PLATAFORMA SOLAR DE ALMERÍA

ANNUAL TECHNICAL REPORT
1998

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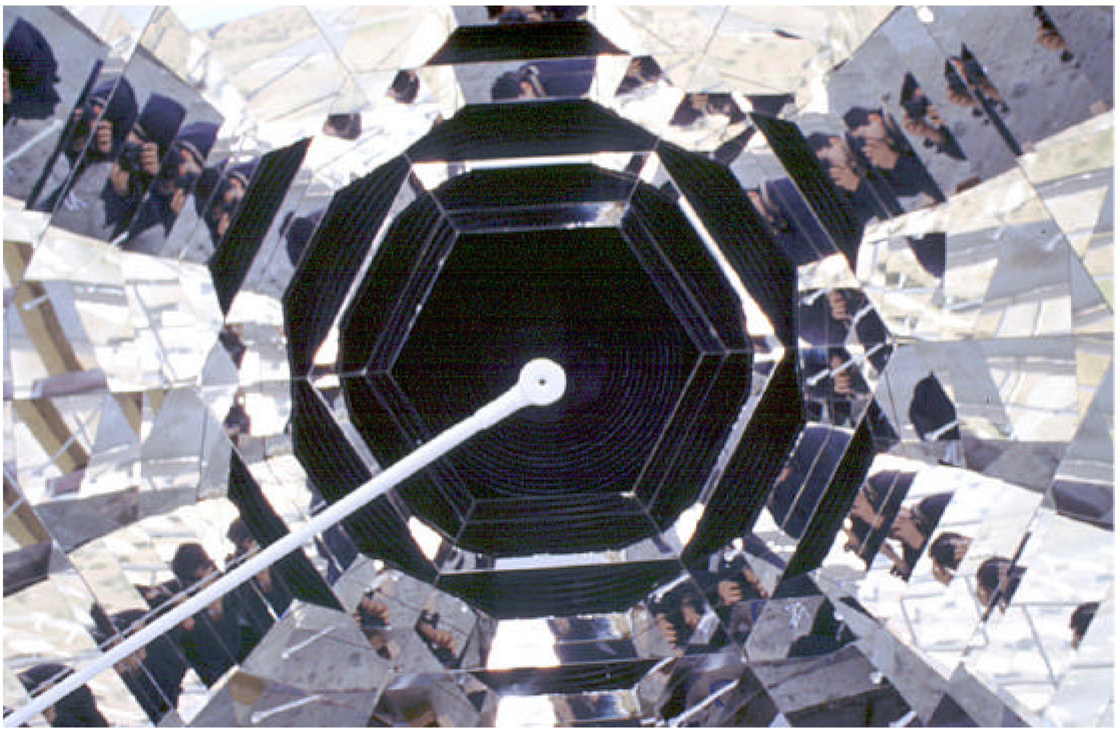

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ANNUAL TECHNICAL REPORT
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Prepared by

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
Instituto de Energías Renovables
Plataforme Solar de Almería
Apartado 22, E-04200 Tabernas (Almería), Spain

Deutsches Zentrum für Luft- und Raumfahrt e.V.
Plataforma Solar de Almería
Apartado 649, E-04080 Almería, Spain

Edited by
Manuel Blanco Muriel

With the collaboration of
Deborah Fuldauer

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1 Overview

1.1 Introduction

As in previous years, this document reports the diverse activities carried out at the CIEMAT's Plataforma Solar de Almería in its field of research, concentrating solar technologies and the chemical applications of solar energy.

M. Blanco

M. Geyer

Two circumstances in 1998 made it one of the most uniquely complicated years since 1987, when this research center began to operate under the Cooperation Agreement between CIEMAT and DLR for long-range utilization of the Plataforma Solar de Almería, traditionally known as the CHA. These were:

The withdrawal of DLR from Annex 1 of the CHA and the approval in Spain of ROYAL DECREE 2818/1998, of December 23, 1998, on production of electricity by facilities powered by renewable energy resources or sources, waste or cogeneration.

The withdrawal of DLR from Annex 1 of the CHA, meaning decreased commitment to these technologies by Germany, one of the countries which together with the United States, Israel and Spain has contributed the most to the development of solar thermal technologies in the last ten years, was not good news for the PSA, nor for the Solar Thermal Community in general. Furthermore, it has meant the need for in-depth restructuring of the PSA, renegotiation of the framework of collaboration between CIEMAT and DLR as established in the CHA, substituting Annex 1 (called Annex 3) and a search for sources of financing to limit or buffer the impact of DLR's decreased economic contribution to the PSA basic budget.

The approval by Spain of Royal Decree 2818/1998, which assigns a premium of more than 30 PTA per solar kWh produced, even though it is not yet clear whether this is applicable to solar thermal electricity, has stimulated solar thermal activities and projects in Spain. Based on this possibility, several industrial consortia have begun to form and take positions in promoting the installation of commercial solar thermal plants in Spain. This initiation of pre-commercial activities in Spain has tended to have its repercussion on the activities at the PSA, which has multiplied its contacts and collaboration with industry, and this, in turn, without doubt, will give rise to increased activity in years to come.

This report is divided into four chapters and four annexes, which describe the activities carried out at the PSA in 1998 in each of its fundamental areas of activity.

The first chapter, PSA Overview, provides general information on the organizational structure of the PSA, its infrastructure and resources.

The second chapter, Research activities, runs through the various PSA research projects carried out in 1998, with special emphasis on the results and advances made in each.

The third chapter, Training and International Cooperation, describes the main activities and success in this field, so vital to a center like the PSA that aspires to international excellence.

Finally, the fourth chapter, Support Services, is devoted to the departments that provide technical support for the research projects, Operation and Maintenance, and Engineering.

1.2 Spanish-German Cooperation after 1998

From 1986 to December 31, 1998, the PSA was jointly operated and financed by the Spanish Ministry of Industry and Energy's "Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas" (CIEMAT) and by the German "Deutsches Zentrum für Luft- und Raumfahrt e.V." (DLR), based on the *"Cooperation Agreement in the Field of Solar Thermal Research, Especially of the Long Term Utilization of the PSA"(CHA).* The Annex I to this agreement provided for 50:50 cost sharing of income and management responsibilities. The annual basic budget and joint plan of work was decided and approved by the PSA Steering Committee.

In December 1997, the German Ministerium für Bildung und Forschung (BMBF) instructed DLR to cancel Annex I of the CHA as of December 31, 1999. In Spring, 1998, the BMBF agreed with CIEMAT to complete only the approved EC DISS, EuroTROUGH and EuroDISH projects and to orient continued CIEMAT and DLR collaboration by project. As a result, the new project-oriented-cooperation Annex 3 was signed by CIEMAT and DLR based on the following principles:

- CIEMAT and DLR shall extend their long years of fruitful collaboration at the PSA in the field of solar thermal technologies beyond 1998.

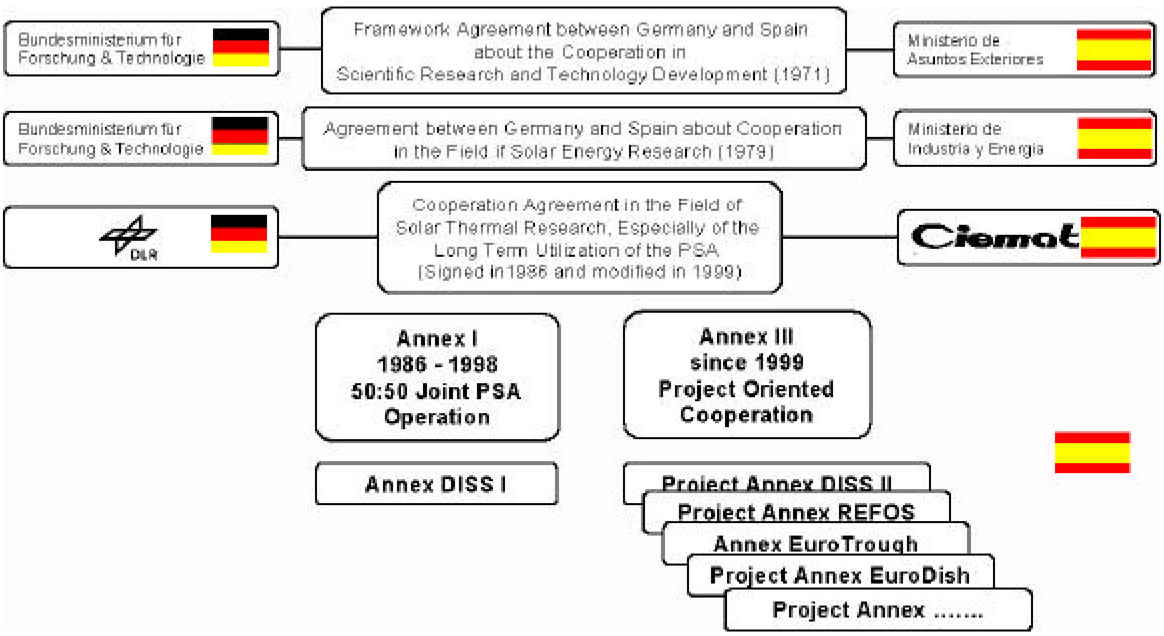


Fig. 1.1 The Transition from 50:50 Joint PSA Operation to Project Oriented Cooperation between Ciemat and DLR

- After cancellation of Annex I to the Cooperation Agreement between CIEMAT and DLR on the Field of Solar Thermal Research (CHA) effective December 31, 1998, CIEMAT shall take over complete responsibility for the management, administration and operation of the PSA.
- DLR may maintain a permanent delegation at the PSA. The number and composition of such delegation shall be negotiated with CIEMAT on the basis of the DLR workload and task schedules associated with the fulfillment of its obligations in the execution of PSA-related CIEMAT-DLR joint programs and projects, DLR's direct financial contribution to the PSA, and the availability of office space.
- CIEMAT wishes to continue with this DLR delegation, in all currently signed joint projects and in any joint project which may be acquired together in future, in the same vein of their past cooperation. The highest priority is given to continuing project-related cooperation between the colleagues of DLR and CIEMAT at the PSA in a trustful and non-competitive working climate.

Therefore, after cancellation of Annex I of the Cooperation Agreement between CIEMAT and DLR in the Field of Solar Thermal Research (CHA) by the German Government on December 31, 1998, CIEMAT took over complete responsibility for the management, administration and operation of the PSA. A new PSA Steering Committee was constituted to supervise issues of cooperation between CIEMAT and DLR at the PSA. Project-oriented cooperation started with the joint EuroTrough, EuroDish, DISS Phase II and HYPIRE projects in a way consistent with the conditions specified in the corresponding contracts signed with the European Commission by CIEMAT and DLR among others.

1.3 Organization

As a consequence of CIEMAT taking over complete responsibility for the management, administration and operation of the PSA, its mission and general objectives have been slightly revised and its organizational structure completely modified. In addition to maintaining its status as the largest and most important European test facility in the field of solar concentrating technologies, more emphasis is being placed on the research and scientific aspects of PSA activities.

CIEMAT is committed to transforming the PSA into an international center of excellence for research, technological development, demonstration and technology transfer in the fields of solar concentration, solar thermal and solar chemistry. Starting January 1st, 1999, it has established the following general goals for the PSA:

- Promote and participate in the technological development of systems, subsystems and components for solar energy and chemistry.
- Promote commercial applications and demonstration projects.

- Generate and transfer knowledge.
- Perform market analysis prospective technological studies.
- Promote the diffusion of the potential of concentrating solar energy and facilitate training of experts.

To achieve these goals, all PSA activities have been grouped and organized into four large research projects:

Training and Access at the Plataforma Solar de Almería

Parabolic-Trough Technology

Chemical Applications of Solar Radiation

Central Receiver Technology

The first project deals with all activities related to training and services to the international scientific community. The second has its nucleus in the DISS Project and, thereby, in the technical and economic development, study and evaluation of direct steam generation in parabolic troughs. The third is articulated around the development of detoxification of both liquid and gas-phase industrial effluents. Finally, the fourth centers on the development of cheaper and more reliable components for the central receiver technology, basically, new heliostats and receivers.

In addition to these Projects, the Area of Management includes the Director and the Director's Office, the Administration Unit (UA), Information Services and Documentation and Archive Services and the Maintenance Unit and Technical Office, all of which are at the service of the Projects. All of these activities related to Management of the PSA are grouped under a CIEMAT Project entitled "PSA Management".

Fig. 1.1 shows the PSA organizational structure as of January 1, 1999. The shaded areas are those functional units and services of the PSA assigned to the Area of Management and consequently, to the "PSA Management" Project.

It should be pointed out that the organizational structure is made up only of CIEMAT and contracted personnel. No DLR personnel are included. This segregation of German personnel from the PSA organization and exclusion from the decision-making bodies constitutes one of the fundamental differences from Annex 1 in the new framework of collaboration defined in Annex 3.

The permanent DLR delegation at the PSA, the DLR EN-PS division, since January 1, 1999, has been organized in accordance with the new cooperation scheme in a strictly project-oriented manner. The project structure as of July 1, 1999, is illustrated in Fig. 1.2. showing the cooperative EuroTrough, EuroDish, DISS Phase II, RENIPplan and REFOS projects.

