130
SENER MONOPODE.	100
- Mechanical characteristics	
- Gear box stiffness 100 mKg/mrad	
- Backlash 1.2 mrad	
- Survival with 130 Km/h. wind	
Heliostat Control System	
- Open loop tracking	
- Central computer PDP11/34	
- Updating tune 4 sec.	
- Local heliostat controllers based on μP INTEL 8085	
- Incremental optical encoders 13 bit resolution	
- Electric motors controlled with solid state relays	
- 16 full duplex asynchronous transmission lines at 9600 bauds	

2. Receiver System

Under this system are included a cavity-type water/steam cooled receiver, an 80-meter concrete tower and the auxiliary piping system. Table 2 contains the receiver system main characteristics.

Table 2 - Receiver System Characteristics

General	
Cavity-type receiver	
Working fluid water/steam	
Forced circulation through evaporating panels	
Aperture centerline elevation (m)	60
Main Characteristics	
Maximum power inside cavity (Kw)	7,677
Design point power inside cavity (Kw)	5,576
Max. heat flux on panels (Kw/m2).	561
Efficiency (D. point) (%)	90.5
Receiver overall weight in operation (Kg)	87,000
Aperture size (m x m)	3.4 x 3.4
Fluid nominal conditions	
- Feedwater inlet (^{o}C/Kg/cm^{2})	185/135
- Steam drum (^{o}C/Kg/cm2).	322/118.5
- Sup. steam outlet (^{o}C/Kg/cm2)	525/110
- Steam mass flow (D.point) (Kg/h)	6,110
Evaporator	
- Surface (m2).	48.6
- Tube material, carbon steel SA-106-B	
- Max metal temperature (^{o}C).	365
Superheater	
- Six passes, three atemperators	
- Surface (m2).	34.6
- Tube material, ferritic steel X-20 Cr-Mo-V	
- Max metal temperature	579

3. Power Conversion System

The power conversion system is based on a regenerative water/steam Rankine cycle as indicated in Fig. 9.

The main component of this system is the turbogenerator. It contains a dual admission multistage condensing turbine, a gear box, and an electric generator.

The system includes also a feedwater preheating cascade with deaerator, one closed feedwater heater, condensate, and feedwater pumps.

Table 3 comprises the main system characteristics.

Table 3 - Power Conversion System Characteristics

General	
Regenerative water/steam Rankine cycle	
Double admission multistage condensing turbine	
- Main steam from the receiver	
- Secondary steam from the storage	
- Aircondenser	
Operation with Main Steam	
- Nominal gross power (Kwe)	1200
- Main steam inlet (°C, Kg/cm2)	520; 100
- Exhaust steam (°C, Kg/cm2).	55; 0.157
- Two bleedings	
- Gross efficiency (%).	27
Operation with Secondary Steam	
- Nominal gross power (Kwe).	840
- Inlet steam (°C, Kg/cm2).	330; 15
- One bleeding	
- Gross efficiency (%)	21

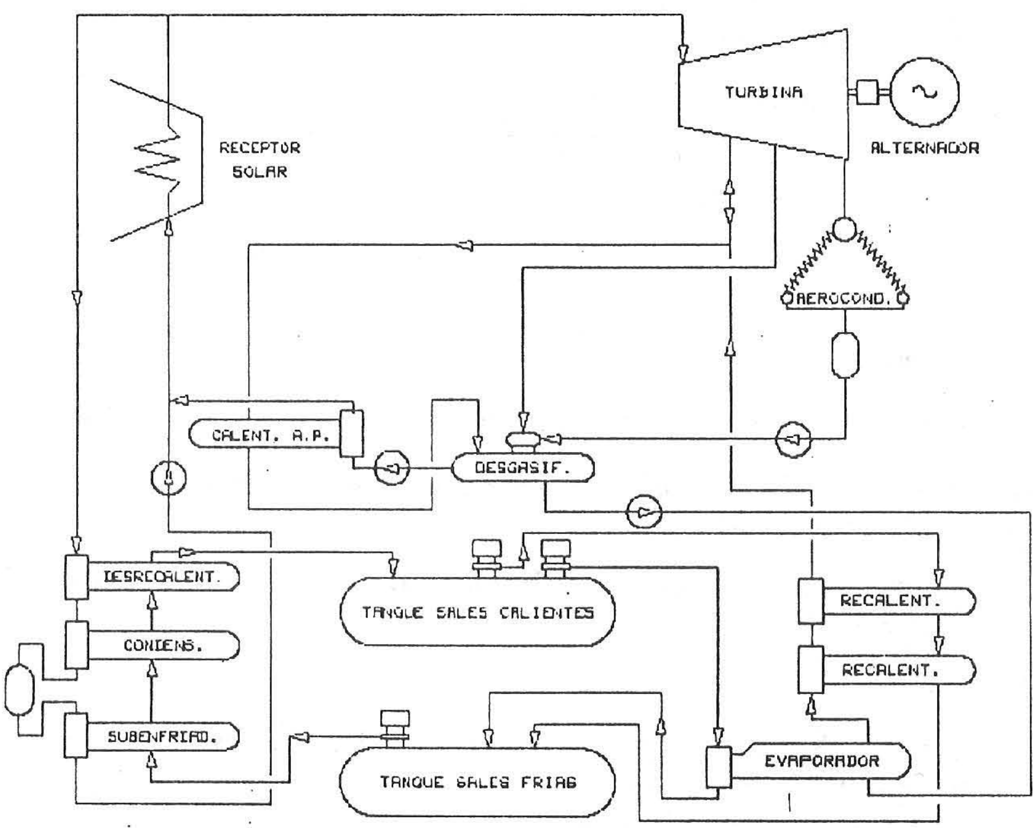

Fig. 9. Cycle Scheme (CESA-1)

4. Storage System

The selected concept for this system is sensible heat thermal storage using molten salts (53% NO_3K, 40% NO_2Na, 7% NO_3Na) as storage media.

The system contains two tanks--hot and cold--and two molten salt loops--charging and discharging--with conventional shell and tubes, heat exchangers and vertical centrifugal pumps.

In Table 4 are the main system characteristics.

Table 4 - Storage System Characteristics

General	
Sensible heat thermal storage	
Fluid: Molten salts (53% NO_3K, 40% NO_2Na, 7% NO_3Na)	
Two-tank storage	
Main Characteristics	
Tank temperatures	
- Cold (°C)	220
- Hot (°C)	340
Storage capacity	
- Salts (Tn).	300
- Thermal (MwH)	3
Circulation by vertical centrifugal pumps	
Shell and tubes heat exchangers	
Nitrogen blanketing system	
Electric/steam heat tracing	

Construction (Figs. 10, 11, 12, 13)

Actual status of the project:

1. Collector System

- All the heliostat structures and gear boxes are already installed.
- 250 heliostats are furnished with mirror modules. Ninety percent of these are already aligned.
- Heliostat control system has been installed. Acceptance tests will begin early in November.

2. Receiver System

The fabrication phase is finished. The receiver is being erected, finishing in December 1982.

The receiver was designed by TECNICAS REUNIDAS, constructed by BABCOCK & WILCOX, SPAIN, and installed in the tower by ABENGOA.

3. Power Conversion and Storage System

The turbogenerator, designed and constructed by SIEMENS/BAZAN, is already installed.

The mechanical, electrical and instrumentation installation is near completion. The preoperational tests will begin in December.

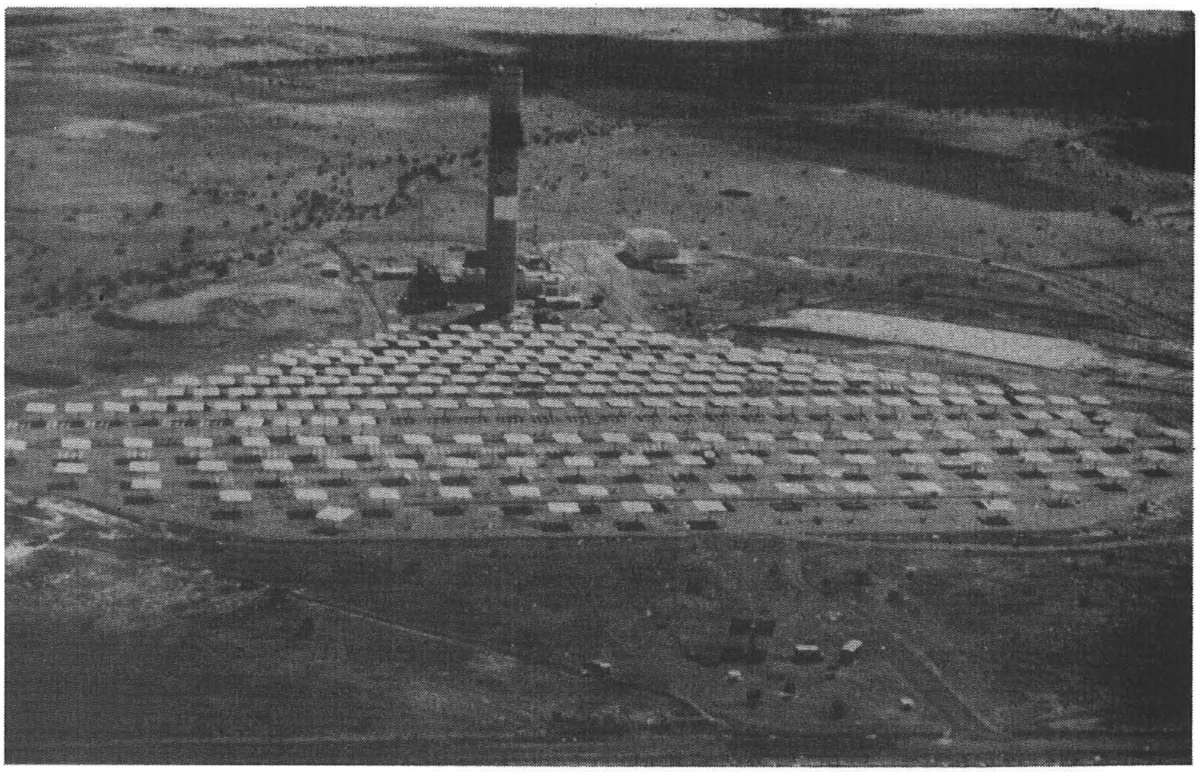

Figure 10. CESA-I Project

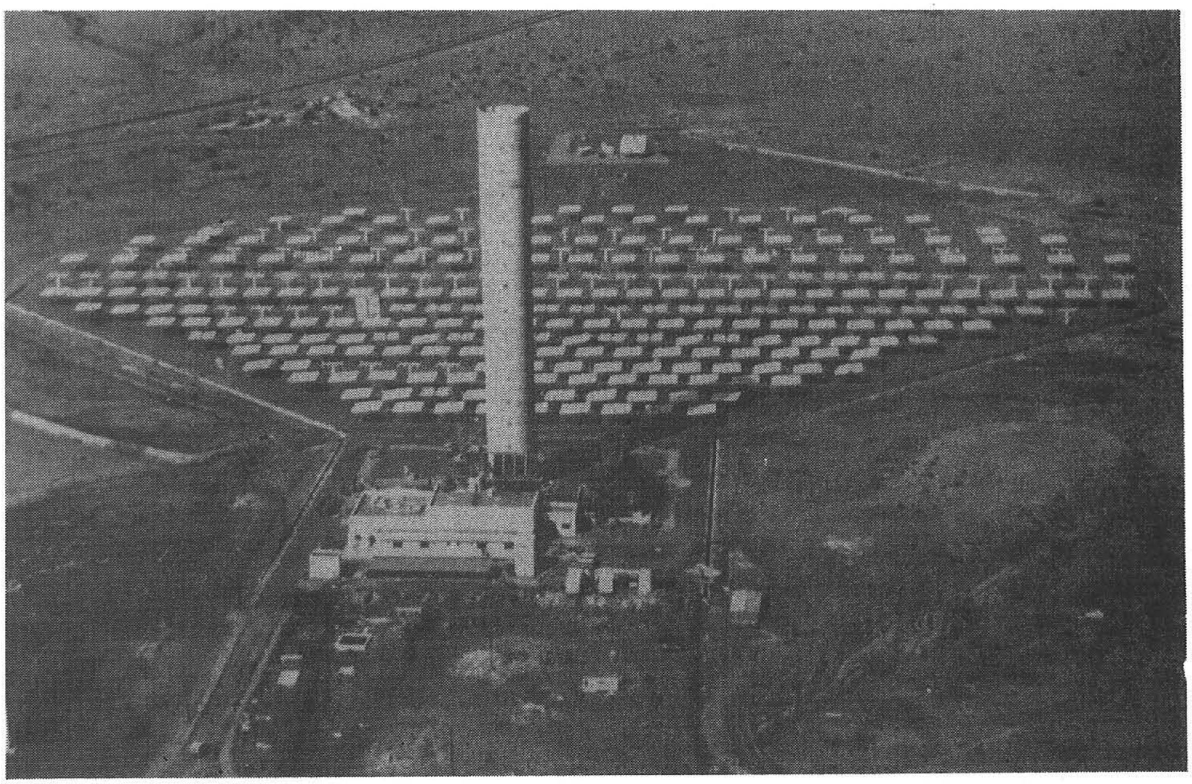

Figure 11. CESA-I Project

Figure 12. Tower and Equipment Area

Figure 13. CESA-I Project

SOLAR ONE

10 MWe SOLAR THERMAL CENTRAL RECEIVER PILOT PLANT

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and

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Introduction

The Solar One Project is the world's largest solar electric generating station. This pilot-scale research and development experiment is a cooperative effort of government and private industry to demonstrate technical feasibility, economic potential and environmental acceptability of the solar thermal central receiver concept. The project, which is formally known as the 10 MW Solar Thermal Central Receiver Pilot Plant, has been constructed in the Mojave Desert on 130 acres of Southern California Edison Company's Cool Water Generating Station near Barstow, California, and will supply ten megawatts of electrical power to the Edison grid. Solar One is a joint project of the Department of Energy (DOE), Southern California Edison (SCE), the Los Angeles Department of Water and Power (LADWP), and the California Energy Commission. The solar portion of the facility was designed and constructed under the direction of the DOE, and the turbine-generator facilities, including the control building, were designed and constructed by SCE.

This paper presents an overview of the project, discusses the costs and schedule, highlights the planned test program including operation and maintenance, and briefly discusses the experiences to date.

Siting and General Design Data

The pilot plant is located east of Daggett, California, and is approximately 12 miles east of Barstow, California. The site is at a latitude of 34.87°N and longitude of 116.83°W. The site is contained in the western half of Section 13, Township 9N - Range 1E, San Bernardino County: San Bernardino Meridian. The reference location for the pilot plant is the receiver tower vertical centerline with coordinates N 501, 260 and E 2, 349, 950. The nominal elevation of the site is 1,946 feet above mean sea level.

The plant is designed to produce at least 10 MWe of electrical power to the utility grid (after supplying the plant parasitic power requirement) for a period of 4 hours on the plant "Worst Design Day" (Winter solstice) and for a period of 7.8 hours on the plant "Best Design Day" (Summer solstice). The "Worst" and "Best Design Days" are based on assumed insolation (solar intensity) conditions which have been developed from actual site insolation measurements. During actual plant operation, the plant capability and electrical output will depend on the current sun and atmospheric conditions. During certain periods of the year (near noon from March through September), the plant energy collection capability can exceed the 12.5 MWe turbine-generator rating.

Plant Systems

The central receiver concept being demonstrated at Barstow integrates the operation of six major systems as depicted in Figure 1. The collector system, consisting of large suntracking mirrors (heliostats), concentrates the solar energy incident upon the earth and redirects it to a tower-mounted receiver (boiler). There the solar energy transforms water into superheated steam which can be used directly to drive a turbine-generator or diverted to the thermal storage system. The thermal storage system can store the energy as sensible heat to extend the turbine-generator operation after sunset. The electric power generation system (turbine-generator) can generate ten megawatts utilizing receiver steam and seven megawatts from thermal storage steam. The master control system is a series of computers that monitors and controls each of the major systems. The beam characterization system is used to align the heliostats and ensure their efficient operation.

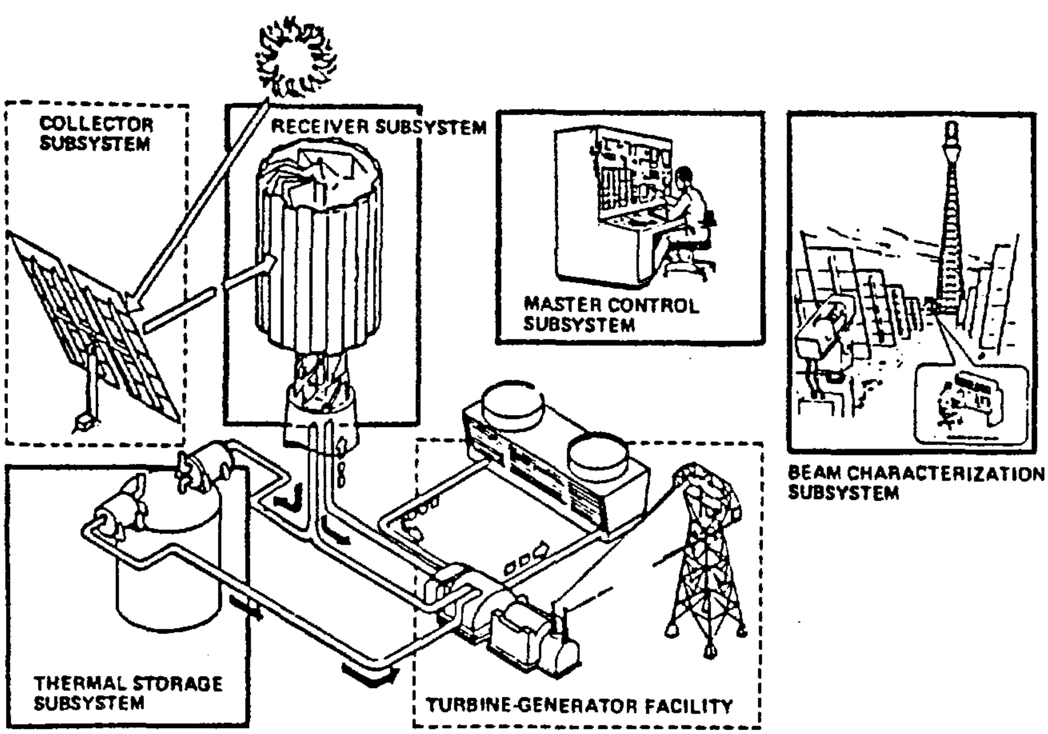
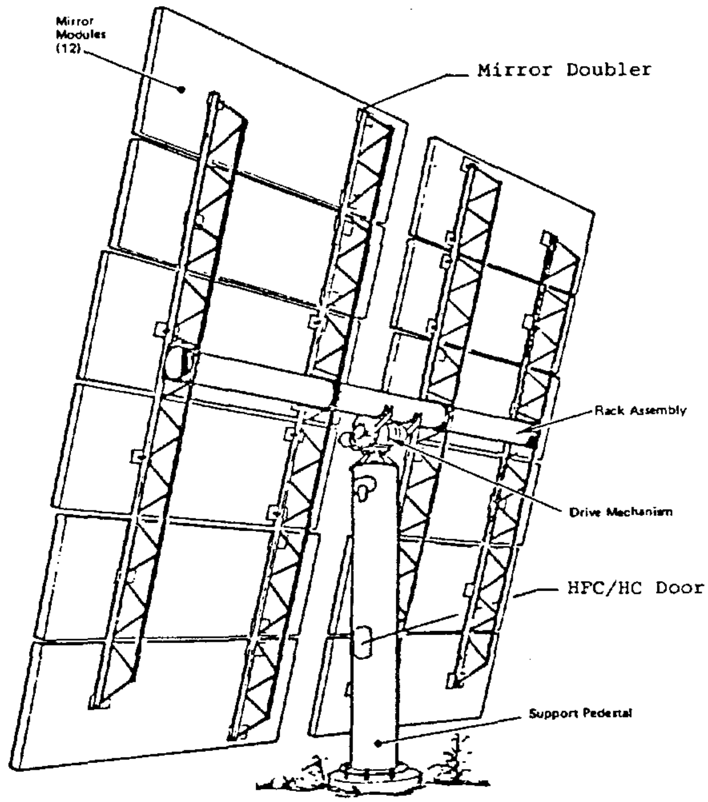


Figure 1

Other plant support systems include the raw water, fire protection, demineralized water, cooling water, nitrogen, compressed air, liquid waste, oil supply, and electrical distribution systems.

Collector System

The collector system is a 360-degree array of 1,818 Martin Marietta sun-tracking heliostats of the type shown in Figure 2.



HELIOSTAT CONFIGURATION

Figure 2

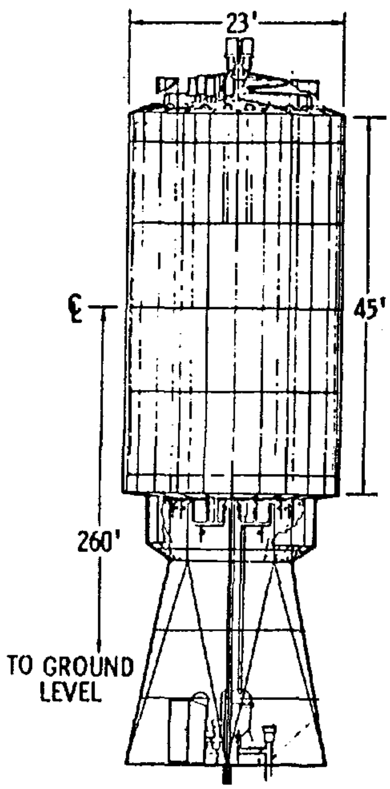
The heliostat field has a total reflective area of 782,000 square feet and is divided into four quadrants. There are a total of 1,240 heliostats in the two northern quadrants and 578 in the two southern quadrants. Each heliostat is made of 12 slightly concave mirror panels totaling 430 square feet of mirrored surface. The mirror assembly is mounted on a geared drive unit for azimuth and elevation control.

The collector control system consists of a micro-processor controller in each heliostat (HC), a heliostat field controller (HFC) for control of groups of up to 32 heliostats, and a central computer called the heliostat array controller (HAC). The annual and daily sun position information for aiming each heliostat is stored within this control system. The heliostats can be controlled individually or by groups in either manual or automatic modes through the HAC which is located in the plant control room. The heliostats are designed to operate in winds up to 50 mph and will withstand winds up to 90 mph when stowed in a mirror-down position.

Receiver System

The receiver system consists of a single-pass-to-superheat boiler with external tubing, a tower, pumps, piping, wiring, and controls necessary to provide the required amount of steam to the turbine. Steam demand can be varied from the control room by the operator, or the receiver system can react to a demand from the electric power generating system up to the receiver's rated output.

The receiver is designed to produce 950°F steam at 1465 psia at a flow rate of 112,000 lb/hr. The receiver has 24 panels (6 preheat and 18 superheat), each approximately 3 feet wide and 45 feet long as shown in Figure 3.



RECEIVER UNIT ASSEMBLY	
DIAMETER	23 FT
NO. OF PANELS	
STEAM	18
PREHEAT	6
PANEL CHARACTERISTICS	
WIDTH	35 IN.
LENGTH	45 FT
NO. OF TUBES	70
TUBE OD	0.5 IN.
TUBE ID	0.269 IN.
TUBE AND HEADER MATERIAL	INCOLOY 800
SOLAR SURFACE COATING	PYROMARK

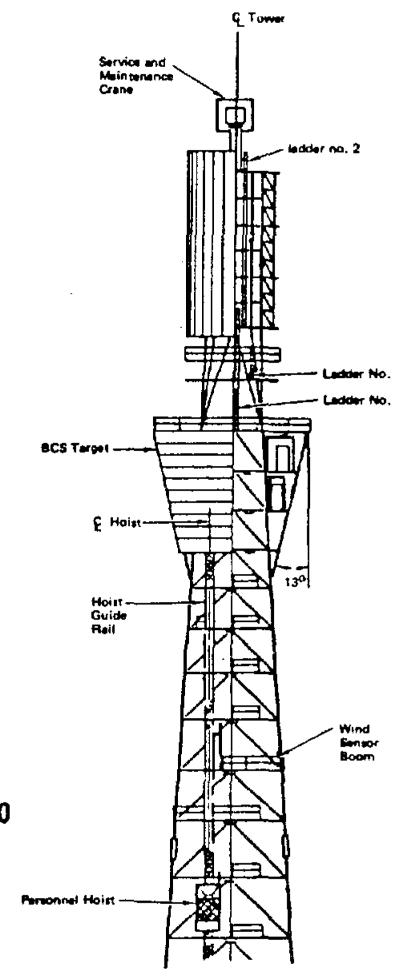


Figure 3

The panels are arranged in a 23-foot-diameter vertical cylindrical configuration with a total surface area of 3252 square feet. Each panel consists of 70 small tubes (0.5 in. OD, 0.27 in. ID) through which the high purity feedwater is pumped and converted to super-heated steam. The external surface of the receiver tubes under normal operating conditions is approximately 1150°F. These thick-walled tubes are made of Incoloy 800 in order to withstand the effects of daily heat cycling as well as cloud transients. Within each panel the tubes are welded to each other over their full length and the panel is coated with a special black paint (Pyromark) to increase thermal energy absorption. The back surface of each panel is heavily insulated and sealed against light leaks.

The lattice steel tower, shown in Figure 3, holds the receiver 300 feet above the desert floor. It stands on four 25-feet-deep footings attached to a 1500-ton concrete base. The flaired area of the tower immediately beneath the receiver is formed by four white aluminum sheet metal targets used for the beam characterization system. The tower space inside these targets houses air-conditioned rooms where the receiver computer and some of the beam characterization system controls are located.

Thermal Storage System

The thermal storage system provides for storage of solar energy to extend the plant's electrical power generating capability into night-time or during periods of cloud cover. It also provides steam for maintaining selected portions of the plant in a warm status during non-operating hours and for starting up the plant the following day. For example, sealing steam is required in the turbine casing even when it is not running in order to maintain vacuum in the condenser and hold proper feedwater chemistry. Even though the primary source for this turbine sealing steam is thermal storage, a small auxiliary electric boiler is also available in case the thermal storage system is depleted or not operating. The thermal storage system is shown schematically in Figure 4.

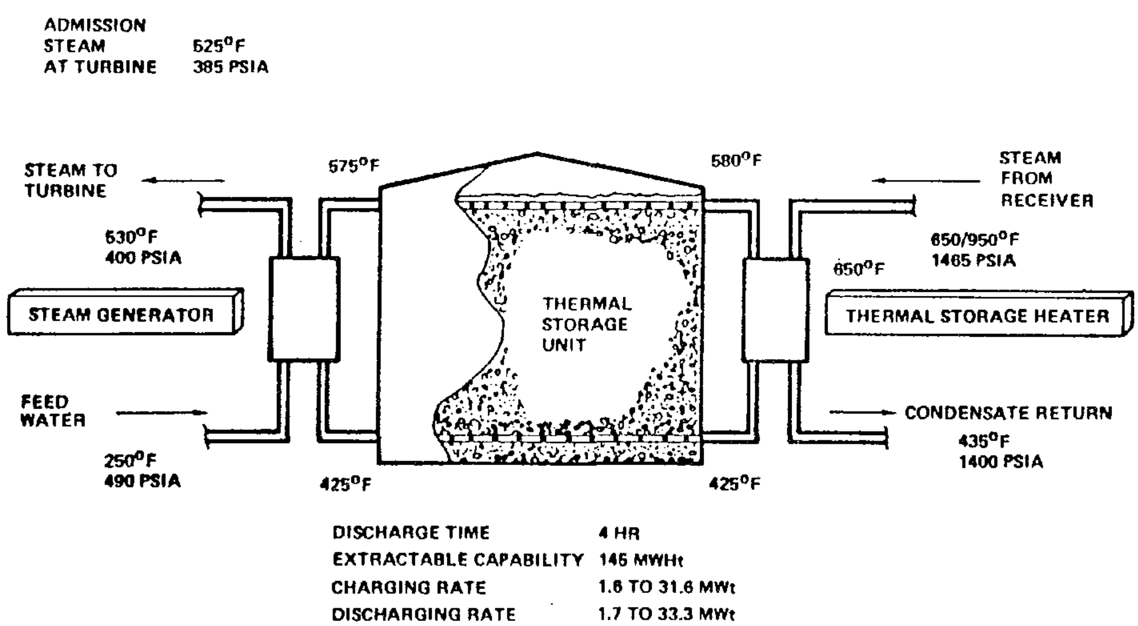


Figure 4

The thermal storage tank is 45 feet high and 65 feet in diameter. It sits upon a special lightweight, insulating concrete foundation for reducing heat loss to the ground. The walls are made of steel plate with one foot of insulation, and the roof is made of aluminum plus two feet of insulation. The 946,000-gallon-capacity tank, filled with 7,000 tons of rock and sand, and about 240,000 gallons of thermal oil (Caloria HT-43), acts as a heat storage vessel.

Desuperheated steam from the receiver is routed through a heat exchanger in which cold thermal storage oil from the bottom of the tank is heated. The heated oil is pumped back into the top of the tank and thermal energy is transferred to the rock and sand. When fully charged, the thermal storage mixture (oil, rock, and sand) will have a temperature of approximately 575°F. When discharging, the hot oil is pumped from the top of the tank through another heat exchanger to boil water, and the cold oil is returned to the bottom of the tank. Steam at 525°F and 385 psia can be produced from the thermal storage system and delivered to the turbine at a rate of 105,000 lbs/hr. The rated electrical capacity of the plant operating on thermal storage energy is 28 megawatt-hours net output, e.g., 7 MWe power for four hours. After discharging, sufficient thermal energy is still available in the tank for heating, sealing steam, and restarting the plant the next day.

As with other plant systems, the thermal storage system has its own computer controls and also can be controlled manually. By selecting plant operating modes, the operator can use receiver steam to charge the thermal storage system alone, or receiver steam can be divided to drive the turbine and charge the thermal storage system simultaneously.

Master Control System

The master control system is a series of computers which provides for control of the plant from the central control room. It supplies overall coordinated supervisory control to individual systems. A sketch of the master control console is shown in Figure 5. Ultimately, the plant will be operated fully automatically with only operator override, making it possible for one person to operate the entire plant. Initially, however, the plant systems must be operated separately with multiple operators.

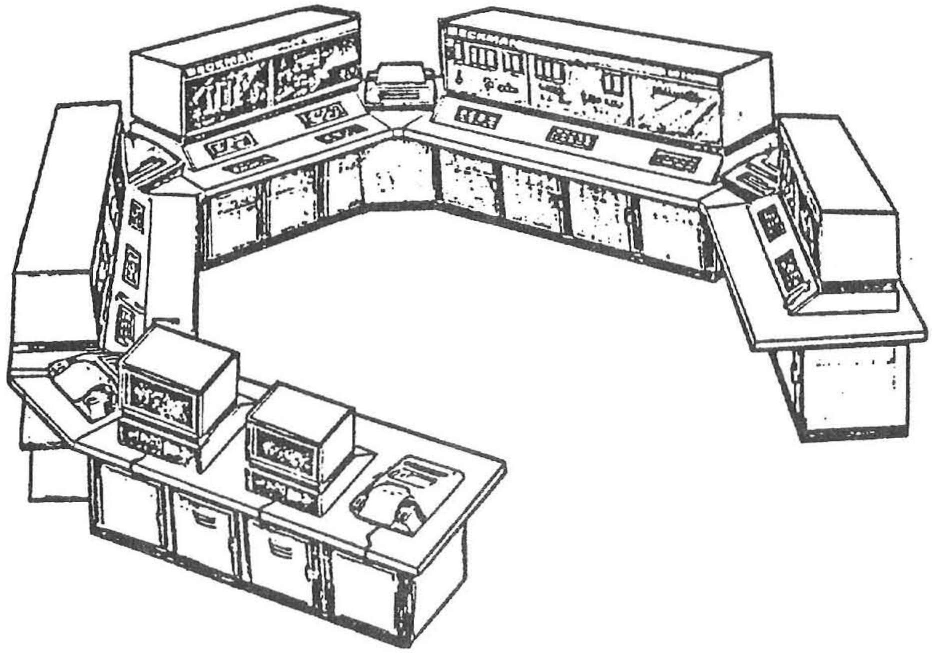


Figure 5

Approximately 2,000 continuous, discrete measurements from throughout the plant are transmitted to the master control system and recorded. Operating data, alarms, and alerts are displayed on control consoles and on graphic displays (CRTs). Additionally, plant piping and instrumentation diagrams are displayed with live time process parameters and valve operating configurations indicated for system status.