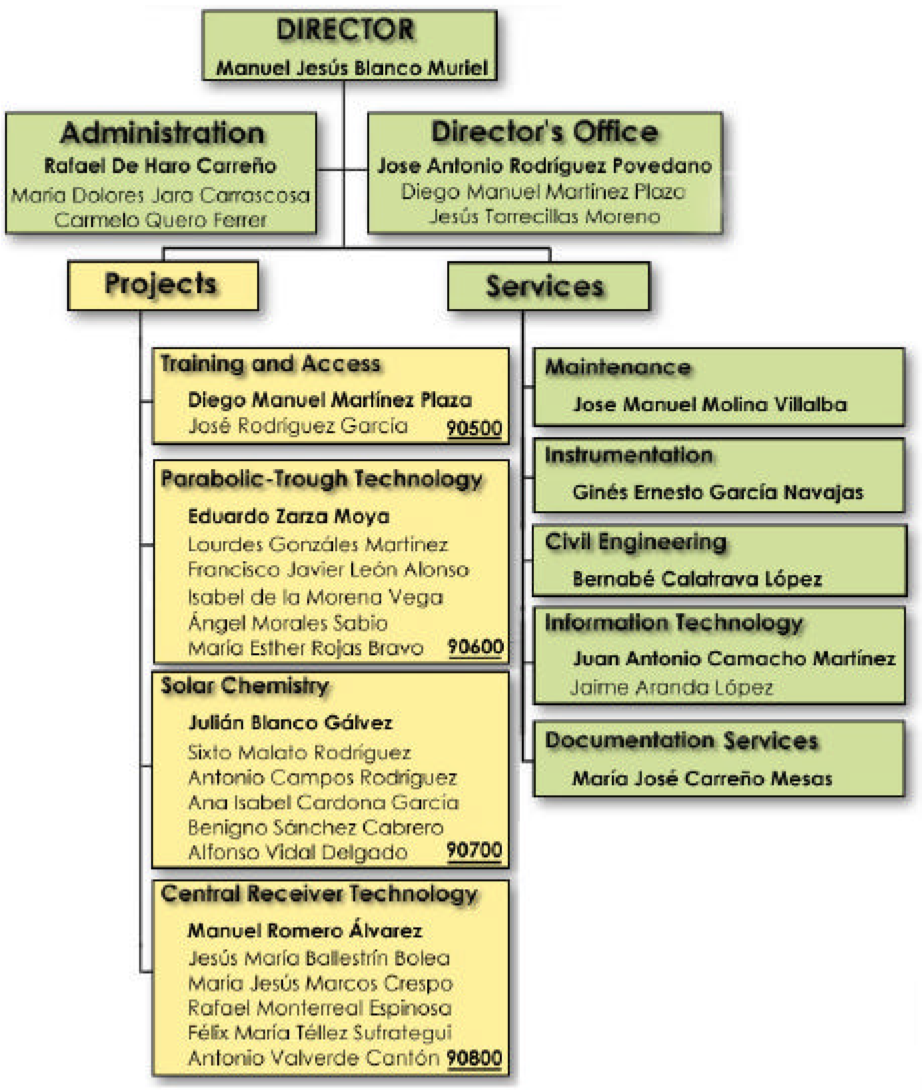


Figura 1.2 Organigrama PSA 1999. En sombra las unidades funcionales y servicios adscritos al Área de Dirección

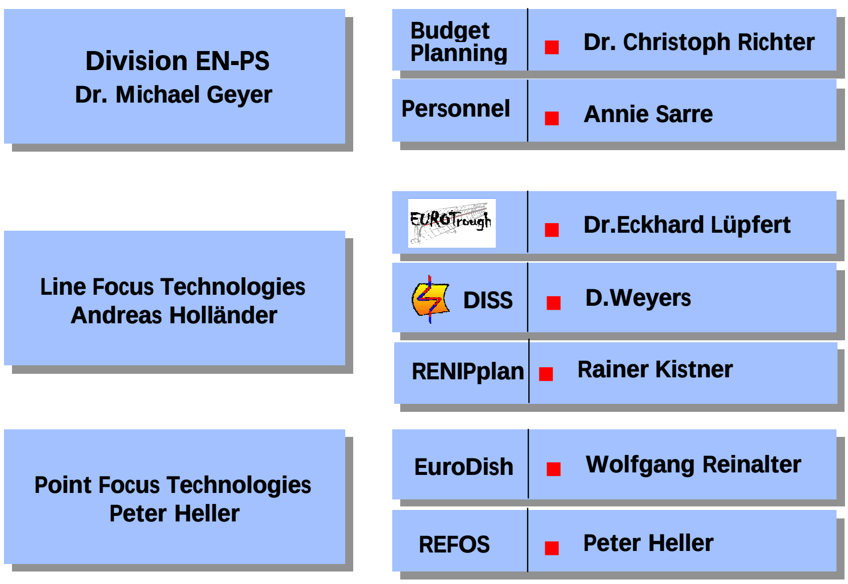


Fig. 1.3 Project oriented organization of DLR's permanent delagation at the PSA as of July 1st, 1999

1.4 The 1998 Budget

The 1998 budget was, from a performance point of view, could hardly have been improved. According to the data gathered and registered in the 1998 audit, by the Arthur Anderson auditors, the deviation of income received from income predicted was only 0.6% (677.7 million PTA income vs. 673.8 foreseen), while the deviation of budgeted expenses from real expenses was only 0.8% (655.4 million PTA spent vs. 650.64 real). Fig. 1.4 shows the development of the CHA Annex 1 budget from 1993 to termination in 1998. It may be observed that the performance of the CHA Annex 1 budget has improved progressively since 1996 as a result of the effort to restructure the PSA Administration Unit and the improvement in the center's procedures and information systems.

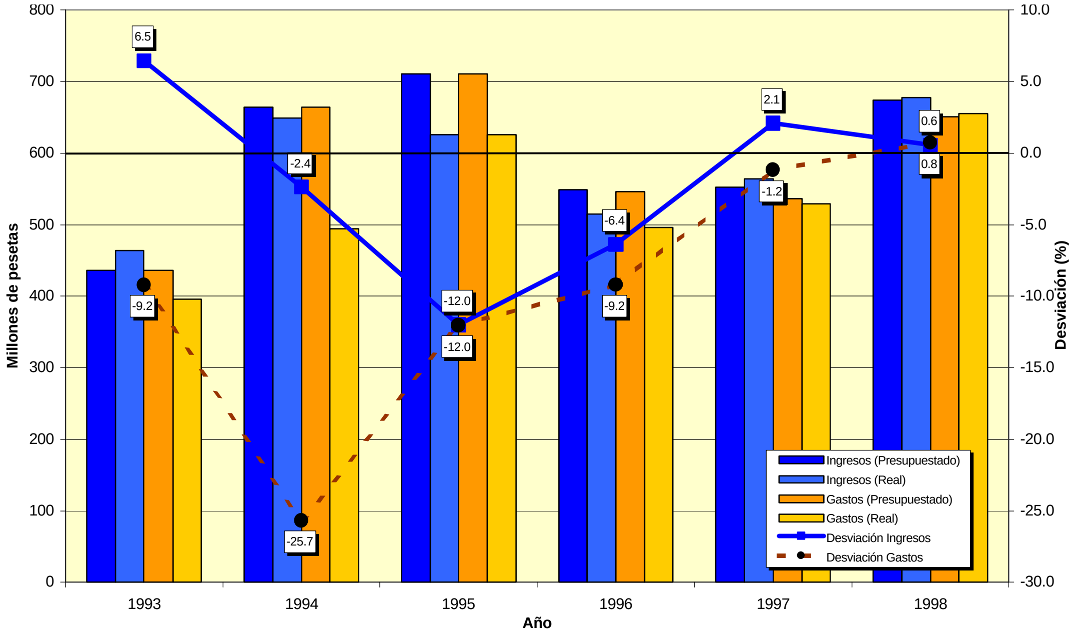


Fig. 1.4 CHA Annex 1 Budget 1993-1998

1.5 The Test Facilities

The PSA test facilities are continuously improving and expanding. The following sections describe the initial purpose, evolution and current capabilities, and technical characteristics of these facilities. Their location is shown in Fig. 1.5.

1.5.1 7 MW_t CESA-I Central Receiver Test Facility

The CESA-I project was developed for the Spanish Ministry of Industry and Energy and inaugurated in May, 1983, to study and demonstrate the viability of this type of plants as well as to develop the specific Central Receiver System technology. At present CESA-I is a test platform for all types of solar tower power plant components and subsystems, such as heliostats, receivers, heat storage, control, etc., as well as those applications that might

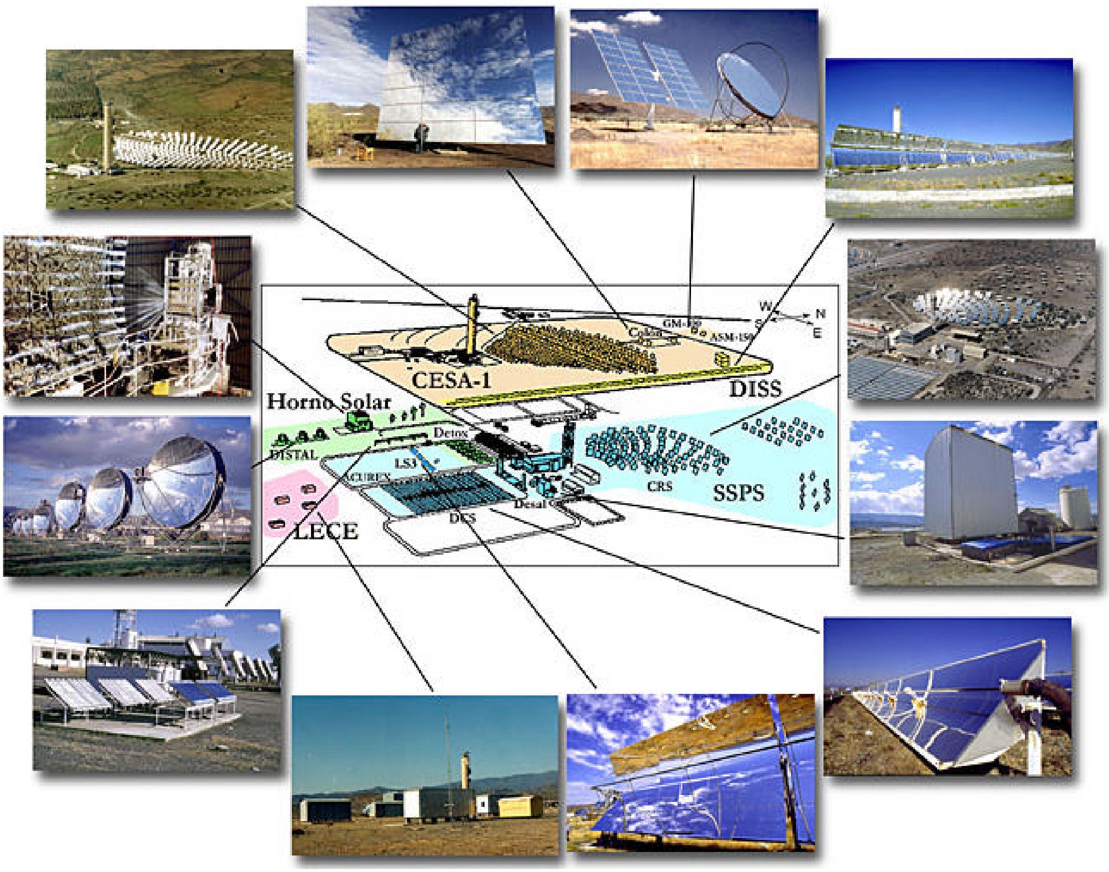


Fig. 1.5 The PSA Facilities

require high photonic concentration onto relatively large surfaces like chemical processes, materials surface treatment or astrophysics experiments. The facility encompasses a north-oriented heliostat field of 300 two-axis-tracking 39.6-m^2 heliostats with an average reflectivity (clean) of 92%, tracking error per axis of 1.2 mrad and beam quality of 3 mrad. The field has two additional test zones prepared for characterization of new heliostat prototypes, one located at 300 m and the other at 500 m North from the center of the tower. Maximum field power onto receiver aperture is 7 MW_{th}. At design point insolation of 950 W.m^{-2} , a peak flux of 3.3 MW.m^{-2} can be achieved. 99% of the power is concentrated within a 4-m-diameter circle and 90% within 2.8 m.

The 80-m high central concrete tower has a capacity of 100 t and provides four testing levels: Solar furnace for materials testing located at the 45-m level, cavity test-bed for housing receivers at the 60-m level, observation platform for astrophysics testing at the 70 m level and a complete 2.5 MW_t volumetric receiver test bed (TSA) including receiver, ceramic checker heat storage and steam generator located over a 10-m-diameter platform on the roof 80 m above ground. For those tests requiring electricity production, the facility provides a 1.2 MW Rankine cycle designed for 520ºC and 100-bar steam, with a double inlet, multistage steam turbine.

The tower has a 5-ton crane at the top and a 1000 kg-capacity elevator for personnel and equipment.

1.5.2 2.7MW$_t$ SSPS-CRS Central Receiver Test Facility

The SSPS-CRS plant, inaugurated as part of the IEA-SSPS (Small Solar Power Systems) project in September, 1981, was originally a 0.5-MW demonstration power plant with liquid sodium as the heat transfer medium. The plant is at present a facility for testing small-scale receivers in the range of 200-350 kW$_t$. The heliostat field is comprised of 93 first-generation individual-tracking 39.3 m^2 units, with 20 second-generation 52 m^2 and 65 m^2 heliostats also available. Their average clean reflectivity is 87%, tracking error 1.2 mrad per axis and beam quality characterized by 3 mrad. At design insolation of 950 W.m^{-2} total field power is 2.7 MWt. 99% of this power is concentrated on the aperture plane within a 2.5-m-diameter circle with a peak flux of 2.5 MW.m^{-2}. 90% power is concentrated within a 1.8-m circle.

The 20-ton capacity structural-steel tower provides two test platforms. The first one, located at 43 m above ground, houses a flexible test bed for small-size volumetric receivers including receiver head structure, heat rejection system and fan. A second experimental platform, occupying both the 32 and 26-m levels, is specially conceived for testing molten salt receivers, including receiver support structure, pump and heat rejection system. A 600-kg-capacity crane on the top of the tower and a 1000-kg-capacity elevator for personnel and equipment are available.

1.5.3 1.2-MW$_t$ SSPS-DCS Parabolic-Trough Test Facility with Storage and Desalination

This facility is composed of three subsystems: a solar collector field, a thermal energy storage system and a Multi-Effect Distillation (MED) desalination plant.

The solar field is a parabolic-trough system made up of 40 first-generation ACUREX 3001 collectors, grouped in 10 East-West-oriented loops with two rows per loop and two collectors per row. Total collector field aperture area is 2 672 m^2 with an average clean mirror reflectivity of 92% and tracking error of less than 0.25º. The operating fluid, Santotherm 55 synthetic thermal oil, flows through the black-chrome-coated collector absorber pipes. The nominal operating temperature is between 180ºC and 295ºC. The maximum oil operating temperature of 295ºC, peak efficiency of 50%, and peak thermal output of 1.3 MWt can be reached at noon with a beam solar radiation of 950 W/m^2. The average daily thermal energy delivered by the collector field is about 6.5 MWth.

The thermal energy storage system consists of a 114-m^3 thermocline tank containing 100 m^3 of Santotherm 55 synthetic thermal oil inertized with nitrogen. The approximately 5-MWht storage capacity is charged and discharged at oil temperatures of 295ºC and 225ºC, respectively. A water-refrigerated oil cooler is connected to the thermocline tank so that the oil can be cooled down quickly if the tests to be performed at the facility so demand.

The MED desalination plant is a 14-stage seawater distillation plant connected to the collector field thermal storage system described above. The plant consumes 190 kWt to produce a nominal 3 m^3/h of distillate, with a performance ratio (e.g., number of kg of distillate produced per 2 300 kJ heat input) of 9. The output salinity is of 50 ppm total dissolved solids. The nominal temperature gradient between the first and last stage is 40ºC, with a working temperature of 70ºC at the first stage. The vacuum system of this plant is driven by two hydro-ejectors. A 200-kWt double-effect BrLi absorption heat pump is also available at this facility, though this device has not been used in recent years.

Coupling of this heat pump unit to the MED plant increases the Performance Ratio of the plant up to 20 by recovering the waste heat rejected at the condenser of the plant when it works alone.

1.5.4 175 kW_t LS-3 Test Facility

The LS-3 Test Facility was designed and implemented at the PSA during Phase 1 of the DISS project as a test stand to evaluate new components (e.g., new mirrors, new absorber pipes, new sun-tracking systems, etc.) for parabolic-trough collectors under real solar conditions.

The facility consists of half an LS-3 collector (only four 12-meter parabolic trough modules instead of eight) as installed in the latest SEGS plants, with the same mirrors, structures and heat collecting elements (absorbers), but having also a pressurized oil tank, oil cooler, oil pump and electric oil heater. The oil loop contains 1000 liters of Dow Chemical Syltherm 800 synthetic oil operating at a maximum temperature of 420ºC. Due to the lower freezing point and specific heat capacity of this oil compared to the Monsanto VP1 oil used in the commercial SEGS plants, system freeze-protection requirements are eliminated. Nominal operating pressure and thermal power output are 18 bar and 175 kW_t, respectivley. The collector tracking axis is oriented East-West to allow testing without cosine or end-losses at noon, and investigation of the influence of different incident angles during the course of the day. The oil cooler (225-kW maximum cooling power) is used to control the oil temperature at the collector inlet, while a centrifugal/magnetic pump controls the oil flow through the system. The electric oil heater (40 kW, 3 x 400 V) at the collector inlet compensates heat losses in the oil loop during certain tests and provides temperature stepping at the collector inlet. A variable-speed fan in the oil cooler controls the cooling power.

1.5.5 1.8 MW_t DISS Test Facility

The full-size DISS Test Facility, implemented at the PSA during Phase 1 of the DISS project, will be used during the second phase of the project to investigate technical questions regarding the

DSG (Direct Steam Generation) process in parabolic trough collectors under real solar conditions. This facility has two subsystems: the solar field and the Balance of Plant (BOP).

The solar field consists of 40 parabolic-trough modules grouped into 11 collectors, which are connected in series in a 550-meter-long North-South-oriented row erected on land with an 0.8º North-South slope. Module aperture is 5.76 m wide by 12 m long. The row is divided into two sections: the evaporating section (the first eight collectors) and the steam superheating section (the last three collectors). Collector tracking axis in the evaporating section can be either horizontal or tilted either 2 or 4º, while collector number nine (the so-called "special test collector" can adopt five different positions: 0º, 2º, 4º, 6º or 8º. This collector will be used to investigate the influence of tilt on two-phase flow parameters. The solar field is provided with water injectors and a water recirculation loop, which together with a water/steam separator allow the system to work in the three basic DSG processes (e.g., Once-through, Injection and Recirculation). Though the solar field was designed for maximum field outlet steam conditions of 400ºC and 100bar, it can also produce superheated steam at 30 and 60 bar. In the once-through process, the nominal water flow is 1 kg/s, while in recirculation, 4 kg/s is possible.

In the BOP, the superheated steam produced by the solar field is condensed and converted into feed water that is pumped back to the field inlet and the water injection system. This allows closed-loop facility operation, thus saving water and energy.

1.5.6 3x 40 kW$_t$ DISTAL I Dish/Stirling Systems

The DISTAL I facility consists of three single-tracking polar-mounted parabolic dishes. Each dish consists of a 7.5-m-diameter, single-facet stretched-membrane concentrator with an average reflectivity of (clean) 94%. Local concentration factors of more than 12,000 have been measured in the focal plane. 90% of the power is concentrated within a 12-cm diameter. A SOLO V160 Stirling engine with a directly illuminated solar tube receiver is attached at a focal length of 4.5 m.

1.5.7 3x50 kW$_t$ DISTAL II Dish/Stirling Systems

The DISTAL II facility demonstrates state-of-the-art dish/Stirling system design. Its enlarged 8.5-m-diameter single-facet stretched membrane concentrator tracks the sun using an azimuth-elevation drive system which allows fully automatic sunrise-to-sunset operation. Due to the enlarged mirror and the reduced focal length of 4.1 m, peak concentrations of about 16,000 suns in the focal plane have been demonstrated. The power conversion unit in the focal point is a reworked SOLO 161 Stirling engine. The facility is also equipped with a propane-gas supply system and tank for hybrid receiver tests. Both facilities can be seen in Fig. 2.3.3.

1.5.8 60-KW$_t$ High-Flux Solar Furnace

Four plane non-concentring 53,61-m^2 heliostats reflect the collimated rays of the sun onto the parabolic dish concentrator, which in turn concentrates the incoming light on the focus, 7.45 m in front of the concentrator.

Each heliostat is composed of 16 facets with 90% reflectivity; the total reflecting area for the whole heliostat field is 214.44 m^2. The concentrator is made up of 89 0.91-m-x-1.21-m sandwich facets with 92% reflectivity and the reflective surface area is 98.5 m^2, which produces 60 kW total power and a black-body temperature of 2500ºK at the center of the 120-mm focal spot. Concentration of sunlight is regulated by a 11.44m-x-11.20 m louvered shutter with 30 slats, placed between the heliostats and the concentrator. The movement of the slats is controlled by a stepping motor capable of setting the shutter to 15,800 positions between 0º (open) and 55º (closed), bringing angle accuracy to 0.00346º and accuracy of flux regulation to $8.01*10^{-5}$ and $4.94*10^{-5}$ respectively. The experiments are mounted on a 0.7-m-x-0.6-m test table movable on three axes with displacement paths of x = 0.85 m, Y = 0.60 m (along the optical axis) and z = 0.45 m.

1.5.9 Solar Detox Facility

The PSA photochemical facility has been extensively used by scientists from many countries. This facility is made up of different solar collector fields that use the radiation for chemical reactions, and the tanks, pumps and sensors are required for on-line management of the chemical reactions.

- The largest field (erected in 1991) consists of 4 two-axis solar-tracking collectors, which were modified for solar chemical applications; they have a concentration factor of 10.5 suns and 58% energetic efficiency in the UV solar spectrum. The collector aperture plane is always perpendicular to the solar rays, which are reflected by four parabolas onto the borosilicate-glass tubes at the focus of each trough, where the contaminated water to be detoxified circulates and where the reaction takes place. The nominal aperture area of each module is 32 m^2, implying a 128 m^2 total effective loop aperture area. The total volume is up to 1000 L.
- The second field (installed in 1994) is similar to the one above, but with non-concentrating compound parabolic collectors (CPCs) and only 8.9 m^2 of total aperture area. Recent developments in solar photocatalytic design have demonstrated that non-concentrating reactors, such as these CPCs, are more efficient than the first concentrating reactors were since they employ both direct and diffuse components of ultraviolet sunlight and they can be easily transported and installed in situ at the point of treatment. The total volume of the PSA CPC field is up to 250 L.
- The most recent field (installed in 1998) consists of twin 3-m^2 CPC reactors, each having three 8-tube modules. The total volume is up to 2 x 40 L. The most important characteristic of this system is that it is possible to run chemical processes un-

der artificial atmospheres by pressurized gas injection and/or to two different tests under exactly the same experimental conditions.

- A smaller CPC system (2 m^2) with an irradiated volume of 10 L (total volume 20 L) was designed for photochemical synthesis (installed, 1996), but could be used for other applications. The most important characteristic of this system is that it is possible to run chemical processes at ambient temperature using a high-power cooling system.

For the required evaluation of experiments carried out in the PSA photochemical reactors, the PSA has a laboratory specialized in waste-water analysis. The most important analytical tools available are Liquid Chromatography (HPLC-UV), Gas Chromatography (GC-FID/ECD), Ionic Chromatography (Anionic), TOC, COD, BOD and UV-Visible Spectrophotometry.

1.6 Milestone Achievements 1998

- Startup of EuroTrough Project.
- REFOS Receiver Module operation.
- Completion of the DISS test loop mechanical assembly and hydraulic pressure tests carried out successfully in November
- Signature of the EC DISS Phase-II contract followed by kick-off meeting on December 1st at the PSA.
- First gold cermet for selective absorber-pipe coating at 500°C obtained.
- Signature of PSA-University of Almería-DLR agreement for five doctoral grants and seven training grants at the PSA.
- TMR mid-term review in which the PSA received high ratings for the number of access proposals, selection process, publication of access and workshops and summer school.
- TMR Summer School in two sessions, Solar Thermal Electricity Generation from July 13th to 17th and Industrial Applications of Solar Chemistry from September 21st to 25th.
- 2nd General Users Workshop on November 10th and 11th.
- Completion of detailed engineering design of the solar part of the COLON SOLAR plant and elaboration of the corresponding final report for the European Commission.
- In the first three months of 1998, the COLON heliostat prototype testing and evaluation program was completed. Evaluation by CIEMAT at the PSA qualified the heliostat which complied with the initial specifications (σ = 2.6 mrad).
- Operational testing of the REFOS pressurized volumetric receiver in October, 1998.
- Finalization of engineering of first stand-alone heliostat communicated by radio and powered by photovoltaic panel in collaboration with the University of Almería.

1.7 PSA Education, Training and Scientific Cooperation

Most **Training Activities** in 1998 were carried out by contract under the EC-DGXII 'Training & Mobility of Researchers Program' (TMR), the modified continuation of the 'Human Capital and Mobility' program (HCM). Its aim is to promote, through the stimulation of training and mobility of European researchers, a qualitative and quantitative increase in human resources for research within the Community and its Associated States (Iceland, Lichtenstein, Norway and Israel).

During 1998, more than 50 scientists from 28 European universities and industries were able to carry out their research projects at the PSA facilities through this activity. The results of their research have been published in numerous scientific journals and congresses. At the second annual Users Workshop on November 10th and 11th, all the groups were able to present their results in three parallel sessions, the proceedings of which were published by CIEMAT in its Conference Series (See List of Publications).

Among this year's milestones was the European Commission's Mid-Term Review of program progress so that any measures necessary to improve it could be taken. The panel of independent experts recruited to carry out this task gave the PSA very good reviews, particularly stressing the large number of access proposals received and the very good selection process, the considerable effort made to publicize access in the scientific community and the additional stimulating intellectual environment provided by the organization of several workshops and a summer school.

Though this was the last year of the TMR contract, such good results have encouraged us to apply for the new Fifth Framework edition of the TMR.

Educational Activities in cooperation with the University of Almería (UAL) continued to be fruitful and were extended to joint organization of doctoral courses in renewable energies, including five grants for doctoral theses. After publication of the grants in the Official Bulletin of the government of Andalusia (BOJA), candidates were selected by a committee composed of University and PSA staff members. In addition to the five doctoral grants, seven training grants lasting from a minimum of 6 months to a maximum of one year were assigned. A PSA investment of 12 860 000 PTA plus a UAL contribution of 1 000 000 PTA financed total of 129 months of student time.

Furthermore, the PSA student program has been considerably increased by participation in the EC Leonardo program through agreements, mainly with German 'Leonardo de Vinci' offices, that have enabled 21 more students to come from Germany and France. The total 'Leonardo' student time of 94 months cost 1 880 000 PTAs.

Concerning **International Scientific Cooperation**, the PSA has been actively engaged in the International Energy Agency (IEA) SolarPACES Implementing Agreement program since its origin with the signing of an agreement for the "Small Solar Power Systems" (SSPS) Project by Austria, Belgium, Germany, Great Britain, Greece, Italy, Spain, Sweden, Switzerland and the USA on the PSA grounds in 1977. After successful review of the SPSS Project by an IEA Renewable Energy Working Party (REWP) in 1990, several of the member countries went on to continue solar thermal R&D cooperation in a new stage of the project, which then became SolarPACES - Solar Power and Chemical Energy Systems. There are currently 12 member countries in SolarPACES (April, 1998): Australia, Brazil, Egypt, France, Germany, Israel, Mexico, Russia, Spain, Switzerland, United Kingdom and United States. The PSA actively participates in all three tasks of the SolarPACES program:

Task I, Solar thermal electric power systems

Task II, Solar Chemistry Research and

Task III, Solar Technologies and Applications

Under SolarPACES, the PSA leads the so-called START (Solar Thermal Analysis, Review and Training) Missions. The goal of these Missions is to help nations in the sunbelt regions develop a rational approach to the deployment of solar thermal electric systems within their country. The PSA has successfully contributed to START missions in Egypt, Jordan and Brazil.

Based on a Memorandum of Understanding between The World Bank and SolarPACES, PSA solar thermal expertise has also been put into service in Worldbank renewable energy reconnaissance missions.