To augment the master control system and also provide individual system control and trouble isolation, each system has its own distributed process controller. The process controllers are digital computers and are tied into the master system. These process controllers control the system valves, motors, pumps, relays, and other equipment, and are physically located near the respective system's hardware in remote stations. As an example, the receiver process controller is located in the tower within a remote station immediately beneath the receiver.

The control system hierarchy is shown in Figure 6. Four Modcomp classic 7863 computers are located in the control room and are designated as follows:

OCS - Operational Control System which provides a console for single operator control.

DAS - Data Acquisition System which records selected control and monitoring data.

HAC - Heliostat Array Controller which supervises the collector field. Two Modcomp units are utilized. One provides full redundancy for the other.

Control and monitoring data are collected and processed from field instruments by way of the distributed process controllers (SDPC). This control hardware is the Beckman MV 8000 system. Five remote processing stations are located outside the control room.

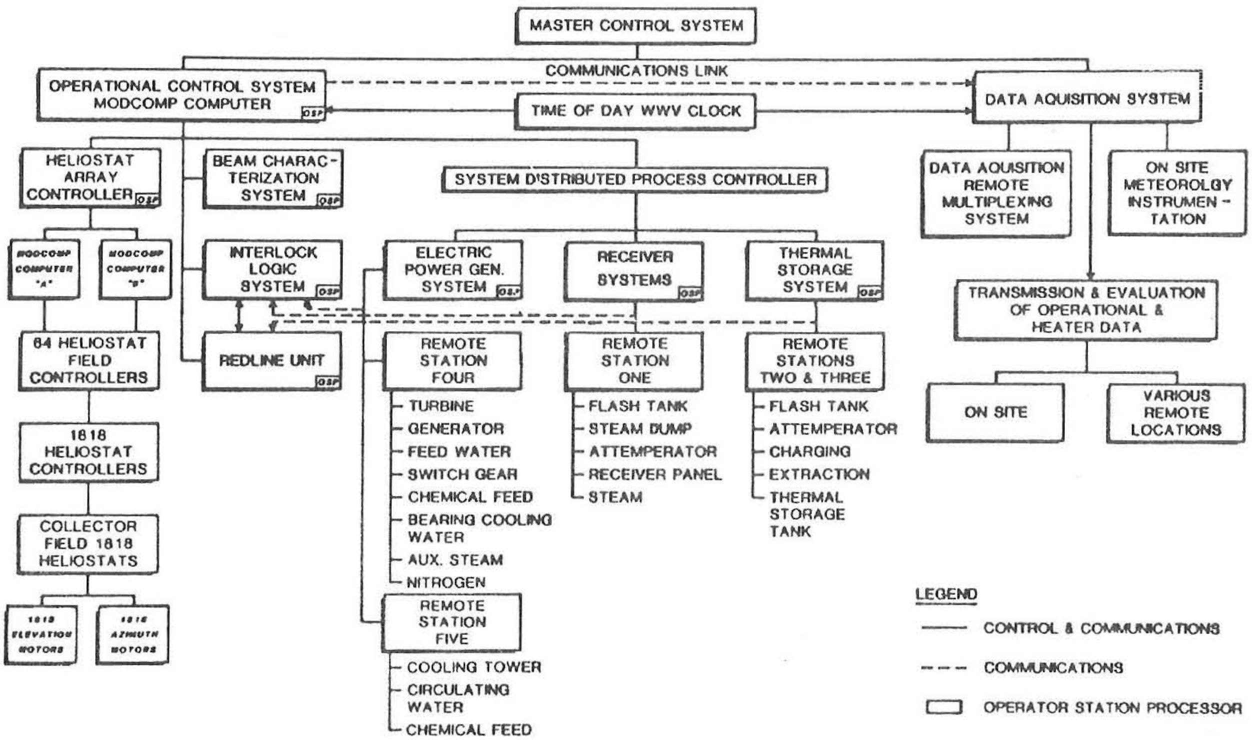


Figure 6

Turbine Generator

The General Electric turbine generator is rated at 12.5 MWe and is a single case design for cyclic duty. It is the same general machine used for marine drives. The turbine has two steam admission ports, one high pressure for receiver steam and a lower pressure port for thermal storage steam. The rated turbine thermal-to-electric efficiency from receiver steam is 35%, and from thermal storage steam, 25%. Receiver steam conditions are 112,000 lb/hr, 950°F, 1465 psia throttle valve capacity for 10 MWe net. Thermal storage steam conditions are 105,000 lb/hr, 525°F, 385 psia admission valve capacity for 7 MWe net.

Figure 7 shows a schematic diagram of the plant. Spent steam is condensed by circulating water from the evaporative cooling tower. Condensed steam is then routed back to the receiver through a full-flow demineralizer and a series of feedwater heaters. The turbine has four steam extraction ports used for three feedwater heaters, and a deaerator. The second point and first point feedwater heaters only operate during receiver operation. The generator is air cooled with a static exciter and 13.8 kv rated output voltage.

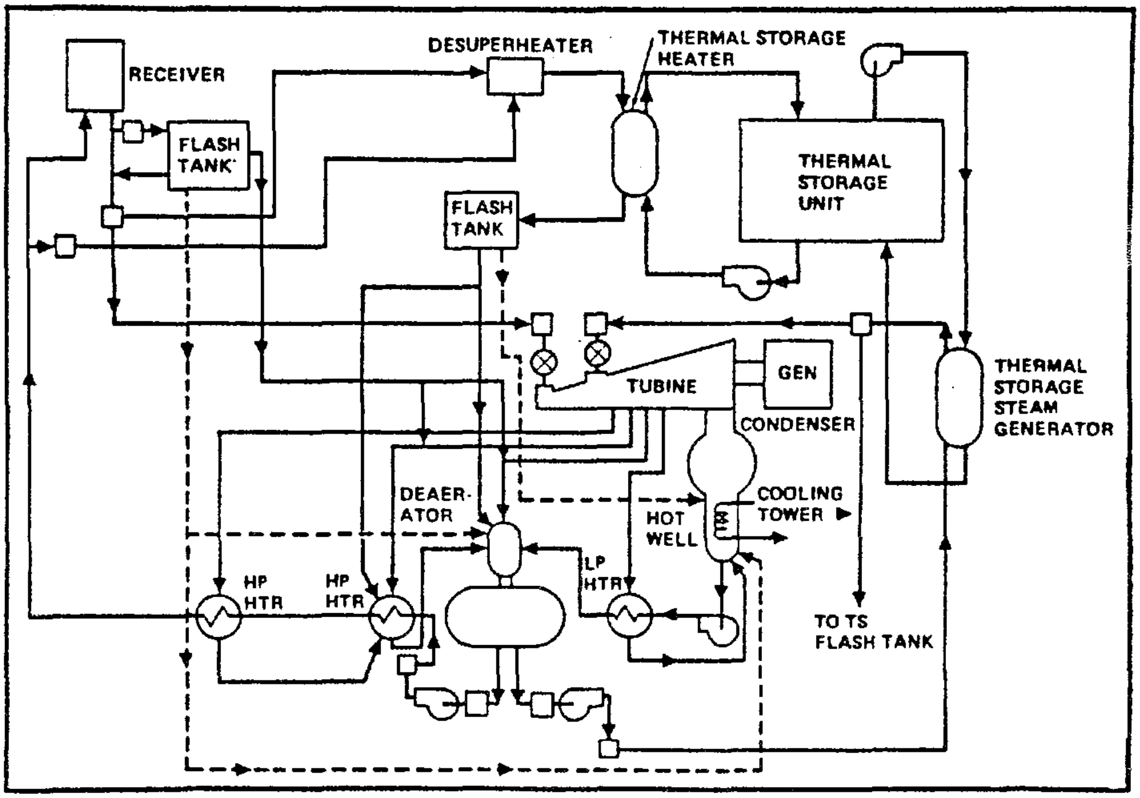


Figure 7

Additional support functions in the electric power generating system include the water chemistry control facilities and an uninterruptible power supply (UPS) battery system for providing power to the computer should the main and backup power sources fail.

Beam Characterization System

Since each mirror module (glass facet) can be canted in one axis, the overall beam from each heliostat can be focused. The beam characterization system is used to calibrate each individual heliostat beam with respect to its aim point on the receiver, its beam shape, and the beam power density. This system consists of a vidicom camera, a microcomputer, and associated controls and is coupled to the collector control system.

Environmental Monitoring

Environmental impacts during construction of the pilot plant have been monitored by the Laboratory of Biomedical and Environmental Sciences at the University of California at Los Angeles. Their studies have found that during plant construction the existing ecosystem within the plant site was completely removed, an estimated 160 metric tons of sand have been blown from the heliostat field to adjacent downwind areas, and some of the annual plant growth has decreased where the most sand has been deposited.

Their studies on restoring vegetation to the disturbed desert areas around the plant site conclude that the most limiting factor will be grazing damage from small animals.

Project Cost

The DOE was responsible for funding the design and construction of the solar facilities including the collector system (heliostats), receiver, thermal storage, and master control systems. The prime contractors were:

- Martin Marietta--Fabrication and installation of heliostats and associated controls;
- McDonnell Douglas Astronautics--Systems integration, master control, receiver (Rocketdyne), thermal storage (Rocketdyne), and A/E services (Stearns-Roger);
- Townsend & Bottum--Construction management.

The DOE budget of $120 million covered completion of construction (April 15, 1982). Start-up of all major systems beyond functional performance was deferred; the following have been or will be activated during the two-year start-up and experimental test phase:

- thermal storage;
- plant level operational status displays software development;
- coordinated and automatic control software development.

SCE was responsible for design, construction, and start-up of the turbine-generator facilities. The $21.5 million capital cost for these facilities is shared on an 80%-20% basis between SCE and LADWP, respectively.

A summary of the total capital costs for the project is shown in Table 1.

TABLE 1
SOLAR ONE CAPITAL COST
(MILLIONS)

SOLAR FACILITY	COST	PERCENT
Solar Facility Design Cost	$ 31.2	22%
Collector Field Fabrication & Construction	40.0	28%
Receiver Fabrication & Construction	23.4	17%
Thermal Storage Fabrication & Construction	12.0	8%
Plant Control System	3.0	2%
Beam Characterization System	1.0	1%
Miscellaneous Support Systems	9.4	7%
TOTAL SOLAR FACILITY DESIGN/FABRICATION/CONSTRUCTION COST	$120.0	85%
TURBINE-GENERATOR DESIGN & CONSTRUCTION COST	$ 21.5	15%
TOTAL PLANT COST	$141.5	100%

A key to future cost reductions for central receiver plants of this type is a reduction in the cost of heliostats. As shown in Table 1, collector field fabrication and construction accounted for 28% of the total plant cost. Receiver fabrication and construction and turbine-generator design and construction costs were 17% and 15%, respectively, of the total cost. SCE's costs totaled $21.5 million, consisting of approximately 25% Edison labor, 25% SCE-furnished materials and equipment, 25% construction contract costs, and 25% construction overheads including an allowance for funds used during construction (AFDC). The largest single piece of equipment, the turbine-generator, accounted for $2.2 million of the equipment cost.

Project Schedule

Start-up testing was initiated in April 1981 and has progressed through the piping system cleaning, flushing, subsystem operations and circulating high purity cold water through the receiver and other piping systems to verify system integrity. Controls testing of the major systems, receiver, thermal storage, EPGS, plant support and the data systems have been completed. Coupled systems tests, receiver and turbine-generator have been underway with an operational procedure developed for weekend power production using receiver-generated steam. The thermal storage tank has been fully charged and discharged. The scheduled goal to have the operators trained for turbine-direct operation from receiver steam, storage charge and extraction by early CY-1983, without technical supervision, is attainable. The balance of the test program will be devoted to exploring the basic operating modes, evaluating performance data from these operations, and incorporating automatic control as detailed in the following.

Planned Test Program

Mode 1 - Turbine Direct (TD)

All thermal power reflected from the Collector System (CS) and absorbed by the Receiver System (RS) flows as superheated steam to the Electric Power Generation System (EPGS) for direct turbine-generator operation. The Thermal Storage System (TSS) is bypassed in this mode.

Mode 2 - Turbine Direct and Charging (TD&C)

Thermal power collected by the receiver is divided between thermal storage (charging function) and the EPGS for direct turbine-generator operation.

Mode 3 - Storage Boosted (SB)

All thermal power collected by the receiver flows to the EPGS and is augmented by admission steam power extracted from thermal storage.

Mode 4 - In-Line Flow (ILF)

All power collected by the receiver flows to thermal storage. Thermal power is extracted from storage for turbine-generator admission steam operation. This mode is used on partially cloudy days to buffer thermal transients from the receiver.

Mode 5 - Storage Charging (SC)

All thermal power collected by the receiver is used for thermal storage charging.

Mode 6 - Storage Discharging (SD)

Thermal power is extracted from storage for admission steam turbine-generator operation.

Mode 7 - Dual Flow (DF)

Thermal power collected by the receiver is divided between both storage and the EPGS. Thermal power is also extracted from storage and routed to the admission steam input of the EPGS.

Mode 8 - Inactive (I)

All systems are inactive and held in a standby condition during overnight shutdown.

The eight operating modes are diagramed in Figure 8. Initially, the testing will concentrate on operation in Mode 1--receiver steam direct to turbine--along with activation of the thermal storage system and testing in Modes 5 and 6--Storage Charging and Discharging. Concurrently, the plant operational displays software package will be completed and installed. This effort is expected to require the balance of 1982.

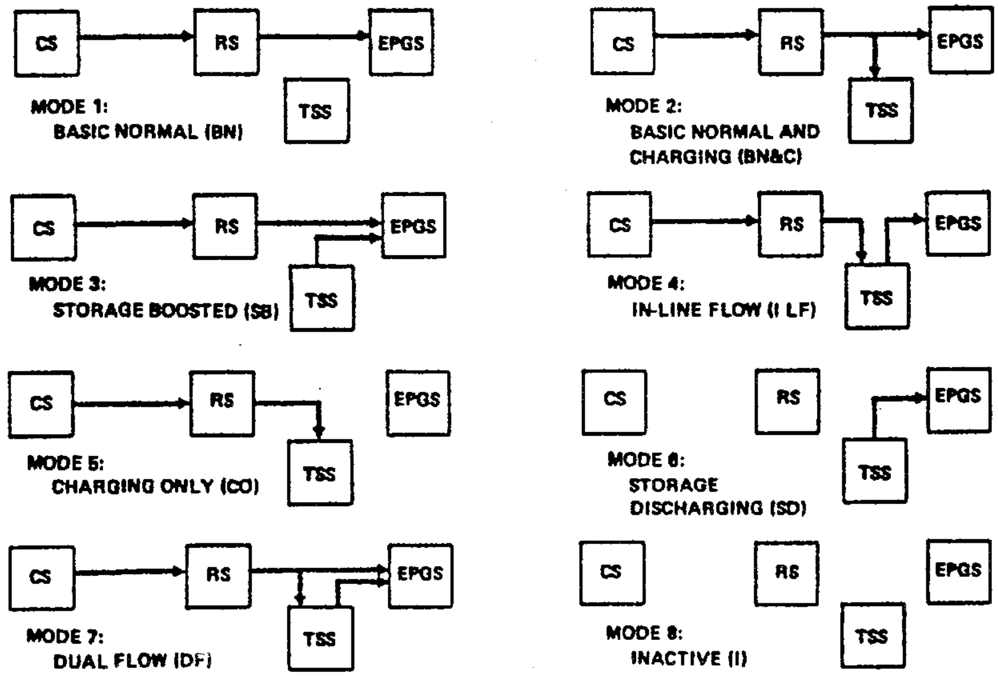


Figure 8

In 1983, the balance of the operating modes will be verified and the coordinated and automatic control software will be developed and tested. At this point, the plant will be operational under fully automatic computer control and completely tested in all of its operating modes. The latter three years of the five-year test program will then be devoted primarily to optimizing power production and testing as a utility resource.

Operation and Maintenance

In accordance with the Utility Associates Cooperative Agreement with the DOE, SCE is responsible for the operation and maintenance of the pilot plant. A prudent minimum level of staffing by full-time experienced SCE operators and maintenance personnel has been developed, consisting of 6 administrative, 20 operating and 10 maintenance people. Of the 36 total, 26 are represented by the local union.

The basic operating crew consists of five people (operating foreman, control operator, two assistant control operators, and plant equipment operator). This crew will be required for two energy production shifts per day, seven days per week. A caretaker crew consisting of three people (control operator, assistant control operator, and plant equipment operator) will make up the back shift. The balance of the personnel will perform administrative, material control, and maintenance activities. Only light maintenance capability has been provided at the pilot plant site. Heavy maintenance will be accomplished at Cool Water Generating Station or other off-site facilities. For the initial year of operation, heliostat maintenance and washing will not be performed on a regular basis but only as required to maintain an adequate power level.

The estimated annual operation and maintenance cost for the power plant is \$3,681,000 (1981\$). This estimate is summarized in Table 2.

TABLE 2

SOLAR ONE ANNUAL OPERATING AND MAINTENANCE BUDGET

Company Labor	\$1,378,000
On-site Contractors	158,000
Operating Supplies & Services	374,000
Maintenance Supplies & Services	242,000
Off-site Repairs	231,000
Overheads	1,298,000
TOTAL ANNUAL COST	3,681,000

Experiences to Date

During the design, construction, and start-up phase of the project, several valuable first-of-a-kind experiences have happened that are worth sharing. Some can be categorized as lessons learned and others demonstrate that the project is on the cutting edge of central receiver technology.

Tower Crane

Design of the tower-mounted receiver called for a service and maintenance crane to be mounted on top of the receiver. Its dual purpose was to facilitate installation of the receiver panels during construction and to remove and replace a panel during operation if one should become damaged beyond in-place repair. After the crane was procured and installed by the tower erector, it was concluded that the crane itself could not accommodate the elevated temperatures expected immediately above the receiver during plant operation. As a result, the crane was removed after construction rather than attempting to modify or protect it at an excessive cost. If panel removal is required, a rental crane will be used. This exemplifies the complex job of integrating all of the construction and operational requirements into plant equipment specifications.

Heliostats

The installation of the collector field was accomplished on schedule and clearly demonstrated the benefit of the "learning curve" when performing repetitive tasks. Fabrication and installation experience by major components is summarized below:

Pedestals

- Installation started November 1980 and was completed June 1981

- Units installed per day were 27-60 (minimum-maximum)

Drives

- Final assembly at Daggett started November 1980 and was completed July 1981
- Units assembled per day were 1-18 (minimum-maximum)
- Installation started November 1980 and was completed August 1981
- Units installed per day were 5-50 (minimum-maximum)

Mirror Assemblies

- Mirror module fabrication in Pueblo, New Mexico, started January 1981 and was completed August 1981
- Module production was 100-279 (minimum-maximum) per eight-hour day
- Final assembly at Daggett started February 1981 and was completed September 1981
- Final assembly production was 2-18 (minimum-maximum) per eight-hour day
- Site installation started February 1981 and was completed September 1981
- Units installed per day were 4-40 (minimum-maximum)

Heliostat Controls

- Denver, Colorado, fabrication started November 1980 and was completed May 1981
- Installation at Daggett started February 1981 and was completed September 1981
- Units installed per day were 10-40 (minimum-maximum)

Problems (and resolutions) which have been experienced with the heliostats during the fabrication, production testing, assembly, installation and initial operation are summarized in Table 3.

TABLE 3

Problem	Resolution
Production drive failed during simulated 90 mph wind load test	Additional elevation pinion gears tested without failures; high wind stow position revised to reduce loading
High glass loss during start-up of mirror module fabrication on ceramic tools	Standard float glass used for approximately 136 heliostats; field performance impacted less than 1%
Sixty-nine doubler pad bond failures have occurred at site. Doubler pads hold mirror modules to structural rack assembly	Adhesive process control improved; pad pull test initiated; riveting retrofit performed on 5400 modules; approximately 150 spare modules available at site
Random communication failures occurred in heliostat control boxes	Boxes modified to increase capacitor size and jumper connections added
Lightning storm caused failure of I/O communication couplers in field and control room	Provide additional grounding protection of control cable in core and field areas to protect against electromagnetic pulses
Corrosion in mirror facets	Under study

Based on pilot plant experience, Martin Marietta has recommended for future central receiver plant installations that the following site construction items be completed prior to the start of heliostat installations:

- Data cabling installed in entire field;
- Power cabling energized in entire field;
- Control room available for permanent control console;
- BCS targets installed.

Thermal Storage Tank Leak

About one month after oil was placed in the tank, evidence of a leak in the tank bottom was observed at the northern edge of the tank. The leak rate remained constant at less than 1 gallon per day (capacity of the system approximates 240,000 gallons). At operating temperatures, however, it was calculated that this rate would increase to approximately 60 gallons which was unacceptable. A tunneling effort was required to expose the leak and a flaw was discovered in one of the floor plates rather than in a weld as initially assumed. The leak has been repaired and the thermal storage system is now being conditioned. This experience points out the need to examine all tank plate material very thoroughly prior to erection.

Freeze Protection

In January 1982, temperatures below 18°F were experienced at the site which caused freezing of some small diameter tubing and components (e.g., flow meters, pressure and temperature indicators, etc.). This initiated a review of the freeze protection criteria and several measures have been taken to correct this situation (e.g., heat tracing of lines has been increased, temporary enclosures and space heating have been installed, special operating procedures have been instituted). Start-up testing was continued after a one-week delay.

Operator Training

Operator training was initiated early in the program utilizing a control room simulator which was developed by McDonnell Douglas at their headquarters in Huntington Beach, California. This approach allowed SCE operators to become familiar with each system early so they could meaningfully contribute during the start-up of the plant. In a matter of days after controls were installed, SCE operators were demonstrating operating capability with the systems.

Site Safety

Site safety measures have been carefully evaluated during start-up. Safety controls were instituted based upon a series of heliostat beam safety tests completed by SCE and Sandia National Laboratories. The tests confirmed the location of limited areas of high solar flux near ground level within the heliostat field as heliostats are moved from the stow position to the receiver standby points. These areas have been appropriately marked to warn site personnel. Several safety briefings were held with all personnel to inform them of the safety precautions necessary during testing.

Thermal Cycling

Without the immediate availability of thermal storage, the major plant systems have been subjected to diurnal temperature cycling from ambient to operating temperature. As a consequence, numerous minor leaks and malfunctions have been experienced. Systematic repair has accommodated most delays and long-lead measures have been identified to minimize the effect of transients. A specific example is that of the steam dump system isolation valve which failed in mid-July. Cooperative efforts between the manufacturer, site maintenance and technical personnel resulted in short-term resolution and a long-term repair. Short-term, the plant operation was impacted by the fact that daily receiver start-up was delayed. Ultimately, the valve was electrically trace-heated to reduce thermal transients while minimizing the delay of start-up. With thermal storage activation, the number of plant systems which undergo thermal cycling will be reduced.

Plant Test and Operating Data

Test and Operating statistics are presented in Table 4. As systems have been activated and operated, trends are favorable: test and power production hours increasing, with plant outage hours decreasing as time has progressed. Review of this data should be accompanied by the fact that the prime activity during these months has been start-up testing. Weekend power production by SCE has been in operation since July 15. An interim operational procedure was prepared and the operators trained during the testing periods. The effect of this is seen in the better than 150% improvement in monthly power production time and energy following June. April and May were good power energy months because the major test activities allowed concurrent power production. The period from June to the present has tested receiver and storage performance realms which precluded turbine operations during the week.

Weather has had a greater than expected effect upon the testing. Weather outage hours have increased since April. In addition, the insolation level has been low. For example, during August insolation, above 950 watts per square meter was not observed. The base design year, 1976, recorded insolation above 950 watts per meter, over four hours, on nineteen days during August.

TABLE 4
MONTHLY HOURLY ACTIVITY SUMMARY

	APR	MAY	JUN	JUL	AUG	SEPT
Test	62	46.5	41	93	94	124
Plant Outage	61	59	88	96.5	73	75
Weather Outage	7	34	31	50	102	120
Power Production	28	48	10	29	27	55
MWe-Hr Net	56.4	215.3	46.7	98.5	142.5	109.1
Activities						
Rec'r Control Test	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx					
Storage Activation		xxxxxxxxxxxxx				
Storage Testing			xxxxxxxxxxxxxxxxxxxxxxxxxx			
Rec'r-Turbine Testing						xxxx
Weekend Power Prod.				xxxxxxxxxxxxxxxxxxxxxx		

Public Interest

Public interest in the project has been high even prior to any visual attraction from plant operation. The visitors information center, which is open 9 am - 5 pm seven days per week, has recorded over 57,000 visitors in the 26 months since its opening in July 1980. Attendance increased as the plant became highly visible due to receiver reflectivity and heliostat beams focusing on stand-by points adjacent to the receiver. A recent photograph of the plant illustrating its visibility is shown in Figure 9.

Figure 9. Heliostat Standby Points

SOLAR ONE UPDATE

October 25, 1982

Paul E. Skvarna
Southern California Edison Company
Rosemead, California

On April 12, 1982, at 3:09 p.m., the Solar One turbine-generator was synchronized to the SCE system for the first time, marking the dawning of a new age of electrical power generation. Since that time, over 780,000 kWh have been generated. On May 19, 1982, just five weeks after turbine roll, Solar One produced 56,600 kWh for a new daily record.

Start-up of the plant has been characterized by the lack of significant problems and a very successful demonstration of the control system. The computer control systems have operated much better than expected and equipment failure has been minimal. Major problems during start-up have included cloudy weather and water chemistry. The receiver (a once-through boiler) has very stringent water chemistry requirements (e.g., 10 ppb iron, 2 ppb sodium, 2 ppb chloride, etc.). This, coupled with extensive complicated piping systems and delays caused by weather, has made water clean-up difficult.

Since turbine roll, receiver steam tests have continued in parallel with power generation and commissioning of the thermal storage system (TSS) and the beam characterization system (BCS).

Test schedules have been worked out so power production is "piggy backed" on receiver steam testing. TSS activation was delayed because a leak in the tank floor was discovered. The leak was caused by a defect in the floor plate when it was manufactured. The leak was repaired and the TSS has been fully charged to 575°F, and a thermocline is now evident. The thermocline (sharp break in oil temperature) occurs over approximately a five-foot height difference within the tank. On August 24, 1982, steam generated from the TSS rolled the turbine to 2.4 MW while synchronized to the grid.

In mid-July, the Department of Energy (DOE) authorized weekend power production. SCE operators, with the guidance of DOE, Sandia, and McDonnell Douglas (MDAC), operated the turbine-generator on the third weekend and established a new record of 60,738 kWh generated over 8-1/2 hours of operation. On October 10--also during weekend operation, without guidance from DOE, Sandia, and MDAC--a new maximum net peak output of 10.4 MW was recorded.

The beam characterization system (BCS) which serves as an aid for identifying heliostats that need maintenance, has been placed in operation. The system allows operators to check individual heliostat focus, aim point, and power across the beam, automatically. The computer software will move heliostats that may block the beam of the mirrors being examined. Therefore, the heliostat being checked has an unobstructed view of the BCS target located just below the receiver on the tower.

Receiver steam tests are essentially completed; however, evaluation of the tests remains. These tests have demonstrated the receiver control system's capability over a wide range of operation up to rated conditions of 960°F and 1465 psi. Normal operation of a power generation boiler is similar to piloting a large ship where the control system's response is generally very slow. The Solar One receiver consists of 24 individual boiler panels that can respond very quickly and operation is more like driving a "Ferarri."

Operator acceptance of the new computer system has been very positive. The training program, conducted by MDAC utilizing a simulation laboratory, really paid off. SCE operators were able to understand system control functions and contribute from the very beginning of the start-up period. This demonstration of competence led to the early implementation of weekend operation.

Instead of the traditional power plant control system that utilizes meters, gauges, and switches, this computer control system utilizes a CRT console and keyboard. Operators "call up" displays that show live on-line schematic diagrams of the plant's systems. The operators can simply use a light pen to identify valves and circuit breakers and operate them from the control console keyboard. In addition, the system has the flexibility to plot component information (e.g., pressures, flows, temperature, etc.) which serves as an aid to the operators.

The collector system consisting of 1818 heliostats has operated without major problems. Because of a lack of funds, heliostat maintenance, including washing, was deferred. In late July, however, the reflectivity of heliostats had degraded to a point where a wash program was required. A random sample of heliostat reflectivity indicated that the original (clean) 91% reflectivity had degraded to approximately 72%. An experimental program was instituted using an existing SCE substation insulator wash truck in an attempt to upgrade the power level of the collector field. SCE operators developed a technique using pressurized demineralized water to rinse off the heliostats and returned the reflectivity to greater than 86%. Approximately one minute was required to wash a heliostat.

Normally, heliostats are awakened prior to sunrise and moved from the stow poisition (mirror face down) to the standby position. The ball of sunlight moves from the focal point at ground level to the standby position adjacent to the receiver in about six minutes. A series of ground and air beam safety tests have been conducted to verify the safety criteria in effect at the plant. Preliminary results have indicated that light intensity approximating 28 suns is present at ground level during a short period when the heliostats are making a transition from stow. Measurements have also been made to determine the level of intensity of the receiver when it is reflecting sunlight. Although the receiver appears to be glowing brightly, the level of reflected light is considerably less than the brightness of the sun when the receiver is operating at its maximum rating.

One major equipment failure has occurred that can be attributed to the unique operational requirements of the plant. In a normal power plant, systems are turned on and run for extensive periods of time to maximize kWh output and to minimize thermal cycling of equipment. At Solar One, systems are started up and shut down every day which places extreme thermal stresses on equipment. This has resulted in failure of the main steam drag valve and has caused numerous leaks in the receiver and thermal storage systems. Start-up procedures and equipment have been modified to minimize the thermal stress. Additionally, consideration is being given to operate the TSS at low levels all night to keep systems at near-normal temperatures ready to resume full operation at sunrise.

The five-year test program is well underway and the pilot plant has demonstrated that the central receiver concept works as expected. The first two years of the test program will be devoted to design verification of the individual systems and components and demonstration of the various modes of operation. Additionally, controls will be updated so the plant can be operated with a minimum operating staff and the collector system will be integrated into the overall control system. The last three years of the program will maximize kWh output and demonstrate plant reliability.