2 Research Activities

2.1 *Low Temperature Applications*

María José Jiménez
Area Head

Juan de Diós Guzmán

Knowledge of the energy behavior of building components is the key to good building design. New legislation in EU countries (Construction Elements Directives 89/106/CEE and SAVE 93/76/CEE) and popular awareness are setting new energy quality standards for the construction sector. Also, new passive design solutions are being used as alternatives to traditional fuel consumption. At the Plataforma Solar, the Area of Low Temperature's LECE laboratory offers the building sector and research centers working in this field the opportunity to test both already existing components and new innovative designs.

2.1.1 The LECE

The LECE (**L**aboratorio de ensayos **E**nergéticos para **C**omponentes de **E**dificación) on the south side of the PSA, forms part of the European PASLINK network of laboratories for energy testing of buildings components. It consists of four test cells with complete instrumentation for testing of the thermal performance of building conventional and passive components under real outdoor conditions (See Fig. 2.1.1) The LECE carries out its experiments as part of a continuous action of the CIEMAT Solar Energy Buildings R&D Group.

The purpose of the LECE facility is to contribute to knowledge on the energy quality of building elements by carrying out experiments to determine thermal properties, such as the overall thermal loss coefficient (UA), solar gain factor (gA), or system time response (τ). Knowledge of these properties can be employed to optimize building design for energy saving without loss of comfort and to predict the thermal behavior of the

Fig.2.1.1 *Overview of a PASSYS Test Cell and control room.*

building. This is a very important feature if you consider that 40% of the energy used in European countries is used for heating, cooling, lighting, etc.

The activities that are being carried out in the LECE can be classified in the following lines of work:

- Experimental support of specifications in rulings and regulation.
- Experimental activities of the CIEMAT Solar Energy Building project.
- Collaboration with the manufacturers of building materials and components.

And its main tasks are the following:

- Accreditation for energy certification of building components. Implementation of a quality system. The LECE is being prepared to join the ENAC (Spanish accreditation institution).
- Experimental testing of natural cooling techniques using vegetation, evaporative roofs and ventilation.
- Test and thermal characterization of vertical and horizontal building components in collaboration with construction product manufacturers. Active solar components, testing and thermal characterization.
- Testing methodologies for thermal characterization in component development and improvement.

2.1.2 Infrastructure

The Laboratory owns four test cells of approximately the same size as a standard room, which are well insulated by 40-cm-thick polystyrene walls. The opposite wall to the service room and the roof are interchangeable with a test specimen.

One of the test cells is provided with a rotating platform, giving experiments new richness, since orientation with respect to the sun can easily be changed.

An additional instrument in the lab is the Solar Transmittance Sensor (STS). This device contributes to the laboratory's capability

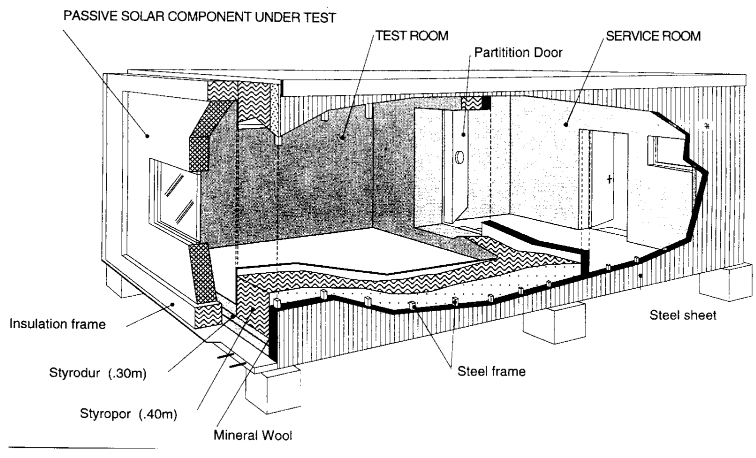


Fig 2.1.2: Global view of a PASSYS test cell

to calculate the energy and light transmittance of non-homogeneous translucid construction components. At the moment, the STS sensor is a pyranometer, so the only measurable variable is total transmittance. Nevertheless, it can be used with a portable spectrometer, which would enable calculation of spectral transmissivity.

2.1.3 Ongoing Projects

The laboratory participated in the following projects in 1998:

2.1.3.1 Projects within the U.E. DG XII JOULE program.

PV-HYBRID-PAS:

The PV-HYBRID-PAS is a Joule project in which the PSA participated as one of the European Laboratories that belong to the PASLINK network. Development of procedures for testing and thermal characterization of photovoltaic components and their application for the characterization of commercial components, for their comparative study, were the general objectives of this project.

PSA tasks consisted of the testing and thermal characterization of *one commercial opaque amorphous photovoltaic component*.

During 1998, installations of sensors and photovoltaic components was completed. Modifications to the data acquisition system were made to store the required data set. The analysis of test data and final reports were also completed.

Fig. 2.1.3: Photovoltaic modules being tested in the PASSYS II test cell.

APISCO (Application of plants for the thermal quality improvement in buildings):

The overall objective of this project in which the CIEMAT Solar Energy in Buildings Team participated was to quantify the thermal and shading effects of vegetation-based techniques in housing and urban planning.

The LECE facility was used for performing tests and characterization of different types of vegetation on the vertical wall of the CESPA -I test cell during the summer. The aim of the tests was to provide data to validate a model of plant thermal and shading effects.

In 1998, experiment design, sensors, data acquisition system and improvements in the infrastructure to enable the test cell and its surroundings to grow the selected plant were implemented. A second test was carried out during the summer, applying the knowledge acquired the year before in this type of experiment.

Fig. 2.1.4 APISCO project experimental setup in a CESPA test cell.

ROOFSOL (Roof Solutions for Natural Cooling):

The overall objectives of this project in which the CIEMAT Solar Energy in Buildings Team also participated were:

- Produce design information, in which energy performance indices accompany a classification of roof solutions and components feasible for the Mediterranean area.
- Provide valuable real scale examples of roof components together with an in-depth analysis on performance and on its potential for saving energy in a diversity of Mediterranean climates.

Within the framework of this project, the LECE was used to perform a relevant part of the experimental task consisting of the installation and thermal testing of *different configurations of an evaporative roof* used as a cooling system by means of semi-passive techniques. The component tested consisted of a roof pond covered with perforated insulation and water sprinkler system.

The tasks carried out at the PSA in 1998 were the installation of additional equipment such as sensors, insulation and sprinklers, and testing and data pre-processing for different roof configurations.

Fig 2.1.5 Evaporative roof with water sprinkler tested in the PASSYS I test cell.

2.1.3.2 Activities in the Framework of Agreements

Agreement between the Polytechnic University of Cataluña and CIEMAT

In this framework the LECE tested and characterized *several types of bricks, fabricated with waste from different industries (textile, cardboard, etc.)* in the test cells.

The activities carried out in 1998 were: data and corresponding report on the first test carried out in the PASSYS II

Fig. 2.1.6 Vertical component made with special bricks installed for testing in a CESPA test cell

test cell in 1997. The test and analysis of data from two other kinds of bricks in the PASSYS II and CESPA IV test cell, following the same procedures as for the fist test.

Agreement between Polytechnic University of Madrid and CIEMAT:

LECE is being used as a basis for the *specific (UNE) regulation* on this type of test sites. The AENOR (Spanish agency for standardization) Technical Committee number 7 (Material Testing) must elaborate these regulations.

2.1.3.3 Accreditation activities

In 1998, the LECE continued to implement quality procedures, following UNE 45.001, in order to comply with ENAC (the Spanish accreditation institution) accreditation requirements. Accreditation activities are also planned for 1999.

Accreditation and quality procedures are being implemented gradually. The fist stage is planned to be a test of U_{value} (Thermal loss coefficient per area). Accreditation for other experiments is planned for the near future.

The activities carried out thus far have been:

- The quality manual and technical procedures have been written.
- Personnel training in laboratory quality system. Attendance at training courses and seminars.
- Infrastructure and equipment setup to implement the quality system: Verification, calibration and accomplishment of technical record.
- Internal auditing.

Diagnosis, development and implantation of the quality system and internal auditing have received financial support from the MINER (Spanish Ministry of Industry and Energy) under the ATYCA program.

2.1.3.4 Other European Programs

The LECE, as one of the PSA facilities included in the TMR program (Training and Mobility of Researchers), collaborated in 1998 with the following Users:

University of Athens: One PASSYS test cell was used to perform experiments on an evaporative material, and to validate results of experiments that were carried out in the same type of cells under other weather conditions in Greece.

University of Patras group: Tests were carried out to study the natural convective effects of a window frame.

2.2 Parabolic Trough Technology

The activities of the Parabolic Trough Technology Area during 1998 were divided among five projects:

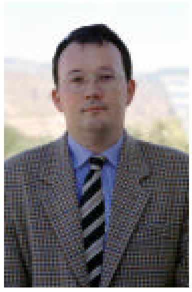
- Direct Solar Steam (DISS)
- PAREX
- EUROTROUGH
- THESEUS
- T.M.R. Control
- T.M.R. Desalination

Eduardo Zarza
Area Head

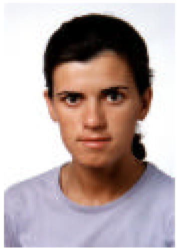
2.2.1 Direct Solar Steam (DISS)

The DISS (DIrect Solar Steam) Project is a complete R+TD program aimed at developing a new generation of Solar Thermal Power Plants with parabolic-trough collectors. This R+TD program has three primary goals:

1. Develop improved components for parabolic-trough collectors (e.g., new absorber pipes with better properties; better-quality mirrors; more accurate tracking systems; etc.).
2. Develop Direct Steam Generation (DSG) in the solar collector absorber pipes, thus eliminating the thermal oil presently used as a heat carrier medium between the solar field and the power block. This would increase system efficiency and reduce investment cost. From a technical stand point, development of the DSG process is the most critical step in the project.
3. Optimize overall plant design to improve solar-field power-block integration and O&M to shorten startup and shutdown times.



Pedro Balsa



Loreto Valenzuela

The final goal of DISS is a 20% increase in performance and 15% reduction in direct investment cost over state-of-the-art parabolic-trough collector solar power plant technology as represented by the SEGS plants currently operating in California. This would lead to a 30% reduction in the cost of electricity generation with this type of solar thermal power plant. Fig. 2.2.1 shows the breakdown of the expected cost reduction. The SEGS plants use oil as the heat transfer fluid (HTF) between the solar field and the power block connected to the external grid. Though these plants have performed well, their potential for cost reduction and increased efficiency is limited. Therefore, the parabolic-trough solar thermal electric technology must seek ways to reduce costs with better performance than now available to become more competitive in the power market. The DISS project is this step toward cost reduction.

Eckhart Lüpfert

Taking into account that 800 tons of CO_2 emissions are saved per GWh of electricity produced with solar energy, the DISS project may also be considered a very important step forward in mankind's effort to achieve environmentally sustainable development in the world.

Rainer Kistner

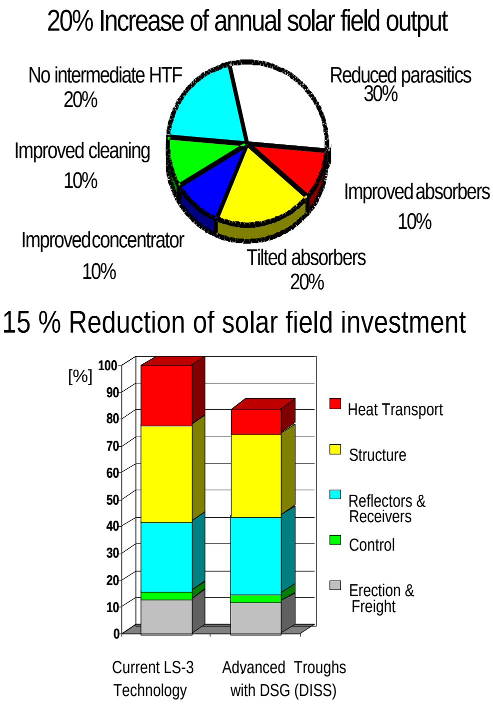


Fig. 2.2.1 DISS Expected benefit

Planned DISS activities are grouped into six different Tasks:

Task 1. Project coordination and management: the complexity of DISS and the number of partners involved in the project demand a specific task for overall coordination, management and reporting.

Task 2. Design and implementation of a life-size DSG test facility (called the DISS Test Facility) at the Plataforma Solar de Almería (PSA): as current questions concerning the DSG processes require a life-size test facility where the three basic DSG processes (e.g. Once-through, Injection and Recirculation) can be studied under real solar conditions, one of the main project deliverables is the design and implementation of such a test facility at the PSA.

Task 3. Test and Operation of the PSA DISS test facility: this task includes all those O&M-related activities required at the PSA for DSG-related tests planned.

Task 4. DSG Applied Research: thermo-hydraulic DSG laboratory scale experiments and studies will be performed in this task. Results of this task will complement the experiments performed at the PSA DISS test facility.

Task 5. Collector Improvement: study, development and evaluation of improved components for parabolic trough collectors under real solar conditions are included in this task. A small test loop has been erected at the PSA for this purpose.

Task 6. System Integration: the results of the other tasks will be used to define the configuration of a first DSG demonstration plant to be erected after project completion.

Due to the extension and complexity of its activities, the plan of work for the DISS project has been divided into three consecutive phases. The first phase (called DISS Phase I) was started in January, 1996, and ended in November, 1998, with European Commission financing under JOULE Program contract JOR3-CT95-0058. The second phase was started in December, 1998, and will end in September, 2001, also with European Commission financing under JOULE Program contract JOR3-CT98-0227. During this second phase, a complete test campaign to study the DSG process under real solar conditions will be performed in the life-size solar test facility designed and implemented for this purpose at the PSA during the first phase of the project.