DESIGN &
CONSTRUCTION

GROUP A DISCUSSION: DESIGN AND CONSTRUCTION

Wilfried Grasse, Chairman

Group A, Design and Construction, consisted of the following representatives: from Barstow, N.J. DeHaven (Southern California Edison) and R. L. Gervais (McDonnell Douglas); from CESA-1, C. Ortiz, (CEE/INITEC); from Eurelios, J. Gretz (ISPRA), E. Schober (MBB), and G. Dinelli (ENEL); from IEA/SSPS, D. de Heering (Belgonucleaire) and D. Stahl (Interatom); from Sunshine, T. Taguchi (Mitsubishi); and from Themis, J. Hillairet (REAM) and H. Lemaignen (Cethel). Wilfried Grasse served as chairman. Group A discussed five subjects:

- Heliostat designs and future developments
- Receivers
- Storage systems
- Power conversion systems
- General plant design

Of the six projects, only four--Sunshine, Eurelios, IEA/SSPS, and Barstow--are in operation; however, only limited results are available. Because Themis and CESA-1 are close to operation, these two projects could contribute information more from the standpoint of design than from performance. But whatever their status, all projects could discuss lessons learned, the emphasis of Group A. Summaries of the discussion topics are provided below. Copies of the presentation vugraphs follow.

Heliostat Designs and Future Developments

The lifetime of the mirror facets still needs to be improved. Research and development efforts should concentrate on corrosion problems and degradations of any kind of curvature or silvering, rather than try to improve reflectivity with new glass, thin glass, or iron-free glass, or any other means, by 2 or 3 percent. Soot, dust, and soiling problems exist in plants all over the world. Effective cleaning methods and devices need to be developed.

Heliostat configurations are becoming more and more similar in sizes, bases, support structures, and panels. The exceptions are those plants that require different solutions because of different situations (in land availability, for example).

It was common opinion that the heliostats used at Barstow, SSPS, and Themis are ready for commercial application, provided that the costs are lowered to competitive figures. While no one wants to discourage the development of new concepts, those new concepts will need to prove their advantages with respect to price, performance, and maintenance.

Significant cost reductions even lower than $175/m^2 must be achieved; the suppliers are very optimistic that with the combination of mass production, the learning curve, and the improvements common to other technologies, the cost can be achieved. Particular constraints such as land availability, plant size, and small aperture diameters might require special designs and smaller heliostats.

Receivers

The discussion of receivers, if it were compared to similar discussions some months or years ago, probably has not revealed much progress. There is still a need for long-term data from accurate testing of the receiver. At this point, everyone is rather satisfied by their receiver designs with one exception--the Eurelios representatives are considering a redesign of their receiver as a result of their experience. All other projects (and this is especially true for SSPS, Sunshine, and Barstow) can say that the design assumptions have been fulfilled. No major problems occurred during construction or assembly testing. Lifetime expectations are still thirty years, and experience will show whether this statement is valid. In answer to the question "what is more advantageous, external or cavity receivers," the reply was "it depends." Choice depends on the size of the plant, temperature levels, particular designs, aiming strategies, etc.

The panel agreed that future receiver development would be in sodium or liquid salt; however, the economics of those types of receivers as part of the whole system still need to be verified or proven. The figures of the Barstow receiver net output have been compared to some of the operational figures from the SSPS sodium receiver, but the SSPS figures tell only the gross output of the plant. Trace heating, heating during the experimental phase, cooling down for plant repair, and so forth have not allowed judgment of the SSPS parasitics--and trace heating, for instance, has had to be switched on very often. There have been good results from the testing of the Martin Marietta receiver at Albuquerque. The French are optimistic with regard to their receiver; however, no experiences or performance data have been made available. No lifetime considerations in France have yet been made. Water-steam receivers demonstrate good performance and remain an interesting option.

Lifetime considerations must be emphasized. Furthermore, the majority of the designers agree that a solar code, according to which solar receivers would be designed, is needed. For instance, the MDAC receiver is designed to codes for similar heat exchangers at other plants. Thermocycling, creep fatigue, and other material difficulties must be taken into consideration; this is the main reason for recommending a code.

In general, the start-up time of the systems needs to be improved.

Finally, some designers would like to see receiver approaches or proposals developed into an analytical design model. This model should not be limited to cavity receivers, in which the convection losses are more complicated than those from other receivers.

Storage Systems

Buffer storage capacity, i.e., fully internal buffering of the plant to guarantee plant operation and flexibility, must be of reasonable size; a half-hour storage capacity is not sufficient.

Leakage in storage tanks has been a problem in several systems. Whether this leakage is a particularly solar problem (related to thermal cycling) or a convection problem is not clear. It may be a solar problem that has to be examined as such. Leakage is not simply a storage problem. It occurs with piping, in the fittings and valves, and in the heat transfer system. Higher leakages have been observed in solar plants than in conventional plants, perhaps as a result of higher thermal cycling.

The concept of an optimum storage size was discussed, but data are not available to make a recommendation.

Power Conversion Systems

The discussion of power conversion, the conversion of thermal power into mechanical and electrical power, emphasized solutions for individual problems, and no extrapolations seemed appropriate. It is clear that with high-performance large turbines, efficiencies in the power conversion cycle increases.

General Plant Design

A solar power plant must be designed with respect to its application. The discussion concentrated on plants for electrical energy generation, but other applications are possible and probable.

Before a plant site is chosen, meteorological data are necessary. Perhaps an organization can set up standards regarding what to measure, when to measure, what defines a solar environment, etc., as well as establish other necessary environmental data before a solar power plant is designed.

Solar multiple is an item of high interest because it is very cost effective. For normal plants that are not operating in stand-alone for instance, a multiple of 1.2 should guarantee sufficient operational flexibility. Each design will require individual optimization levels.

VUGRAPH I - GROUP A

HELIOSTAT FIELD

- LIFETIME OF MIRRORS TO BE IMPROVED
- R & D WITH RESPECT TO CORROSION AND DEGRADATION RATHER THAN TO HIGHER REFLECTIVITY
- SIMILAR DUST PROBLEMS WITH ALL PLANTS RECOMMEND DEVELOPMENT OF EFFECTIVE CLEANING MEANS
- PRESENT BASE CONFIGURATION ACCEPTABLE FOR COMMERCIALIZATION
- NEW CONCEPTS MUST PROVE ADVANTAGES REGARDING PRICE, PERFORMANCE, MAINTENANCE
- SIGNIFICANT COST REDUCTIONS (< 175 $\$/M^2$) TO BE ACHIEVED (SUPPLIERS ARE OPTIMISTIC)
- PARTICULAR CONSTRAINTS (LAND, SIZE) REQUIRE SPECIAL DESIGNS

VUGRAPH II - GROUP A

RECEIVER

- ACTUAL RECEIVER PERFORMANCES SATISFACTORY (EURELIOS CONSIDERS REDESIGN)
- TYPE (EXTERNAL/CAVITY) DETERMINED BY PLANT SIZE AND TEMPERATURE LEVEL
- FUTURE DEVELOPMENT TOWARDS SALT/SODIUM; HOWEVER, ECONOMICS WITH REGARD TO TOTAL PLANT SYSTEM TO BE PROVEN
- WATER-STEAM DEMONSTRATED GOOD PERFORMANCES AND REMAINS AN INTERESTING OPTION
- LIFETIME CONSIDERATIONS, NEW "SOLAR CODES" NEEDED
- REDUCTION IN START-UP TIME FOR IMPROVED PLANT PERFORMANCE
- DATA & EXPERIENCES → ANALYTIC MODEL

VUGRAPH III - GROUP A

STORAGE SYSTEM

- SUFFICIENT BUFFER CAPACITY NEEDED FOR OPERATIONAL FLEXIBILITY
- VESSEL DESIGN FOR "SOLAR" THERMAL CYCLING
- TENDENCY TOWARDS HIGHER INTERFACE LEAKAGES OBSERVED (FLANGES, VALVES)
- NO PARTICULAR INPUTS FOR OPTIMAL STORAGE CONCEPTS

VUGRAPH IV - GROUP A

POWER CONVERSION

- SOLUTIONS FOR DEMONSTRATION PLANTS ONLY OF INDIVIDUAL INTEREST
- HIGHER EFFICIENCIES WITH BIGGER UNITS

VUGRAPH V - GROUP A

- OPTIMAL DESIGNS TO BE BASED ON INDIVIDUAL APPLICATION NEEDS
- METEOROLOGICAL DESIGN BASE TO BE IMPROVED (LONG-TERM DATA)
- SOLAR MULTIPLE MIN. ,2 (OPERATIONAL FLEXIBILITY)

  INDIVIDUAL DESIGNS TO SELECT THEIR FIGURES ACCORDING TO THEIR INDIVIDUAL OPTIMIZATION

STAFFING FOR O&M

GROUP B DISCUSSION: STAFFING FOR OPERATION AND MAINTENANCE

Clif Selvage, Chairman

Group B, Staffing for Operation and Maintenance, consisted of the following representatives: from CESA-1 (replacing the representative from ASINEL), C. Selvage; from Eurelios, G. Dinelli (ENEL); from IEA/SSPS, F. Martinez (Sevillana); from Sunshine, M. Matsui (EPDC); from Themis, F. Pharabod (AFME); and from Barstow, P. Skvarna (SCE). Clif Selvage served as chairman.

Most of the panel members were advised before the meeting of the panel's general objective: to discuss the staffing needs for the operation and maintenance of solar central receiver facilities and to try to reach an understanding of what is needed to operate a plant. The panel avoided discussion of social (or other) constraints that might prevent reduction of staff.

The effects of several variables on staffing were covered:

- automation

- converting the present plant to a 100 MWe plant

- size of the power plant

The number of operators required by the utility for each plant, of maintenance personnel, and of administrative staff was discussed. The number of operators differed for each plant, raising an interesting point: how can plants operate under similar conditions and sets of constraints and have such a wide range of operator requirements? In the case of the Sunshine plant, only five operators are needed. This is possible because the Japanese union is cooperative and interested in the success of solar technology. Each person works six days (eight-hour shifts) with two days off and then five days with one day off. It is a unique situation and not a matter of automation.

Eurelios also has a small staff: nine operators and three electrical maintenance people. As in other plants, these three are basically roving plant operators who can replace the operator when necessary. So, given another plant's definition, Eurelios has twelve operators. It should also be remembered that Eurelios has limited operation. Its small storage shuts down every night, and the plant does not operate on Sundays. The plant is not kept hot. When staff leave at night, the plant is put on an alarm system that is connected to a hydroelectric plant across the street. If trouble occurs, staff from the hydroelectric plant are notified.

The most important conclusion of the panel was that all of the plants are staffed as if the plants were power-production facilities; they are not staffed as research test facilities. Some countries regulate the maximum hours that an operator can work (e.g., Sevillana requires the thermal plants to have six sets of operators for every position, with a 40-hour per week limit on each person).

Increased automation can cause a small decrease in staff. In most cases, for every person there must be a backup person. These numbers probably cannot change. But automation, such as automatic heliostat equipment, might reduce the number of maintenance staff. (However, for large plants that have 20,000 heliostats, reductions may not be possible.)

Dr. Hildebrand pointed out that utilities are determining the staffing levels for solar plants based on normal utility considerations. These numbers reflect the automated process of the big plants. He recommended that a time-and-motion study be conducted on a solar plant to check the solar processes against the activities of the more typical plants; perhaps today's operator requirements are valid and perhaps they're not.

The last conclusion is a result of looking at the projected staffing of Solar 100 (prepared by Southern California Edison). In this draft, thirty-seven operators are used. Possibly some automation could be integrated into plant operation, thereby reducing operator levels. Fourteen maintenance people are projected. (Some of the group felt this number was optimistic for a plant with 20,000 heliostats.)

In sum, the panel had hoped to discover that no constraints existed, automation was possible, etc., but those hopes do not represent the reality of the situation.

Copies of the presentation vugraphs follow this summary.