Project partnership in DISS-phase I was made up of three Spanish electric utilities (ENDESA, IBERDROLA and UNION ELECTRICA FENOSA), three research centres (the Spanish CIEMAT and the German DLR and ZSW) and three companies from the industry (the Spanish INABENSA and German PILKSOLAR and SIEMENS-KWU). Thus all sectors of the electricity power market are involved in the project and commercialization of its results is assured from the very beginning.

Summary of Activities in 1998

Task 1, 2, 4 and 5 activities were performed at the PSA in 1998 within the framework of DISS Phase I. These activities and their achievements are summarized below:

Task 1. "Project Coordination and Management": The first phase of DISS ended in November, 1998, with the official presentation of results at the PSA on November 30th. The second phase of the project was officially started on December 1st with the Kick-off meeting held at the PSA with the participation of all the project partners and the European Commission.

Task 2. "Design and implementation of the DISS Test Facility at the PSA": Implementation of a life-size test facility fulfilling certain requisites (e.g., flexibility for operating under a wide range of operating loads, and large enough to perform the complete water-evaporation and steam super-heating process), for experimental evaluation of the three basic DSG processes (once-through, injection and recirculation) under real solar conditions, was completed at the PSA in 1998. This test facility will be used for Phase II testing.

The DISS test facility implemented at the PSA (see Fig. 2.2.2), which is composed of a Solar Field coupled to a Balance of Plant (BOP), is the only DSG facility in the world for experimental investigation of the process at life-size and under real solar conditions. This test facility, implemented with specially designed advanced components, has placed the PSA at the head of research in this field.

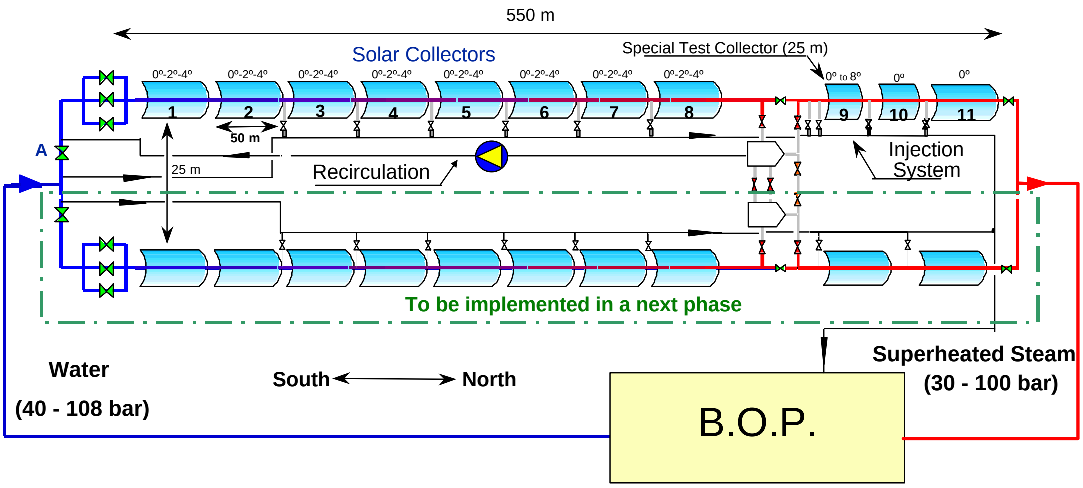


Fig.2.2.2. Schematic diagram of the DISS test facility

The facility's complete solar field is to be composed of two parallel rows of collectors, however, only one row was designed, erected and hooked up to the BOP during the first phase of the project. The implementation of the second row depends on the success of Phase II testing with the single row system. This implementation strategy reduces the financial risk of the project because the second row will not be implemented until the basic technical questions of the DSG processes are positively evaluated with the single-row system.

Table 2.2.1 Specifications of the first row of DISS solar collectors implemented at the PSA

No. of parabolic-trough modules	40
Module aperture/length:	5.76 m /12 m
No. of solar collectors	11
Reflecting surface	3000 m^2
Inclination of the tracking axis:	0º,2º,4º,6º,8º
Orientation:	North-South
Absorber pipe inner/outer diameter:	50/70 mm
Mass flow per row (once-through configuration)	1 kg/s
Max. recirculation rate:	4
Max. outlet steam temperature/pressure:	400ºC/100 bar

All the solar collectors are composed of four parabolic-trough modules, with the exception of collectors nº 9 and 10 which are composed of only two modules. Collectors nº 1,..,8 have been designed so that their focal axes can be tilted at three different angles: 0º, 2º or 4º. Collector nº 9 (called the Special Test Collector) may be tilted at 5 different angles: 0º, 2º, 4º, 6º or 8º so that the influence of angle of tilt on the two-*phase flow pattern inside the absorbers may be studied.*

Though the DISS solar field is to be operated over a wide temperature/pressure range, the three main operating modes are:

	INLET	OUTLET
Mode 1:	water at 40bar/210ºC	steam at 30bar/300ºC
Mode 2:	water at 68bar/270ºC	steam at 60bar/350ºC
Mode 3:	water at 108bar/300ºC	steam at 100bar/375ºC

Fig. 2.2.3. View of the DISS solar field at the PSA

In the BOP, the superheated steam produced by the solar field is condensed and converted into feed water that is pumped back to the field inlet and the water injection system. This allows closed-loop facility operation, thus saving water and energy.

The steam produced in the solar collectors enters a water/steam separator in the BOP where the pressure is between 30 and 100 bar. Solar field outlet pressure is controlled by a pressure control valve and a pressure reduction valve. The approximately 25-bar steam delivered by the pressure reduction valve is condensed in an air-cooled heat exchanger (steam condenser). The condensate delivered flows into a feed-water tank. The main feed pump sends water through a preheater to the solar field inlet. The water injection system is also fed by this pump and injection valves are used to individually control the flow rate of water in the corresponding injection nozzle.

Three valves installed in parallel at the collector row inlet control the water flow rate by means of the pressure drop across the valve. As it is impossible to use a single valve to control the flow of water for all three DSG processes due to their different parameters, one valve has been implemented for each process.

The recirculation system is composed of a water/steam separator and a recirculation pump which recirculates the water entering the separator between the evaporating and superheating sections of the solar field to the field inlet.

Task 4. "DSG Applied Research": In this task, a simulation computer program to predict the behavior of the DISS test facility was developed at the PSA. This computer code will be extensively used during Phase II to improve facility operating procedures. The PSA also participated in the implementation of the once-through and recirculation process control schemes.

Task 5. "Collector Improvements": Within this task in 1998, CIEMAT continued development at the PSA of an open-loop sun-tracking system for parabolic-trough collectors, based on a calculated position of the sun (as opposed to active closed-loop sun-sensor tracking of the sun) which has been implemented in the DISS loop. Performance of this system will be observed during the tests to be performed in the Phase II.

2.2.2 PAREX Project

The objective of the PAREX project is the development and testing of advanced absorber pipes for parabolic trough collectors in order to:

- reduce thermal losses at higher temperatures
- reduce thermomechanical loads due to cyclic and uneven heating of the absorber pipe

thereby increasing the competitiveness of parabolic-trough solar thermal power plants.

Two PAREX test campaigns were carried out at the PSA in 1998. In July, the performance of an end reflector which reduces losses occurring during non-normal incident solar radiation was tested. According to calculations, yearly parabolic-trough collector efficiencies can be increased by up to 2% by means of the use of an *end reflector* placed on the north end of each trough (in a north-south oriented plant in the northern hemisphere consisting of 100-m of troughs). A 6.4-m² end reflector was designed and installed in the 48-m east-west orientated DISS-Reference-Loop. The end reflector consists of aluminum frames mounted on steel supports which can simply be attached to existing LS-3 collector structures. The reflective surface is high specular anodized sheet aluminum with an average solar reflectance of 88-90%. Fig. 2.2.4 shows how the end reflector improves collector

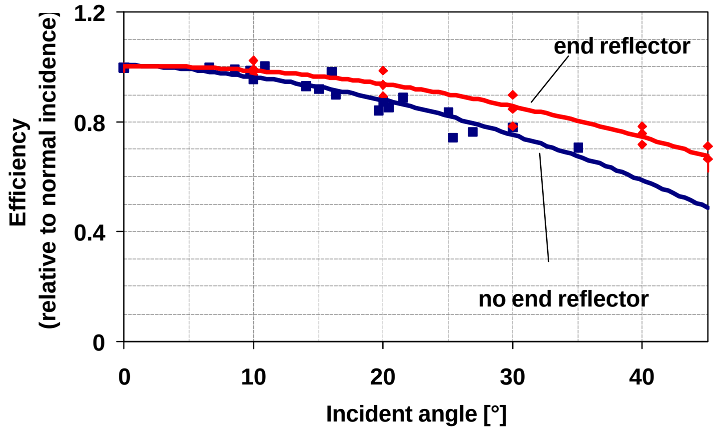


Fig. 2.2.4 Influence of the end reflector on the collector efficiency

efficiency as the incident angle increases.

From these data, valid for a north-south collector located at 35° north, an annual efficiency of 42.6% was estimated compared to 39.9% without an additional end-reflector. Cost of the end reflector is approximately 1500 Euro.

A second series of tests was carried out in October, when equipment solving a repair problem was tested. This equipment may be installed if the glass absorber-tube sleeve is damaged to reduce thermal loss. An individual damaged tube cannot be simply replaced because many of them are welded together in one loop. For repair the whole loop has to be shut down, which is not economical until more tubes require replacement. To solve this problem, two easily-mounted halves of a glass tube with additional thermal insulation on the side not receiving concentrated radiation are installed.

The step-by-step procedure included tests of the absorber in its original condition, the absorber without evacuating glass sleeves, with the repair device mounted and finally, the bare tube. Average results of measured thermal efficiency at comparable weather conditions (irradiation: 925 – 990 W/m², wind speed: 3.7–6 m/s) were:

- original absorber: 58%
- unevacuated absorber: 52%
- repair equipment: 51%
- bare tube: 28%

Theoretically, the repair device should be more efficient than the unevacuated absorber. In practice a slight gap between the two halves of the glass pipes led to convective heat losses. Therefore a modified device will be tested in 1999.

2.2.3 EUROTROUGH Project

The EuroTrough project comprises development and prototype testing of a new industrial parabolic trough collector module. As part of the EuroTrough project, a new European collector for applications in the field of process heat and electric power generation is being designed with special emphasis on cost reduction to less than $200/m². Further topics of development are:

- lightweight construction
- drive system
- control system
- concentrator technologies
- absorber elements
- mass manufacturing technology
- transport and assembly concept
- automation of operation, minimization of O&M requirements
- integration of solar heat source into co-generation processes.

Power can range from a few Megawatts to several hundred Megawatts.

Fig. 2.2.5 The success story of the SEGS plants in California (photo: Pilksolar) is the paragon for recent ambitious European collaboration

The first phase of the project, partially financed by the European Commission under JOULE contract JOR3-CT98-0231, started in August, 1998, with collection of the preliminary specifications for the new design and will continue until January 2001.

Based on previous industrial collectors, especially from the SEGS plants at Kramer Junction, California, and the recent PSA DISS-plant installation experience, design boundary conditions and technical specifications have been prepared imposing certain limitations to reduce the large number of free design parameters, while attempting to leave enough constructive freedom to optimize costs. Moreover, absorber flux distribution was

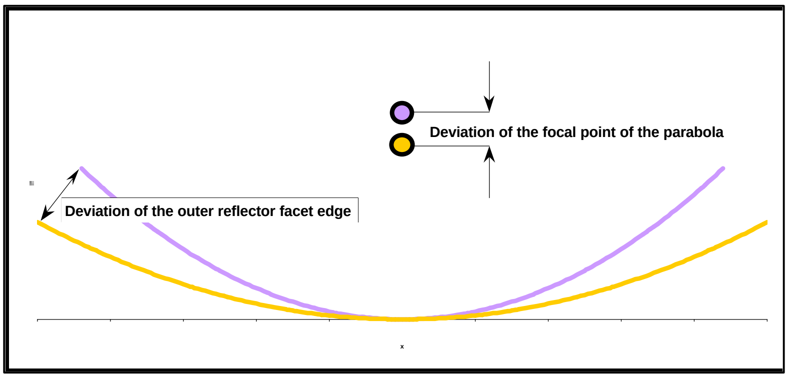


Fig. 2.2.6 Trough collector deviations studied: Alignment of reflectors and absorber influence collector cost and efficiency

calculated to define the design accuracy needed to obtain sufficient collector optical performance. Work on a first design concept has begun and is due to be completed by April, 1999. Instrumentation and data acquisition concepts have been specified.

Project partners are:

- INABENSA, Instalaciones Abengoa, S.A:
- Schlaich, Bergermann und Partner GbR
- Fichtner GmbH & Co KG
- PILKINGTON Solar International GmbH
- DLR
- CIEMAT
- Centre for Renewable Energy Sources (C.R.E.S.)

A project consortium has been arranged for common development and marketing of the collector module.

Once the full-size collector and solar field concepts will have been designed, a representative collector segment of up to 500 m^2 including all the key components will be identified, depending on the final collector design and cost, for validation of the concept. In this second phase, this segment will be connected to the PSA heat transfer loop (LS-3 HTF loop) with Syltherm 800 thermal oil, oil heaters and coolers, which will enable the

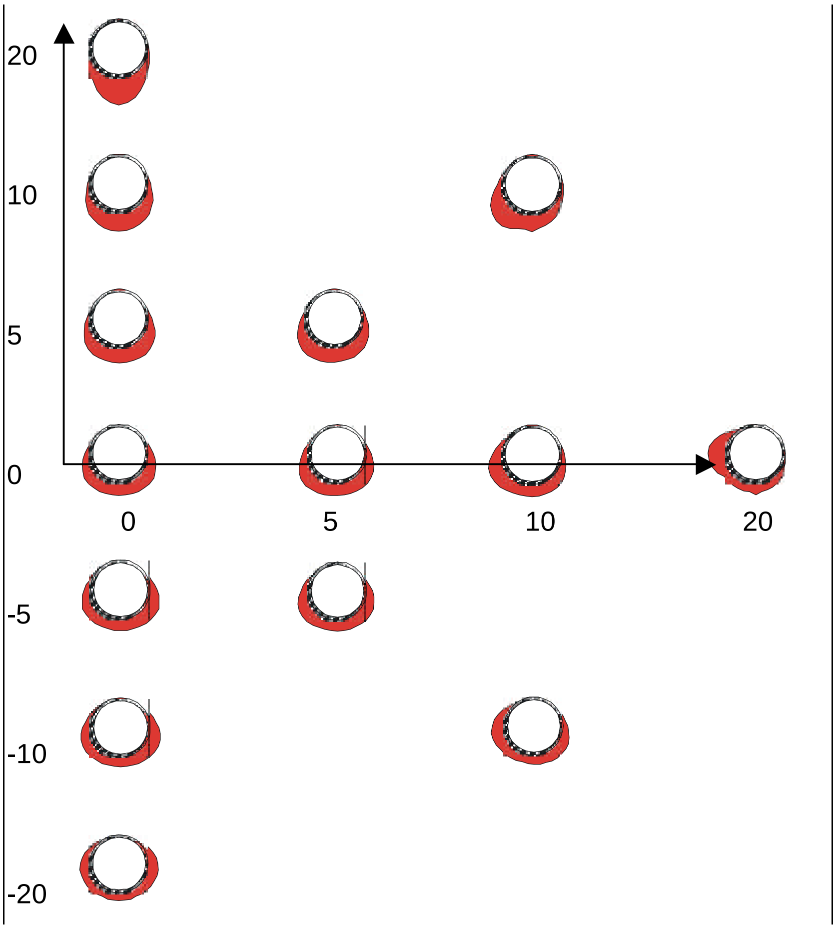


Fig. 2.2.7 Influence of absorber tube misalignment (in mm from focal point) on the flux distribution (arbitrary units) on the absorber tube surface (DLR)

EuroTrough collector segment to be tested and validated over the full 200 – 400°C temperature range required.

2.2.4 THESEUS Project

The objective of this project is the implementation of the first large-scale European parabolic trough power plant, of 50 MWe nominal capacity, on the Greek island of Crete. The proposed project site is located in the Frangocastello area on the southern coast of western Crete in the county of Sfakia. The power block will be a conventional Rankine cycle reheat steam turbine. The solar field energy source will be supplemented with an LPG-fired heater to supply limited auxiliary process steam for startup and solar field freeze protection.

The project was funded under the EC program THERMIE from 1.1.1997 until 31.12.98 and the original THESEUS consortia consisted of Pilkington Solar International (Germany), Fichtner (Germany), Eucomsa (Spain), Preussen Elektra (Germany), ENEL (Italy), O.A.DY.K (Greece), DLR (Germany), CRES (Greece).

The following goals were achieved during 1998:

- An Independent Power Project ownership structure was selected
- The related Cretan company, the THESEUS S.A., was incorporated
- THESEUS S.A. applied for an Installation License under Greek National Law 2244/94
- A German Venture Capital Fund, committed to raising the equity capital of the project, took over the majority of THESEUS, S.A. stock
- Frangokastello, which has the best measured direct-normal radiation conditions in Europe, was selected as the most appropriate site location.
- A complete technical design report was prepared.

The technical design report results are summarized below:

The power plant is comprised of a moderate-pressure, low-temperature Rankine reheat steam cycle electric generating system, using solar thermal energy as its primary energy source. Fig. 2.2.8 shows the system thermodynamic heat balance diagram.

The thermal energy of the steam is transformed in a reheat steam turbine into electricity which is delivered to the grid. Due to the turbine inlet steam quality, solar-mode Rankine-cycle turbine efficiency is only about a moderate 38% gross compared to conventional fossil-fired power plants with better steam conditions which can surpass 40%.

Process support for solar field freeze protection, heat gain in cold start-up and some maintenance of turbine operation under fluctuating solar insolation conditions will be obtained by an LPG-fired heater. The necessary small amount of fuel for process maintenance is expected to be delivered to a newly constructed pier near the site. Seawater will be used for plant cooling.

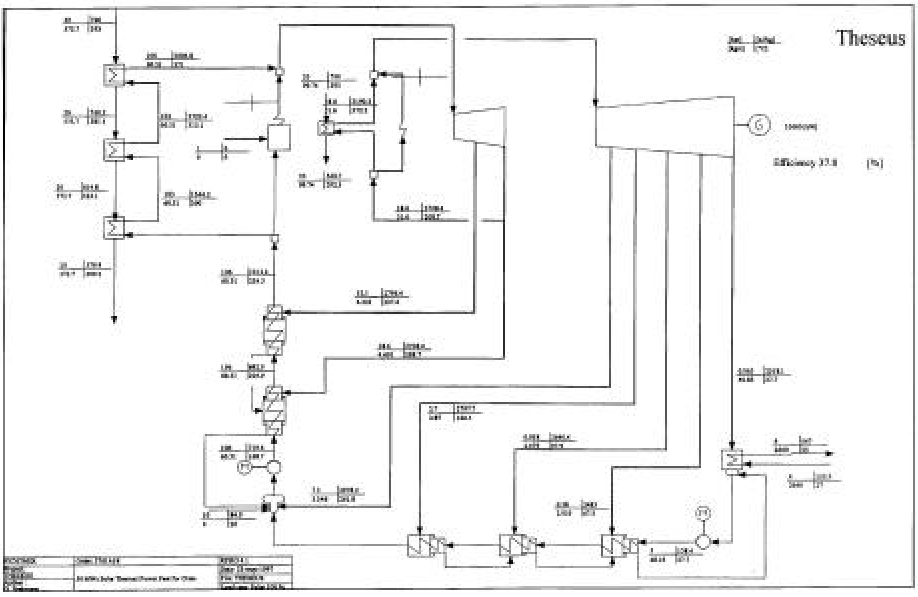


Fig. 2.2.8 Thermodynamic diagram for Theseus 50 MW_e Power Cycle

Table 2.2.2 Summary of 50-MW_e THESEUS Plant Specifications

Project Data		
Total Collector Aperture Area	m^2	296,480
Performance Indicators		
Output Power Rating / Peak power	net MW_e	50
Annual Operating Hours (Equiv. full-load on-line	hrs)	2,250
Annual Total Electricity Delivered to Grid,	net MWh_e	112,508
Annual System (Solar-to-Net-Electric) Efficiency	%	15.7
Utilization Factor, (operating hours/8760)	%	32.4
Capacity Factor	%	25.7
Plant availability	%	93*
Annual Process Fuel Consumption	metric tons/a	496
Fuel type for process support		LPG
Lower Heating Value	kWh/kg	12.89
Fuel Cost	ECU/metric ton	249
Peak System (Solar-to-Net-Electric) Efficiency	%	23
Parasitics	MW at full load	4.8
Major Subsystem Efficiencies		
Peak Gross Turbine Efficiency	%	38.2
Peak Solar Field Thermal Efficiency	%	70.0
On-line hours of the day		Summer-12; Winter-7
Solar Operation Indicators		
Annual direct normal insolation	kWh/m^2-a	2409
Sunshine hours, annual usable	h/yr	3060
Design Conditions for Solar Field		
Direct normal insolation	W/m^2	800 (@12:00, 21.June)
Avg. site temperature at solar usable hours	°C	22.4
Avg. site wind at solar usable hours	m/s	5.24
Rated thermal power output	MW_t	147
Solar field collector availability	%	99%
Annual Solar Field Thermal Output	MWh	350,021
Annual Solar Field Thermal Efficiency	%	49.0
Annual Solar Electricity per Unit Area	kWh_e/m^2a	379
Other Performance Parameters		
Site characteristics		see Table 3
Solar Field Outlet Temperature	°C	393
Turbine Steam Inlet Pressure	bar	98
Turbine Steam Inlet Temperature	°C	368.6
Seawater Use	$10^3\ m^3/h$	9.5
Cost and Economic Parameters		
Unit Cost	ECU/kW	2196

* Based on solar field availability, 99% power block availability, 97%; scheduled maintenance, 96.7%

Table 2.2.2 above summarizes the configuration, performance, site and design parameters. At full load, the solar IPP system will deliver 50 MWe net to the grid. The advanced solar field design will consist of LS-3-type parabolic troughs, like those used at the 80 MWe SEGS plants in California, but improved by a number of innovative features developed over the last few years.

2.2.5 TMR Control Project

The ACUREX parabolic-trough collector field was included among the PSA facilities offered for access under the EC DGXII Training and Mobility of Researchers program as a test bed for the development and testing of advanced control algorithms. Although developed for solar power plants, the techniques applied to this facility may also be applied to other industrial processes and the work carried out has served as an impulse for new theoretical development.

PSA control activities, which had been running under the TMR Control project financed by the EC DG XII Training and Mobility of Researchers program since 1990, concluded in 1998.

The main achievements in 1998 within the framework of this project are briefly listed below:

- Two papers presented at the 1998 American Control Conference and another two accepted for the 1999 European Control Conference (two of the most important worldwide control events).
- Six papers presented at European congresses and symposia.
- A chapter of a book on fuzzy control applied to solar power plants (University of Oulu).
- 100% occupation of the weeks of access committed in the TMR contract for the third year.

Besides development and testing of advanced control algorithms, this project has been very active academically. Four Ph.D. theses are currently underway. There was an exchange of postgraduate students among institutions involved in the project. At several European universities, the project has also had a strong impact on undergraduates through the PSA student grant program and the Fundación Gómez-Pardo research grant program, and has provided industrial experience for researchers from different European universities.

The institutions involved are having a hard time maintaining the tight TMR time schedule. In an effort to overcome this lack of time, a model of ACUREX field accuracy designed by the University of Seville was distributed among the participants so they could simulate the performance of their controllers and adjust them accordingly before coming to Almería.

At the Second Annual TMR Workshop in November, a separate session was devoted to the work in the ACUREX field. At this session, six presentations were given showing the results obtained during the year.

The controllers tested under real operating conditions at the ACUREX field in 1998 were:

2.2.4.1 Dept. of Engineering Cybernetics, Norwegian University of Science and Technology (Norway)

Gain-scheduling Controller

A gain-scheduled pole placement control strategy on the basis of local linear ARX models was tested. The results showed that the gain-scheduled control strategy performs very well when compared to other experimental studies at the same plant available in the literature. The results with a linear controller show that good performance can only be achieved with a linear controller in a small operating regime. Hence, the need for a nonlinear controller is evident.

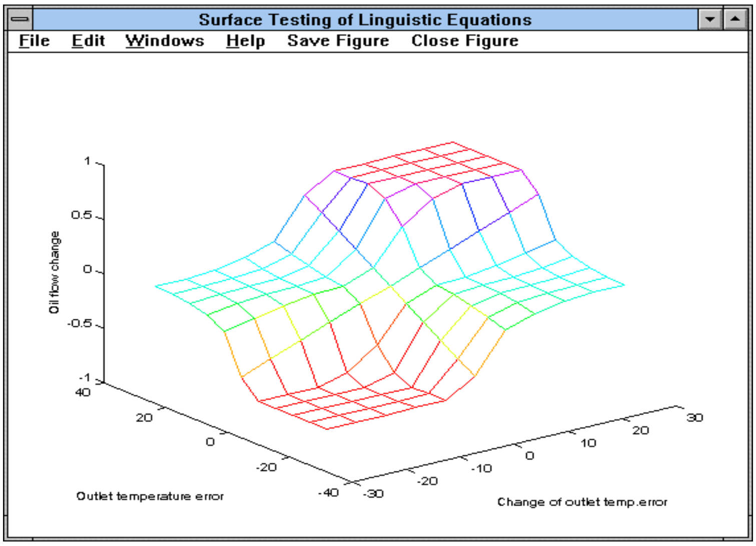


Fig.2.2.9 Control surface of the Linguistic Equation Controller (Univ. of Oulu).

2.2.4.2 INFOTECH Oulu and Dept. of Process Engineering, University of Oulu (Finland)

Linguistic Equation Controller

The Linguistic Equation (LE) approach provides a flexible environment for combining expertise in development of intelligent systems. The LE approach increases the performance of the fuzzy control considerably by combining various control objectives and adaptation to the changing operating condition into a very compact implementation. The LE approach result also very efficient as a modeling technique: models can be generated from data, various types of fuzzy rule-based models can be represented by LE models, and any LE model can be transformed to fuzzy rule-based models. During this year the improved scheme developed in 1997 was tested in the real system with very good results.

2.2.4.3 Dept. de Engenharia Electrotécnica, Universidade Nova de Lisboa (FCT/UNL) (Portugal)

Adaptive Predictive Controller

In 1998 experiments, FCT/UNL has performed tests with an adaptive predictive control algorithm based on the nonlinear structure of the process. This controller has variable sampling time according to the flow regimen. This allows stepping at reference input with wider amplitudes without exciting non-linearity.

During the test campaign this group also tested a gain-scheduling PID controller also for the purpose of overcoming nonlinear behavior.

2.2.4.4 Control Engineering Laboratory, University of Bochum (Germany)

This university collaborated with the FCT/UNL in testing a non-linear predictive controller and also tested an adaptive controller based on a multi-model. The results obtained during testing could be used to plan following tests and to improve the control algorithm employed.