VUGRAPH I - GROUP B

CONCLUSIONS

1. ALL PLANTS ARE STAFFED FOR POWER PRODUCTION

2. SOME COUNTRIES REGULATE MAXIMUM HOURS THAT CAN BE WORKED (SPAIN & FRANCE)

3. INCREASED AUTOMATION CAN CAUSE SOME SMALL DECREASE IN STAFF

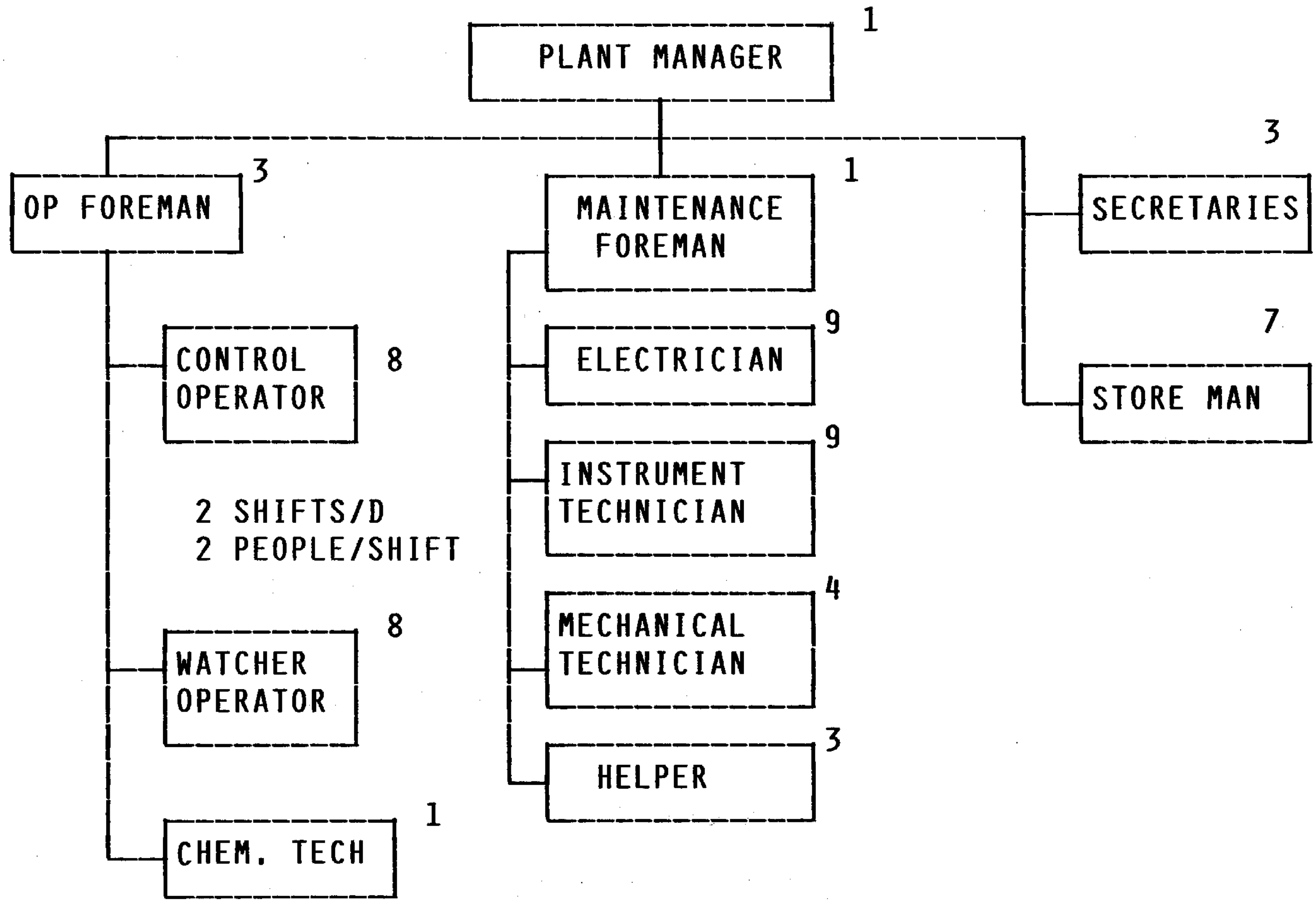
4. THERE IS SOME STORAGE RELATION TO STAFFING NEEDS

5. A TIME-AND-MOTION TYPE STUDY OF STAFF VS. AUTOMATION BY SOME COMPANY (E.G., DUPONT) COULD BE PRODUCTIVE

6. MAINTENANCE STAFF INCREASES WITH SIZE

VUGRAPH II - GROUP B

CESA-I

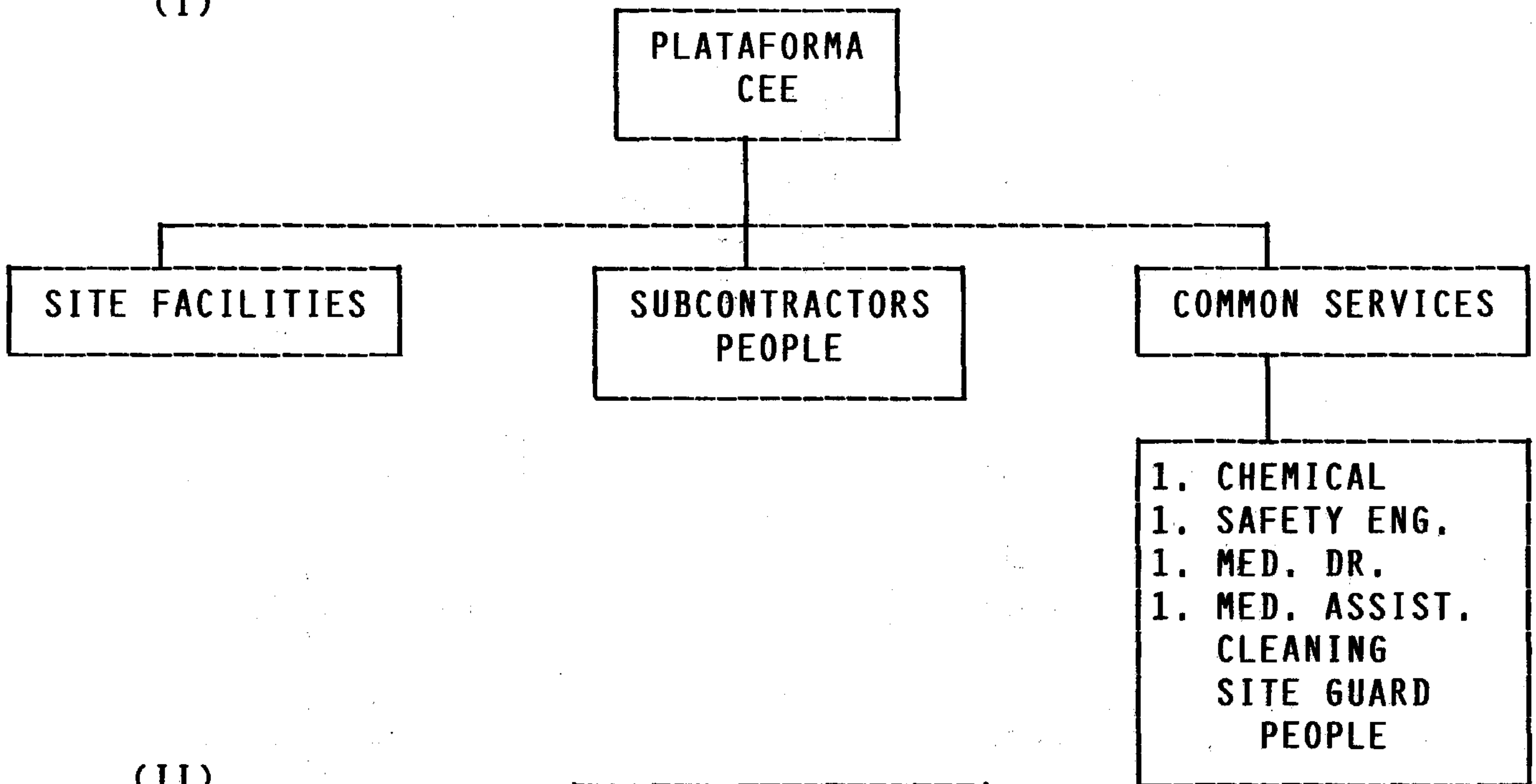


20 OPERATORS

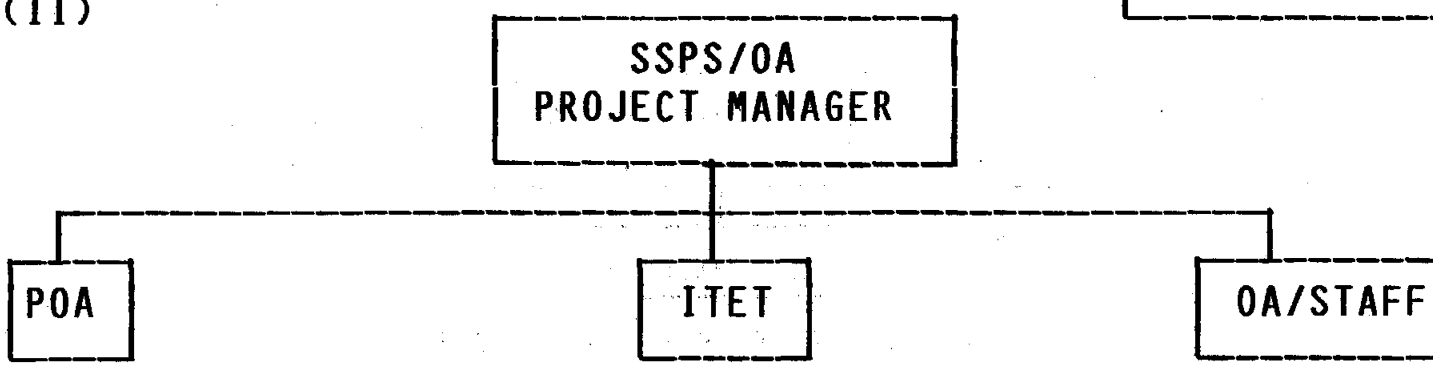
32 TOTAL

VUGRAPH III - GROUP B

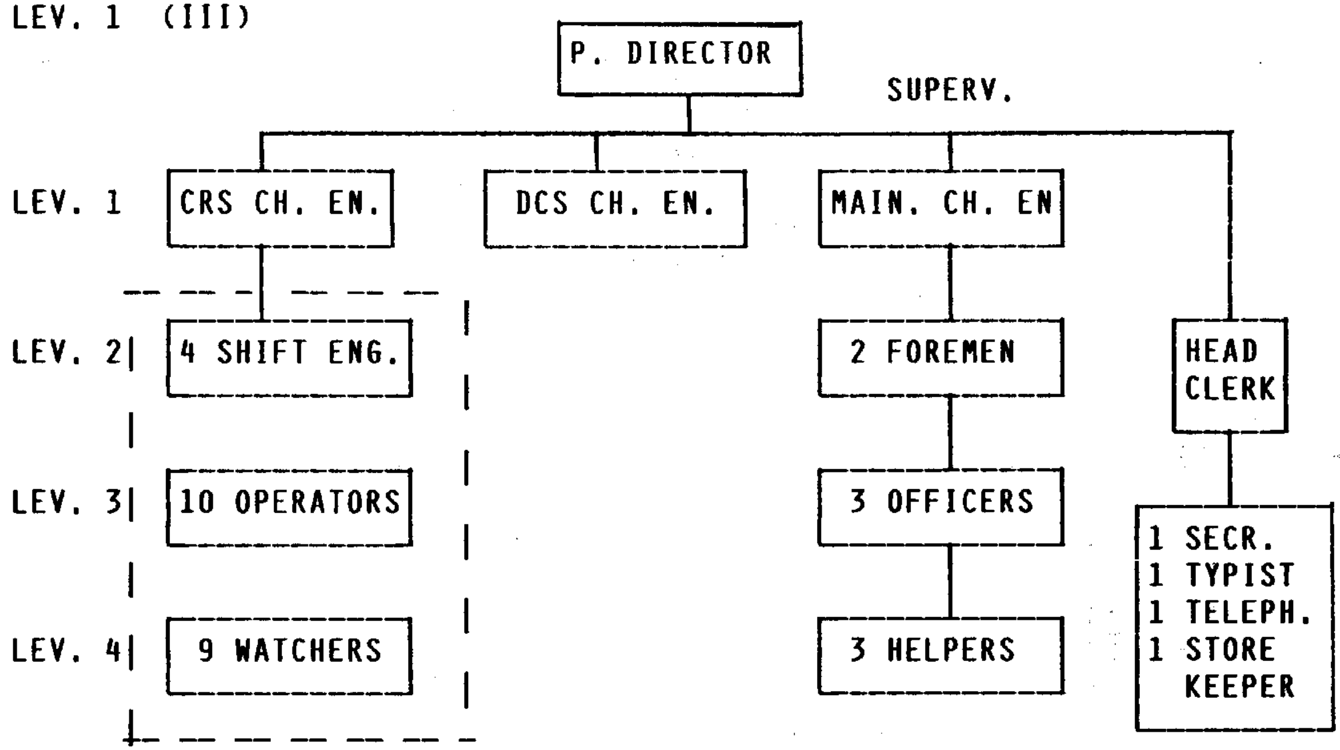
(I)



(II)



VUGRAPH III - GROUP B (CONT'D)



CRS

1ST SHIFT: 7:00 - 15:00 1 SHIFT ENG. (40) 29 SEVILLANA

OP. 2 OPERATORS 11 SUBCONTRACT

2 WATCHERS (CEE)

2ND SHIFT: 15:00 - 23:00 1 SHIFT ENG.?

2 OPERATORS ? CRS - 18 OPS (INC

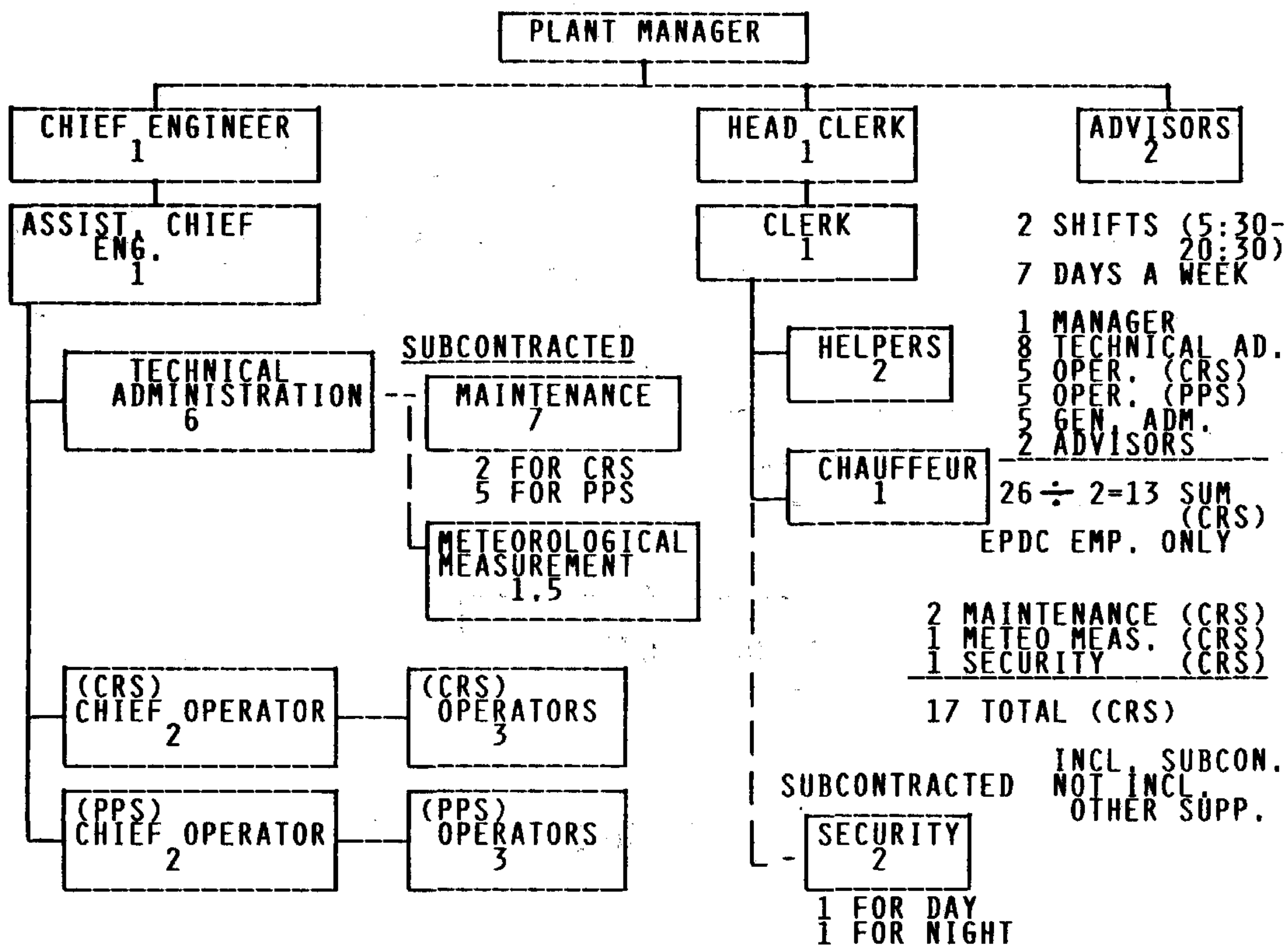
3 WATCHERS ? SUPV.)