2.2.4.5 Dept. de Engenharia Informática, Universidade de Coimbra (Portugal)

Fuzzy supervisor of PID Controllers

2.2.4.6 Industrial Control Centre, Strathclyde University (United Kingdom)

PID-Type Fuzzy Controller (PI-FLC)

Based on fuzzy rules, the PI-FLC in series with a feed-forward controller was easy to implement, requiring no exceptional control

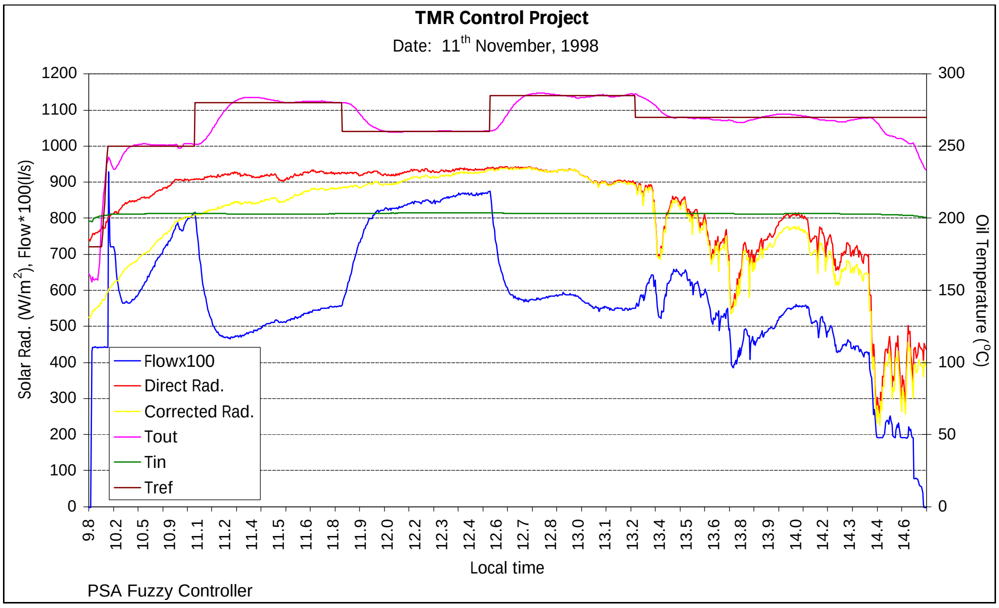


Fig.2.2.10 Controller response during a set-point tracking test

expertise for its design, with an extremely user-friendly procedure. The greatest difficulty in the design procedure is tuning the system, especially the scaling factors. Satisfactory performance was achieved, and the controller was able to cope well with transients in solar radiation.

2.2.4.7 Other control-related activities

A simple, quickly implemented feed-forward controller based on the system energy balance in steady conditions was also improved, combined with PID and fuzzy controllers and tested in 1998. This feed-forward function designed by the PSA was also used by some of the institutions involved in the TMR Control project.

Outside the TMR program but also related with Control activities, the Horus Project permitted the Instituto de Engenharia de Sistemas e Computadores (INESC) of Lisbon (Portugal) to test an innovative class of control algorithms in the ACUREX field, amenable to application in other industrial plants with similar dynamics.

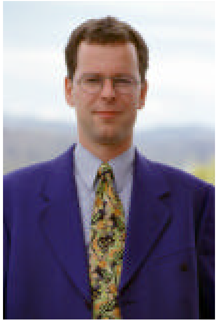
2.2.6 TMR Desalination Project

The Solar Desalination Plant was included in the PSA TMR program to promote solar desalination studies in European countries. The project deals with the work carried out from 1987 to 1993 within the PSA Solar Thermal Desalination project.

In 1998 the center for Performance Research On the Built Environment (PROBE) of the University of Ulster (Northern Ireland) tested a new advanced collector, tracking concentrating inverted absorber CPC, for low temperature applications obtaining very useful results.

2.3 Dish/Stirling Systems

Peter Heller (Area Head)



Wolfgang Reinalter

Francisco Martín

2.3.1 Distal I

The DISTAL I facility had been built up in the year 1991 and demonstrated for about 30.000 hours of operation on sun the progress in this technology. With the modifications of the Stirling engine SOLO V161 and some of its components during the DISTAL II project it became more difficult in 1998 to keep the systems operational. Since no further R&D project had been foreseen for 1998 the facility was used as a study and training object for scientists and engineers in the framework of the Training and Mobility of Researchers Programme (TMR) funded by the EU. There had been three groups using the facility for training and investigations:

- University of Avila, Italy
- ENEL (utility), Italy
- VIOLAMP, Greek

For a total of about 33 days, these groups studied dish/Stirling-related applications, such as the pumping of water for agriculture, the alternative free-piston Stirling technology for the engine and general aspects of integrating dish/Stirling systems into their utility supply structures, including system operation & maintenance.

2.3.1 HYHPIRE

To overcome the disadvantage of solar systems not being able to produce energy during periods without sunshine, whether because of clouds or at night, hybrid systems have been developed using natural gas, for example, as a backup fuel.. In the past, only a small number of hybrid receivers had been tested around the world. The HYHPIRE project ('Development of Advanced Hybrid Heat-Pipe Receivers in dish/Stirling Systems for Decentralized Power Production') was funded by the EC for a 3-year period and was extended during 1998 until June 30, 1999, due to delays in the course of the project.

The scope of the project is the development and testing of a hybrid heat-pipe receiver that is capable of absorbing the concentrated radiation of the dish, as well as transfer heat from a fossil burner system to the same Stirling engine working fluid (helium). The heat transfer fluid is sodium that is evaporated by the heat and condensed at the Stirling heat exchanger tubes. A sketch of the design of the heat pipe receiver is shown in Fig. 2.3.1.

The advanced receiver design relying on the results and experience of a first and second generation heat-pipe receiver developed at DLR, integrates a new low-emission combustion system. A new cost-effective simplified manufacturing method based on plasma spraying has been developed and replaces the welded wick with a plasma-sprayed porous structure.

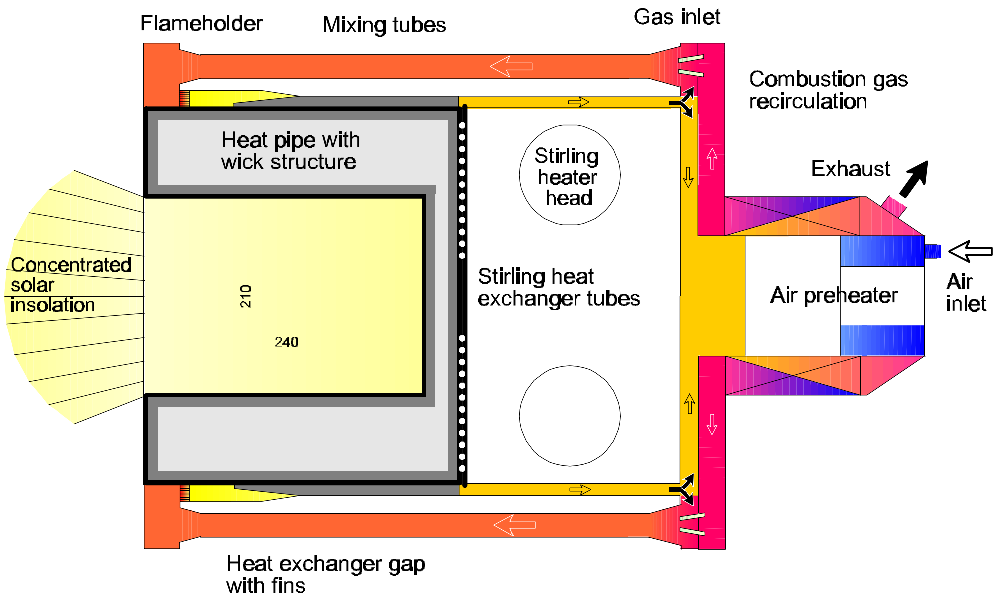


Fig. 2.3.1 Design of the hybrid heat-pipe receiver with integrated combustion system

The PSA work package in 1998 was the preparation of the site, modification of the concentrator, implementation of a gas supply system and integration of the first heat-pipe system in the DISTAL II's North Dish.

The gas supply system shown in Fig. 2.3.2, consisting of a tank with a 2450-l capacity, a distribution system of fixed tubes and flexible hoses was delivered, installed and tested.

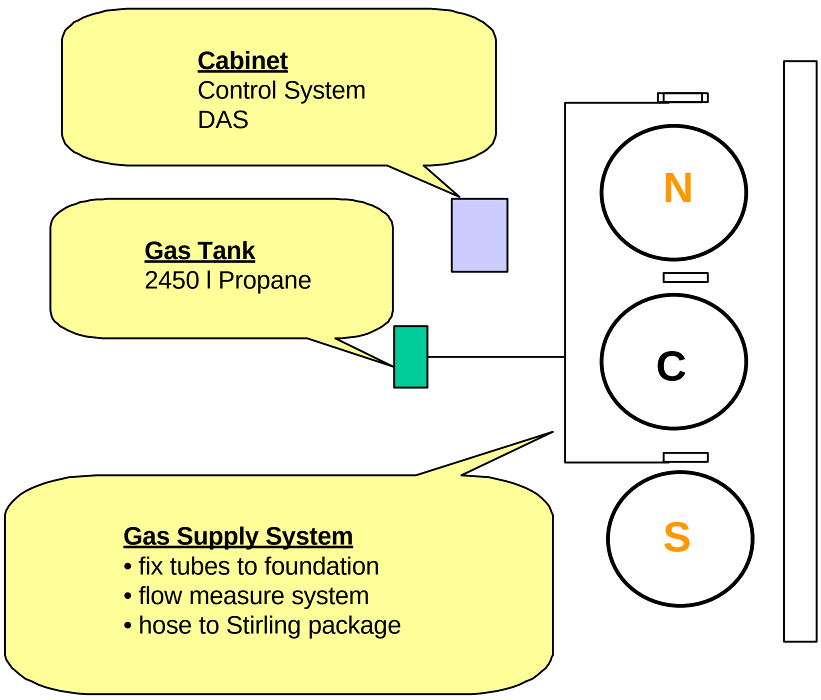


Fig. 2.3.2 New HYHPIRE project gas supply system at the DISTAL II facility

A flow measurement unit for each dish/Stirling system was installed close to the electric switchbox. A cabinet was built close to the North Dish to house the control and data acquisition computer and provide easy access to equipment. The data acquisition system is based on 'Integrated Measurement Pods (IMPs)'. Necessary wiring was completed for the procedure foreseen to enable quick, easy data exchange between the DISTAL II DAS and HYHPIRE. Access to the weather data from the local meteo station was available in time.

A second control system for two Dish/Stirling systems was installed and prepared to operate in parallel to the existing DISTAL II system. 'Interbus-S' is used for communication between the control units. The additional wiring was planned and installed.

Counterweights had to be welded onto the concentrator structure to compensate for the difference in weight and point of gravity of the package compared to that of DISTAL II. The first heat-pipe system arrived at the PSA in autumn and was installed on the North Dish.

After connecting the package to the gas system on the ground, first trial runs were performed and gas mass flow adjusted depending on the load, temperature and pressure at the Stirling engine.

The delay in the project led to an extension until June, 1999, for 6 months of system operation in solar only, gas only and hybrid mode.

2.3.2 DISTAL II/EuroDish

The DISTAL II facility, erected and put into operation in 1996/97, demonstrates the current European dish/Stirling design. The three 10 kWe systems with their azimuth-elevation tracking, enlarged concentrator and reworked SOLO 161 Stirling engine have been operated on-sun for about 2000 hours. Since June, 1998, the systems have been used as a test bed for the pre-qualification of new components within the new EC-funded *EuroDish* project.

2.3.1.1 EuroDish Project Objectives and Expected Achievements

Tentative cost analysis studies have shown that with increased production of 10 000 units per year, system cost could be lowered 1.500 to 2.500 ECU/kWel for a hybrid dish/Stirling system. In this case the levelized energy cost of dish/Stirling systems is comparable or even lower than the stationary Diesel engines currently used in similar applications. With this environment protective and resource-saving technology a huge export market could be developed for the industrialized nations.

The technical feasibility of the SBP dish/Stirling system has been proven with several prototypes in more than 30 000 on-sun operating hours at the PSA. The main barrier to introducing

Fig. 2.3.3 The DISTAL II Facility

dish/Stirling systems on the market are acceptable system costs. SBP's dish/Stirling design has already come down to 11 000 ECU/kWel for single prototype installations. Further cost reductions are only possible by developing new optimized components and small-series production. For first market penetration in remote areas and island installations, system costs have to be below 5 000 ECU/kWel which requires a minimum production level of 100 to 500 units (1 to 5 MWel) a year.

This will be achieved in the EuroDish project by:

- Component cost reduction
  Completed prototypes have been built using available off-the-shelf components which are, however, expensive and not well suited to dish/Stirling applications. Thus new components (system control, tracking system, Stirling components and packaging, etc.) will be developed, manufactured and tested in two of the PSA Distal II units.

- Development of a new concentrator manufacturing procedure
  The actual cost of prototype steel parts is approximately 6 to 7 ECU/kg. The material costs, however, are only 0.5 to 1 ECU/kg. Thus new component design and manufacturing concepts and the tools required for them will be developed in order to reduce that cost to 2.5 to 3 ECU/kg.

- Stirling engine
  The manufacturing costs for the Stirling engine will be reduced by developing adequate tools for small series production.

- Development of a cost-effective erection procedure
  A cost-effective erection procedure will be developed, and the required tools fabricated and tested.

- Remote monitoring and protected control via World Wide Web (WWW)
  A remote monitoring and control system required for a cost-effective servicing concept will be developed, tested and

installed at the existing installations at the PSA. Part of the updated information on the installations will be visualized (camera, charts, statistics) and published continuously to the public via WWW.

- Test of pre-commercial units as reference systems
  The newly developed components and procedures will be integrated into a complete system and two units will be built and tested under real weather conditions at the PSA.

2.3.1.2 1998 Activities

First tests of new dish/Stirling components were conducted at the end of the reporting period. The goal of these improvements was to enhance system availability and to avoid unnecessary emergency system shutdowns (detracks). Control software was revised accordingly.

The concentrator tracking system was analyzed to reduce highly redundant positioning devices and the possibility of integrating a beam-focus control system using thermocouples around the Stirling aperture.

A new water-cooled cavity was installed to avoid the degradation of the former ceramic design. Its low-maintenance durability or unacceptable losses still have to be proven.