3RD SHIFT: 23:00 - 7:00 1 OPERATOR

(SUP. STBY. OP) 1 WATCHER

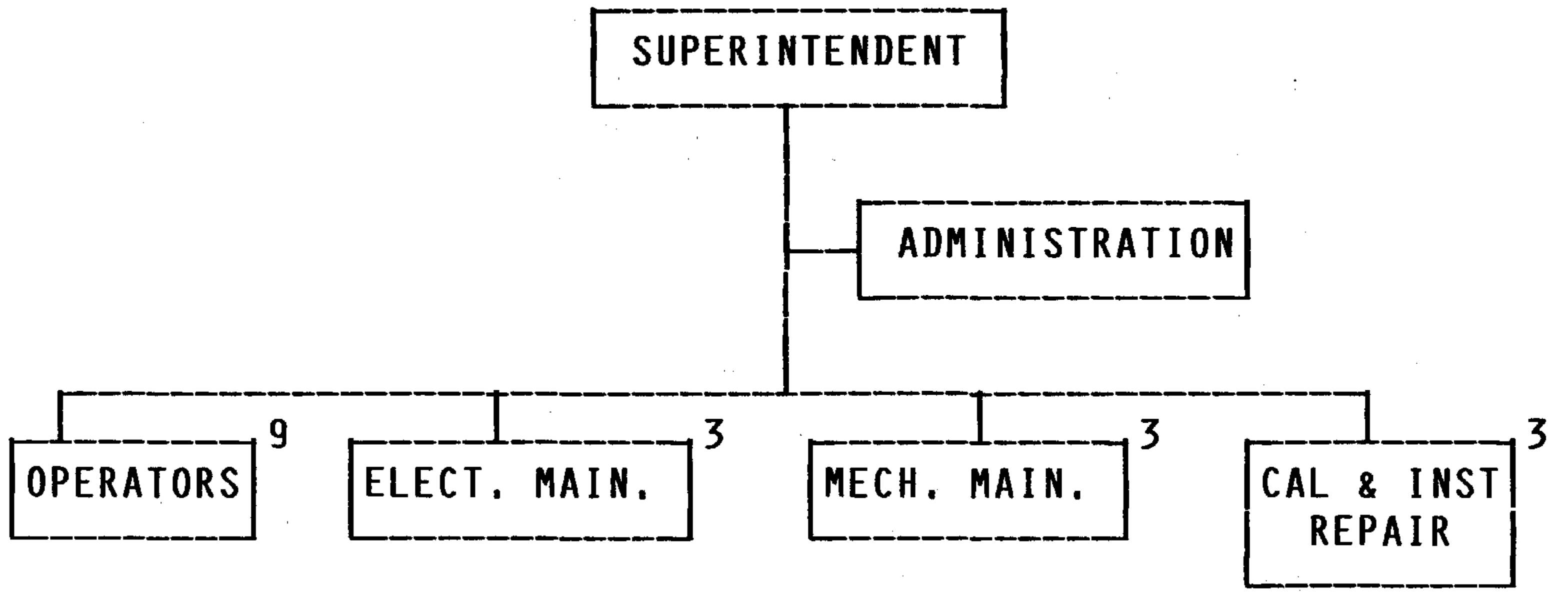
VUGRAPH IV - GROUP B

NIO PLANT OPERATION AND MAINTENANCE ORGANIZATION FOR TWO UNITS



VUGRAPH V - GROUP B

EURELIOS



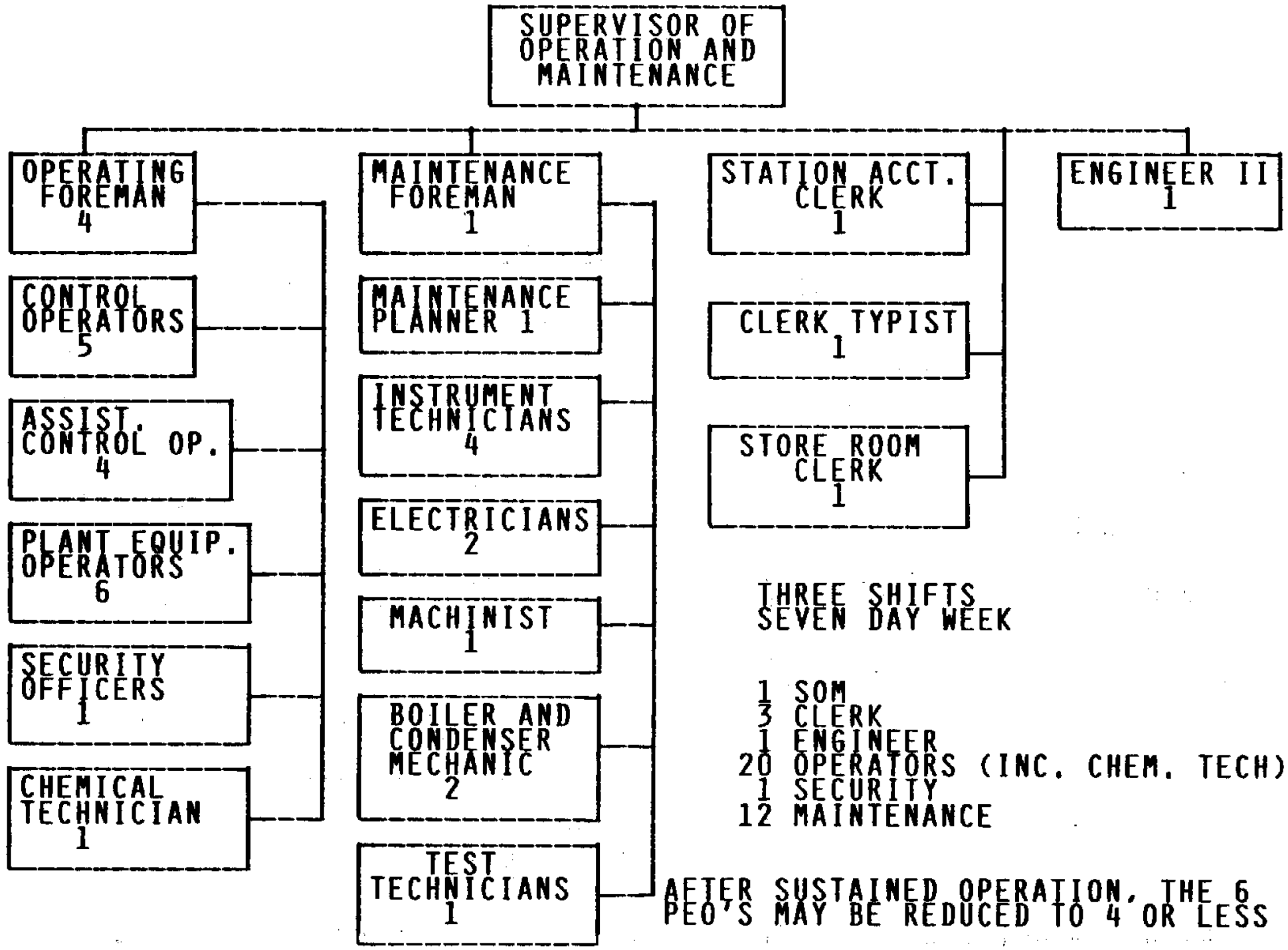
OPS 12

TOTAL 20

NIGHT SHUTDOWN, SUNDAY SHUTDOWN

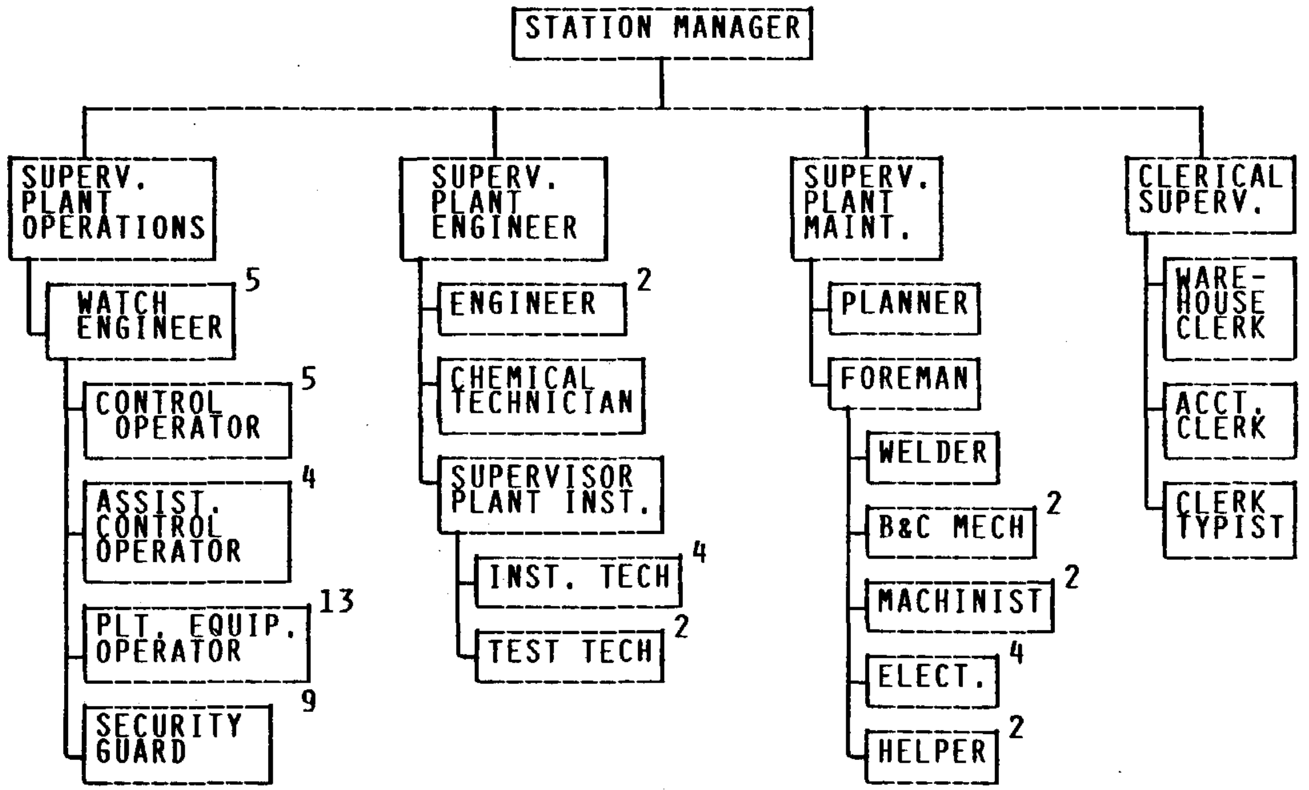
VUGRAPH VI - GROUP B

PILOT PLANT OPERATION AND MAINTENANCE ORGANIZATION



VUGRAPH VII - GROUP B

PROBABLE SOLAR 100 MANNING (SCE PLANNED STAFFING FOR A 100 MWE PLANT)



VUGRAPH VIII - GROUP B

STAFFING

EUR.	CESA-1	IEA	NIO	THEMIS	SOLAR 1
OPERATORS					
12	20	13	5	20	21
MAINTENANCE					
9	7	6	3	11	12
ADMINISTRATION					
2	5	3	9	6	5
20	32	23	17	37	38
DINELLI	SELVAGE	MARTINEZ	MATSUI	PHARABOD	SKVARNA

MAINTENANCE &
RELIABILITY

GROUP C DISCUSSION: MAINTENANCE AND RELIABILITY

Jan Holmberg, Chairman

Group C, Maintenance and Reliability, consisted of the following representatives: from Eurelios, J. J. Faure (CETHEL); from IEA/SSPS, H. Kleinrath (Tech. University of Vienna) and M. Loosme (SSPS-ITET); from Sunshine, N. Ikeda (NEDO); from Themis, F. Pharabod (AFME); and from Barstow, C. Lopez (SCE). CESA-1 was not represented. Jan Holmberg served as chairman.

Panel members were asked to report on plant problems. Themis reported on insolation problems and on wind damage to the heliostat field. Sunshine gave a report on maintenance, failures (receiver and valve leakage),and most of the traditional reliability problems. The SSPS report included information on a sodium fire, mirror attachment failure, heliostat communication problems, damages from a lightning strike, and sodium pump and valve leakage. Barstow has experienced several problems, such as generator overheating, electric boiler deficiencies, thermal storage feedpump failure, and receiver steam dump valve failure.

In all, sixty-seven items were reported. An attempt to categorize them showed that many problems and failures occurred on the mechanical side; there were fewer electrical problems. Problems were experienced with controls, as well as with design contracting, sites, corrosion, insolation, and staffing. Leakage, lightning strikes, reliability, and sodium and prewater treatment problems seem to be the most common items.

The panel recommendations can be summarized as follows:

General Facility Improvements

- Improve construction quality assurance
- Increase participation of the operating and maintenance personnel in the design review process
- Increase the use of conventional power plant design personnel
- Purchase equipment designed for solar application
- Consider the site when designing the plant

Collector Field

- Include ground grids, lightning arrestors, and lightning-protected ground wires in evaluation of lightning protection.
- Evaluate failure mechanisms and corrective actions of items to improve reliability (e.g., mirror silver corrosion, water intrusion into mirror envelopes, loss of control system communications, slow master controller communications)

- Increase quantity of heliostats to reduce plant start-up time as well as to maintain full plant capacity in case of reduced heliostat reflectivity

Receiver

- Improve receiver design to reduce the maintenance currently required by daily thermal transients

- Revise the thermal expansion guidelines for heat transfer surfaces

Thermal Storage

- Revise the material selection criteria for those systems designed for storing or conveying salt process fluids

- Improve storage design to reduce the maintenance currently required by daily thermal transients

- Improve thermal insulation standards to reduce excessive heat losses

- Increase thermal storage system capacitance

Controls

- Install redundant controllers for improved reliability

- Increase the transfer rate of communication data

Prime Movers

- Purchase prime movers designed specifically for operation at solar facilities

Plant Grounding/Lightning Protection

- Establish grounding and lightning protection standards to minimize the loss of communications and electronic component failures

Water Chemistry

- Install on-site make-up water demineralizers

- Install water analysis and control equipment in the solar portion of the power plant

Copies of the vugraph presentation follow this summary.

VUGRAPH I - GROUP C

THEMIS INCIDENTS/PROBLEMS

- VARIABILITY OF INSOLATION
- WIND DAMAGE TO HELIOSTAT FIELD
- LIGHTNING PROBLEMS

VUGRAPH II - GROUP C

SOLAR ONE INCIDENTS

- THERMAL STORAGE FEEDPUMP FAILURE
- TURBINE-GENERATOR MOTORING
- GENERATOR OVERHEATING
- ELECTRICAL SYSTEM VOLTAGE EXCLUSIONS
- RECOMMENDED ELECTRICAL CIRCUIT REV.
- PLANT FIRE SYSTEM PROBLEMS
- ELECTRIC BOILER DEFICIENCIES
- PLANT WINTERIZATION
- RECEIVER STEAM DUMP VALVE FAILURE
- STEAM TURBINE PROBLEMS
- RECEIVER PANEL TEMPERATURE GRADIENT

VUGRAPH III - GROUP C

SSPS INCIDENTS

- FLOODING OF SITE
- SODIUM FIRE AT TRANSPORT CONTAINER
- MIRROR ATTACHMENTS FAILED
- HELIOSTAT COMMUNICATION PROBLEMS
- SODIUM PUMP BLOCKAGE
- SODIUM LEAKAGE AT COLD STORAGE
- BEAM INCIDENT RECEIVER
- STEAM ENGINE WATER HAMMER
- DAS MEMORY ERROR
- HFS DAMAGES DUE TO LIGHTNING STRIKE
- SODIUM PUMP LEAKAGE
- SODIUM VALVE LEAKAGE

VUGRAPH IV - GROUP C

NIO

- MAINTENANCE
  - DAILY
  - ANNUAL
- FAILURES
  - RECEIVER LEAKAGE
  - VALVE LEAKAGE
- RELIABILITY
  - CHANGE OF COMPONENTS
  - REFLECTIVITY OF MIRRORS
  - TRACKING ACCURACY OF HELIOSTATS

RECOMMENDED SOLAR FACILITIES IMPROVEMENTS--GENERAL:

- IMPROVED CONSTRUCTION QUALITY ASSURANCE
- INCREASED PARTICIPATION OF EXPERIENCED OPERATING AND MAINTENANCE PERSONNEL IN THE DESIGN REVIEW PROCESS
- INCREASED UTILIZATION OF CONVENTIONAL POWER PLANT DESIGN PERSONNEL
- PURCHASE OF EQUIPMENT DESIGNED SPECIFICALLY FOR SOLAR APPLICATION
- PLANT DESIGN SHOULD GIVE ADDITIONAL CONSIDERATION TO PLANT SITE DESIGN CRITERIA
- REDUCTION OF PARASITIC POWER

COLLECTOR FIELD

- FURTHER EVALUATION OF LIGHTNING PROTECTION TO INCLUDE GROUND GRIDS, LIGHTNING ARRESTORS, AND LIGHTNING PROTECTORS GROUND WIRES
- EVALUATE FAILURE MECHANISM AND CORRECTIVE ACTIONS FOR ITEMS TO IMPROVE RELIABILITY:
  - MIRROR SILVER CORROSION
  - WATER INTRUSION INTO MIRROR ENVELOPES
  - LOSS OF CONTROL SYSTEM COMMUNICATIONS
  - SLOW MASTER CONTROLLER COMMUNICATIONS
- INCREASE QUANTITY OF HELIOSTATS TO REDUCE PLANT START-UP TIMES AS WELL AS TO MAINTAIN FULL PLANT CAPACITY IN THE EVENT OF REDUCED HELIOSTAT REFLECTIVITY

VUGRAPH V - GROUP C (CONT'D)

RECEIVER:

- IMPROVED DESIGN TO REDUCE THE AGGRAVATED MAINTENANCE THAT IS PRESENTLY REQUIRED CONSEQUENT TO DAILY THERMAL TRANSIENTS
- REVISE THERMAL EXPANSION GUIDELINES FOR HEAT TRANSFER SURFACES

THERMAL STORAGE:

- REVISE MATERIAL SELECTION CRITERIA FOR SYSTEM DESIGNED FOR THE STORAGE OR CONVEYANCE OF SALT PROCESS FLUIDS
- IMPROVED DESIGN TO REDUCE THE AGGRAVATED MAINTENANCE THAT IS PRESENTLY REQUIRED CONSEQUENT TO DAILY THERMAL TRANSIENTS
- IMPROVE THERMAL INSULATION STANDARDS TO REDUCE EXCESSIVE HEAT LOSSES
- INCREASE THERMAL STORAGE SYSTEM CAPACITANCE

CONTROLS:

- INSTALL REDUNDANT CONTROLLERS FOR IMPROVED RELIABILITY
- INCREASE COMMUNICAION HI-WAY DATA TRANSFER RATE

PRIME MOVERS:

- PURCHASE PRIME MOVERS DESIGNED SPECIFICALLY FOR OPERATION AT SOLAR FACILITIES

VUGRAPH V - GROUP C (CONT'D)

PLANT GROUNDING/LIGHTNING PROTECTION:

- ESTABLISH SOLAR FACILITIES GROUNDING AND LIGHTNING PROTECTION STANDARDS TO MINIMIZE LOSS OF COMMUNICATIONS AND ELECTRONIC COMPONENT FAILURES

WATER CHEMISTRY:

- INSTALL ON-SITE MAKE UP WATER DEMINERALIZERS

- INSTALL WATER ANALYSIS AND CONTROL EQUIPMENT IN THE SOLAR PORTION OF THE POWER PLANT

NOTE: THE MAINTENANCE RELIABILITY PANEL MEMBERS WERE EACH VERY OPEN AND FRANK REGARDING THEIR RESPECTIVE PROJECTS. AS A RESULT WE HAVE GREATLY BENEFITTED FROM EACH OTHER'S PARTICIPATION IN THE WORKSHOP AND WE NOW LOOK FORWARD TO PARTICIPATION IN SIMILAR FUTURE WORKSHOPS.

EVALUATION

GROUP D DISCUSSION: EVALUATION OF PROJECT RESULTS AND EXCHANGE OF INFORMATION

Claude Etievant, Chairman

Group D, Evaluation of Project Results and Exchange of Information, consisted of the following representatives: from CESA-1, F. Sanchez (CEE) and J. Avellaner (CEE); from Eurelios, D. Borgese (ENEL); from IEA/SSPS, M. Becker (DFVLR), P. Kesselring (EIR), and M. Fisher (DFVLR); from Sunshine, T. Tani (Electrotechnical Lab.); from Themis, B. Bonduelle (CNRS) and R. Aureille (EDF); and from Barstow, J. Bartel (SNLL) and K. Ross (SCE). Claude Etievant served as chairman.

The panel discussed two topics: data evaluation and data exchange. Data evaluation concerned the evaluation efforts that have been made by each project, such as measuring techniques, system simulation, obtained results, experimental programs, and evaluation teams. Exchange of information was also covered, but not as thoroughly.

Data Evaluation

It is clear that a considerable amount of information is required for evaluation of central receiver systems as electric power plants. The evaluation should emphasize annual electric energy production; it should include off-design point characteristics; it should evaluate receiver/heliostat interactions and performances.

Special topics for consideration were identified:

- reflectivity problems and trends
- transient characteristics and their interaction with storage
- start-up and shut-down processes and procedures
- for steam systems, safety vs. burnout/distortions
- operational modes as a function of technology (more modes make a plant more efficient)
- convective losses
- cost, capital, and operation
- site-specific insolation characteristics should be documented and evaluated against predictions
- energy, materials, and investment

As far as evaluation is concerned, it is clear that the return on investment is dependent on the importance of the evaluation team at each plant. The table in Vugraph II shows, according to the plant representative(s), the number of people working on evaluation at each project. Changes to this table may be appropriate.

Data Exchange

It is urgent to facilitate data exchange since many projects will be completed in two years. Exchange among central receiver projects should be organized. Several ways to do this were considered:

- more meetings

- topical task forces (e.g., reflectivity, convective losses, standardization)

- exchange of personnel

- bimonthly newsletters

The panel agreed that annual meetings are very useful. Topical task forces are a good idea. Personnel exchanges might be desirable in specific cases, but it creates some problems. Opinion on the newsletter was divided.

A common basis for plant simulation modeling is recommended. The SOLTES code, an example of such a simulation code, will be used to model the SSPS, Barstow, and CESA-1 plants. Input data requirements for a good simulation code will create a commonality in the data reported by the projects. A common basis will also help establish comparison standards among the plants.

The panel also pointed out that the external release of data might require a special releasing organization.

The panel concluded the following:

1. The workshop was a good idea and should be held again.

2. Two levels of interaction were identified.

   - Overall plant information exchange (overall performance, scaling, cost/performance extrapolations, etc.)

   - Detailed special topics exchange (operational "tricks," mirror soiling/washing experiences, start-up/shutdown techniques, leaks, thermal losses, lightning protection, measuring techniques, cost analysis, etc.)

3. Each level of interaction has impacts and implications.

   - For overall plant information exchange, a major meeting could be held. This meeting, which would probably require sponsorship by an official organization, would be a forum for major technology issues.

- The exchange of detailed special topics would be more informal. Short-term problems and solutions would be exchanged. Emphasis would be on sharing problems and successes at each facility. Cooperative efforts can reduce the duplication of errors.

4. It is urgent to establish comparison standards, i.e., main specification standards, performance and economic data, and meteorological data and site selection criteria.

5. Instrumentation standards need to be developed for reflectivity, insolation, etc.

6. The panel proposed that a catalog be organized for the diffusion of information. The catalog would include publications, available computer codes, events, and the evolution of projects. A mailing list of people interested in each project should be established.

7. Finally, conclusions 4, 5, and 6 could be carried out by a permanent evaluation group (perhaps based on the membership of this panel). Volunteers have already come forward to help establish a standardized form for performance and economic data and to organize a catalog for information diffusion to the central receiver community.

Copies of the presentation vugraphs follow this summary.

VUGRAPH I - GROUP D

DATA EVALUATION

- CONSIDERABLE AMOUNT OF MEASUREMENTS ARE REQUIRED FOR EVALUTION OF CENTRAL RECEIVER PLANTS AS ELECTRIC POWER PLANTS

- EVALUATION SHOULD EMPHASIZE ANNUAL ELECTRIC ENERGY PRODUCTION

- EVALUATION SHOULD INCLUDE OFF-DESIGN POINT CHARACTERISTICS

- EVALUATE ESPECIALLY RECEIVER/HELIOSTATS INTERACTIONS AND PERFORMANCES

- SPECIAL TOPICS FOR SINGULAR CONSIDERATION:

  1) REFLECTIVITY PROBLEMS AND TRENDS
  2) TRANSIENT CHARACTERISTICS - INTERACTION WITH STORAGE
  3) START-UP, SHUTDOWN PROCESSES AND PROCEDURES
  4) FOR STEAM SYSTEMS, EVALUATE SAFETY MARGINS OF THE RECEIVER AGAINST BURNOUT/DISTORTIONS
  5) OPERATIONAL MODES AS A FUNCTION OF TECHNOLOGY (MORE MODES MAKE A PLANT MORE EFFICIENT)
  6) CONVECTIVE LOSSES
  7) COST, CAPITAL AND OPERATION
  8) SITE-SPECIFIC INSOLATION CHARACTERISTICS SHOULD BE DOCUMENTED AND EVALUATED AGAINST PREDICTIONS
  9) ENERGY, MATERIALS, INVESTMENTS

EVALUATION TEAMS
(Number of People Working on Evaluation)

PLANT	ON-SITE	VISITING	TOTAL
CESA-1	3 CEE (4 TO 7 EXPECTED)	2 (MADRID)	5
EURELIOS	0	4 x 3 4 TEAMS	12 PART TIME
IEA/SSPS	8 ITET	2 OA (KOLN)	10
SUNSHINE	4 OR 5	6	10-11
THEMIS	2 CNRS	4 OR 5 EDF (Chatou)	6-7
SOLAR ONE	1 SANDIA 2 UTILITIES	6 SANDIA 1 UTILITIES	10

VUGRAPH III - GROUP D

DATA EXCHANGE

1) URGENT: MANY PROJECTS ARE COMING TO COMPLETION OF PROGRAMS IN TWO YEARS

2) EXHANGE AMONG CENTRAL RECEIVER PROJECTS SHOULD BE ORGANIZED

CONSIDERED	CONSENSUS
• MORE MEETINGS	• AT LEAST YEARLY
• TOPICAL TASK FORCES (REFLECTIVITY, CONVECTIVE LOSSES, STANDARDIZATION)	• GOOD IDEA
• EXCHANGE OF PERSONNEL	• MIGHT BE DESIRABLE FOR SPECIFIC CASES
• BIMONTHLY NEWSLETTERS	• DIVIDED

3) COMMON BASIS FOR SIMULATION OF PLANT:
   - SOLTES CODE, OFFERED AS EXAMPLE, WILL BE USED TO MODEL SSPS AND BARSTOW
   - INPUT DATA REQUIREMENTS FOR A GOOD SIMULATION WILL CREATE A COMMONALITY IN DATA REPORTED BY PROJECTS
   - WILL HELP ESTABLISH COMPARISON STANDARDS

4) EXTERNAL RELEASE OF DATA MIGHT REQUIRE SPECIAL RELEASING ORGANIZATION

VUGRAPH IV - GROUP D

PANEL D SUMMARY

1) THE WORKSHOP WAS A GOOD IDEA - IT SHOULD BE HELD AGAIN.

2) TWO LEVELS OF INTERACTION WERE IDENTIFIED:

A. OVERALL PLANT INFORMATION EXCHANGE
- OVERALL PERFORMANCES
- SCALING, COST-PERFORMANCE EXTRAPOLATIONS

B. DETAILED SPECIAL TOPICS EXCHANGES
- OPERATIONAL "TRICKS"
- MIRROR SOILING/WASHING EXPERIENCES
- START-UP/SHUTDOWN TECHNIQUES
- LEAKS
- THERMAL LOSSES - CONVECTIVE LOSSES
- LIGHTNING PROTECTION
- MEASURING TECHNIQUES
- COST ANALYSIS

3) IMPACTS AND IMPLICATIONS:
- 2 (A) ABOVE WOULD BE MAJOR MEETING, PROBABLY REQUIRING SOME SORT OF "OFFICIAL" ORGANIZATION. MAJOR TECHNOLOGIES ISSUES WOULD BE DISCUSSED.
- 2 (B) WOULD BE MORE INFORMAL. SHORT TERM PROBLEMS/SOLUTIONS WOULD BE EXCHANGED. EMPHASIS WOULD BE UPON SOLVING AND SHARING PROBLEMS AND SUCCESSES AT EACH FACILITY. COOPERATIVE EFFORTS ARE DESIRED TO REDUCE DUPLICATION OF ERRORS.

VUGRAPH IV - GROUP D (CONT'D)

4) ESTABLISH COMPARISON STANDARDS - URGENT -
   A. MAIN SPECIFICATION STANDARDS
   B. PERFORMANCE AND ECONOMIC DATA OF ALL PROJECTS SHOULD BE GATHERED IN A STANDARDIZED FORM
   C. METEO DATA AND SITE SELECTION CRITERIA

5) ESTABLISH INSTRUMENTATION STANDARDS
   A. REFLECTIVITY
   B. INSOLATION
   C. OTHER

6) ORGANIZE A CATALOGUE FOR DIFFUSION OF INFORMATION
   - PUBLICATIONS
   - AVAILABLE COMPUTER CODES
   - EVENTS, EVOLUTION OF PROJECTS

A MAILING LIST OF PEOPLE INTERESTED IN EACH PROJECT SHOULD BE ESTABLISHED.

7) TASKS 4, 5, 6 ABOVE COULD BE CARRIED OUT BY A PERMANENT GROUP OF EVALUATION (MAYBE ON THE BASIS OF PANEL D)
   - ALREADY VOLUNTEERS FOR TASK 4B, TASK 6

EXCHANGE OF INFORMATION

PANEL DISCUSSION: WAYS TO IMPROVE EXCHANGE OF INFORMATION ON SOLAR CENTRAL RECEIVER SYSTEMS

Lars Astrand, Chairman

The panel on Ways to Improve Exchange of Information on Solar Central Receiver Systems consisted of G. Braun (U.S. DOE), C. Etievant (CNRS), J. Gretz (Commission of European Communities), J. Winter (DFVLR), N. Ikeda (NEDO), and C. Ortiz (CEE). Lars Astrand served as chairman.

Before the discussion began, a letter from G. R. Bishop (Joint Research Centre, Ispra Establishment, Commission of the European Communities) to A. Skinrood (SNLL) was read. A copy of this letter, which invites the participants of the workshop to a second workshop in 1983-84, follows this summary.

The panel members congratulated the organizers and participants of the workshop on a successful meeting. The offer for a second meeting was welcomed; a second meeting could be very productive, since more operating experiences would be available in another year or two.

Individual remarks included:

--A desire to establish a framework for the interchange of information. To be successful, the exchange must be organized; the people who request the information should receive it as efficiently as possible. Perhaps at the next workshop, information exchange could be discusssed. (Panel D might also be able to continue its work before the next meeting, thereby assisting this effort.) As regards data exchange, a simple suggestion was to send data to colleagues as the data develop. In the process, some standardization of reporting should occur.

--Exchange of people. Specialists might be exchanged between projects for three to six months. Difficulties with this suggestions exist, but they should try to be resolved in the spirit of mutual cooperation. Specification of the required "give" and "take" for each party might build each other's confidence and trust in such an arrangement. Perhaps the utilities could address this issue and assert some leadership.

--Appreciation for the open atmosphere of the workshop. This spirit allowed for discussion of failures, mistakes, and drawbacks as well as successes.

--Increased awareness of the degree of mistakes in nonsolar-type technology. Quality assurance plays an important role not only in new technologies, but also in conventional technologies that are being adapted for solar power plants.

--The character of the second international workshop. The next workshop should not repeat the information presented at the first meeting, but should look at the future of solar technologies (including solar fuels and chemicals). Exploration of items that are not yet related to existing solar technology but may soon be (i.e., a new generation of solar applications) is suggested. However, the workshop should also include reports on the operational activities of the different projects, especially operation and maintenance experience. Presentation of results from the various projects can be fruitful for everyone.

A workshop is, by definition, a place where people work. In this sense, this workshop was a success. It was gratifying that so many qualified experts came and contributed material. That the workshop was judged useful was reflected in the general agreement that a second workshop should be held. One reason for the workshop's success was the candid reports made by the contributors.

The initiative for the workshop was taken by the U.S. Department of Energy. Their efforts are appreciated, as are those of Sandia National Laboratories for organizing the meeting. The meeting was adjourned with the hope of reconvening in Ispra in 1984.

Commission of the European Communities

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The Director of the Establishment

Ispra, 8th October 1982
JG/IBC
10/426/82

Dr. A.C. Skinrood
Chairman of the "International
Workshop on the Design, Construction
and Operation of Solar Central Receiver
Projects"
Sandia National Laboratories
Solar Central Receiver Department
LIVERMORE, 94550 Calif.

Dear Dr. Skinrood,

The Commission of the European Communities would be glad to invite the parties participating in the First International Workshop on the Design, Construction and Operation of Solar Central Receiver Projects to the Second Workshop on the same subject in 1983-84.

Most of the World's First Solar Central Receiver Power Plants represented at the First Workshop in California in 1982 are operating for about one year or less, and the special interest of this Workshop is the dissemination of initial information on this new technology in the field of power generation. A Second Workshop in one or two years time is to amplify and complete information on the experience with solar power plants which by then will see first improvements on components and modes of operation.

As location for the Second Workshop we propose the site of the Joint Research Centre (JRC) at ISPRA in the Province of Varese (~ 60 Km from Milano) where adequate infrastructure to hosting such a Workshop is available. The ISPRA car service would offer free and individual transport from the airport Milan to ISPRA.

./.

After the Workshop a visiting tour to some or all of the European Solar Power Plants can be organised. From Milan there are direct flights (~ 2 hours) to Catania (EURELIOS, Italy); a flight connection to Almeria, via Madrid or Barcelona (IEA-ALMERIA, CESA-1, Spain) and flights to Marseille or Perpignan from where to proceed to Targassone (THEMIS, France).

This invitation is made in agreement with Dr. A.STRUB, Director of the Directorate E, Commission of the European Communities, Directorate General XII, Science, Research and Development, Bruxelles.

The exact date of the Second Workshop is proposed to be worked out together and in common agreement at the forthcoming Workshop in California.

Yours sincerely,

G.R. Bishop

G.R. BISHOP

Copy: Dr. A. STRUB
Mr. J. GRETZ

ATTENDEES

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