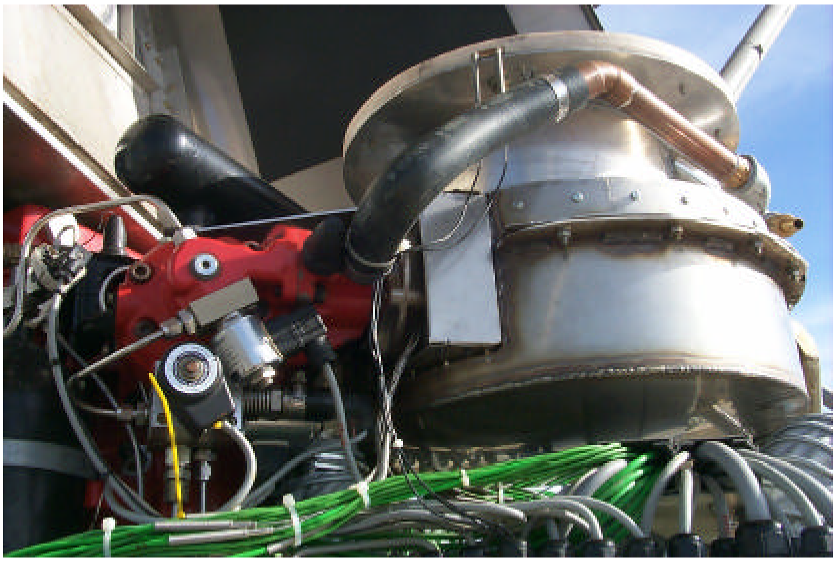


Fig. 2.3.4 New water-cooled cavity design

New optimized engine components were installed to evaluate their long-term behavior. These tests will go on throughout the coming year. At the end of 1999, site preparation will begin for the construction of two complete new EuroDish units in 2000.

2.4 Central Receivers

The projects in the Central Receiver Area in 1998 concentrated on the implementation and investigation of large power plants such as the Colón Solar and Theseus projects, as well as the new component technology program for receivers (Refos, HitRec), heliostats (Colón, Autonomous) and improvements in flux measurement systems. An increasing part of the work was devoted to simulation models for the design of heliostat fields, heliostat optical quality and financial and economic solar power plant simulations.

After the 23rd Steering Committee meeting in May, 1998, the Central Receiver area was restructured to include the flux measurement activities and dish/Stirling facility. In this report, the previous structure is still maintained. The work on the Theseus project is described in section on "Parabolic Trough Technology" (2.2.4). The description of the flux measurement system hardware can be found in Chapter 4.3.

2.4.1 The Colon Solar Heliostat

Complete characterization testing of the Colon Solar Heliostat prototype developed by the Spanish company, INABENSA, took place during the first three months of 1998 within the framework of the Colon Solar Project. Built in collaboration based on previous CIEMAT experience in facet design, structure and control, the 70-m^2 heliostat consists of 21 facets (1.1 m x 3.0 m each) having 94% clean reflectivity and 90% estimated annual average reflectivity. The dense reflective surface and face-up survival position make better use of the land configuration available for the heliostat field at the Colon Solar site. The prototype incorporates local control and electronic card GA2696A, fully developed at the PSA.

The extensive test campaign included eight different groups of tests: local control performance, optical quality, aiming error, electrical consumption, flux measurement, wind load and surface analysis. The heliostat was qualified for use at the COLON SOLAR plant. The design beam quality was 2.9 mrad, which in the field tended to produce an eliptical image with an optical beam quality of 2.4 mrad. (X axis) and 3.1 mrad (Y axis). Maximum elipticity is recorded near sunrise and sunset. The main sources for that error were identified as the curving table and the aspect ratio of the facets. Flux distribution on the target for the slant range of testing (380 m) revealed a typical Gaussian profile with 58.5 kW total power, concentration factor of 5.4 and R 90% = 2.8 m. In a limited number of wind tests, winds up to 20 $km.h^{-1}$ were recorded and showed reflected-beam errors below 0.68 mrad.

Under all conditions, the encoder was able to keep working within a ±1 bit margin of error, that is, that under all circumstances the reference point is guaranteed with an accuracy of 1 bit in 14400 on both tracking axes. The overall electrical consumption of the heliostat measured is about 285 $Wh.day^{-1}$,

Peter Heller (Area Head)

Eckhard Lüpfert

Manuel Romero

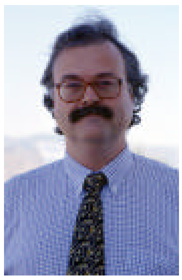
Jesús Ballestrín

Frank Schillig

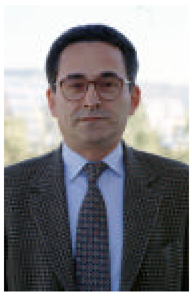
Rainer Kistner

Diego Alarcón

Rafael Monterreal



Javier León



Antonio Valverde

the use of speed controllers being essential in the local control box to optimize consumption.

2.4.2 The Autonomous Heliostat

The PSA and the University of Almería designed the first Stand-Alone Heliostat during Phase one of the project during the second half of 1998. The heliostat consists of a glass-metal configuration with typical T-shape structure and 70 m^2 of mirrors. Its great innovation is that it is completely unconnected by cabling, either for drive-motor power or for communications, since its autonomous system is driven by a PV module and batteries and communication is by advanced radio modem. External sensors measure atmospheric parameters required for operation. The objective is two-fold. On one hand, the civil engineering and infrastructure costs related to the preparation of the heliostat field are minimized and on the other, the heliostat does not need any intervention to guarantee the aiming point during the day or the safety and self-protection under adverse conditions, being able to operate in isolated stand-alone applications. Its main advantages versus conventional wired heliostats are:

- Very low Infrastructures costs (wires, channels, electrical distribution and protection elements, UPS,…)
- Immunity to damage from lightning
- Each heliostat has its own Uninterrupted Power Unit and is independent from power supply grid
- It uses incremental encoders which are not only cheaper, but do not lose the reference
- The field continues to operate during software or electricity failures
- It is very easy to add new heliostats to the field

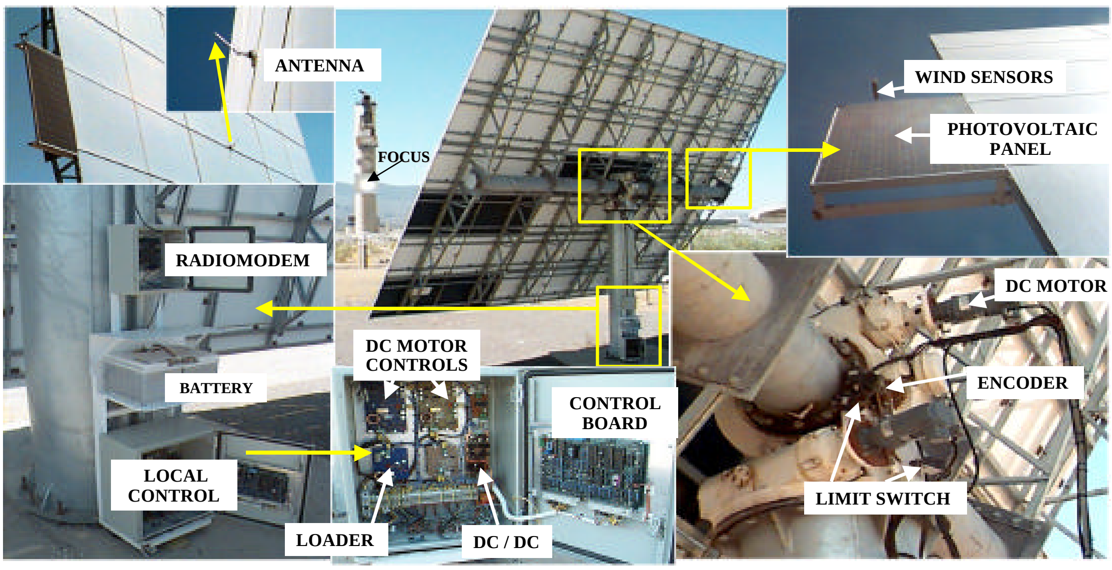


Fig. 2.4.1 The new PSA prototype stand-alone HELIOSTAT

One 70-m^2, classical glass-metal "T" heliostat has been adapted to include all the stand-alone concepts, as depicted in the figure. The PV system is able to drive two sun-tracking DC motors from 5 to 24 Vdc and 0 to 15 A. The heliostat communicates with the control room 400 m away by safe-transfer radio modem at frequencies of 400-800 MHz and 9600 baud. Messages and data transmission are encrypted. The heliostat is provided with anemometer, wind switch, light sensor and temperature. With this information the heliostat is able to operate autonomously and decide whether to enter into stow under low battery loads. The microprocessor included within the control card calculates sun position within a 0.5 minutes of arc margin of error. It also includes a correction for atmospheric refraction depending on ambient temperature.

The local control continuously monitors the reference parameters and measures the most representative consumption and electrical values producing a self-diagnosis log file in case of failure. The control card sets the exact position of the heliostat by reading the incremental angular encoders and adjusting the motor speed accordingly. Low speed tracking is about 2º/min for close positions and 7.5º/min for positions further from the reference.

During 1998, the entire autonomous configuration, hardware acquisition and installation were completed. During 1999 an extensive test campaign will serve to evaluate the reliability of the concept, availability of operation and the main consumption figures, as well as cost estimations compared to the conventional wired units.

2.4.3 REFOS

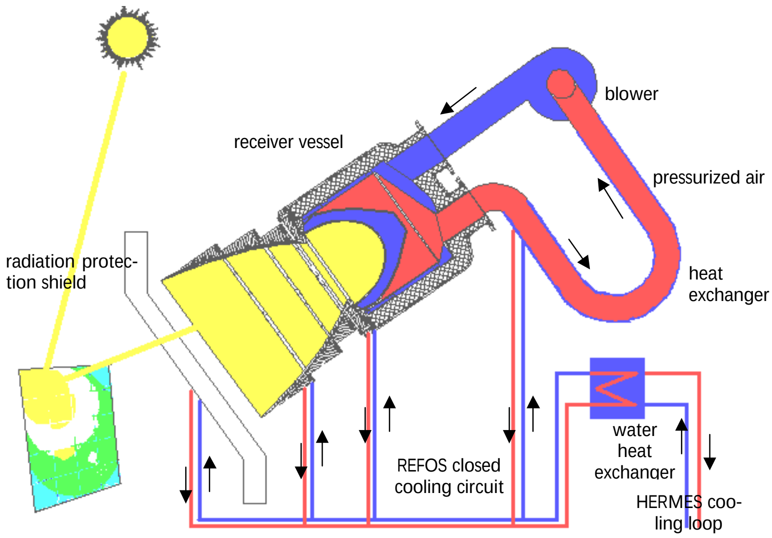
The REFOS project comprises the activities on development of a volumetric air receiver for solar and fossil gas turbine and combined cycle power plants. The strategic aim is integration of a significant share of solar energy into gas-turbine-based power systems making the most use possible of the high exergy content of concentrated solar radiation. The conversion efficiency of solar energy to electricity on the order of 28% by a solar air-preheating concept in an enclosed volumetric receiver with a secondary concentrator cone and quartz window in a modular 350 kW unit as shown in Fig. 2.4.2 is a promising milestone on the way to lowering the cost of solar energy. The REFOS unit has been installed at the 60-m level of the CESA-1 tower, making use of existing infrastructure. Main 1998 REFOS project activities were:

- Termination of test preparation and set-up
- Testing and evaluation of the secondary concentrator for one module, measuring of concentrated energy with a water-cooled calorimeter, qualification of the installation and measurement techniques.
- installation of the pressurized-air receiver module, including closed test loop (air at 15 bar, 800°C)

- operation and evaluation of the entire module up to design conditions

a)

b)



c)

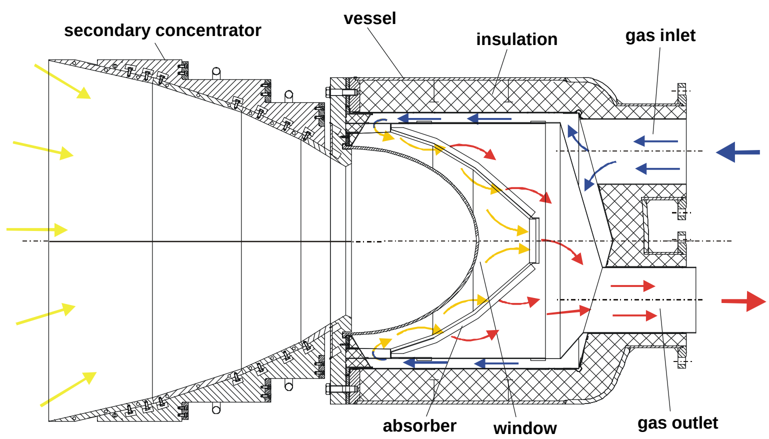


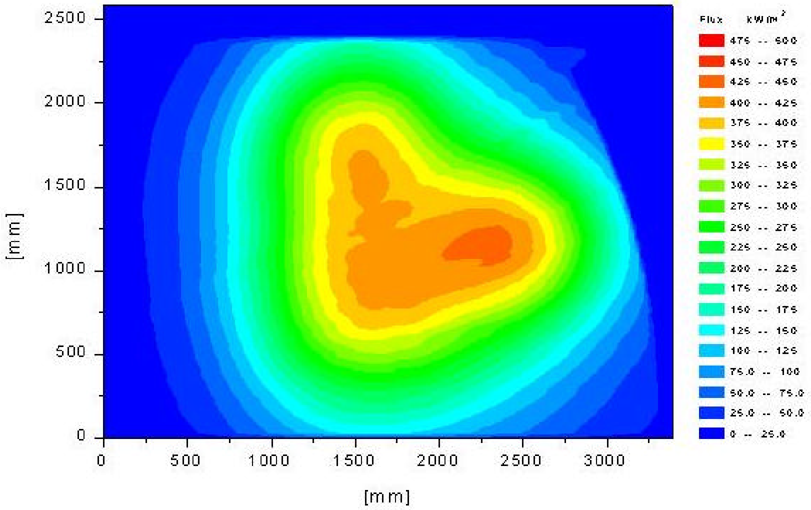
Figure 2.4.2: REFOS receiver tests at PSA. a) test operation on CESA tower, b) scheme of the pressurized test loop (air, 800°C, 15 bar), c) section of one receiver module (350 kW)

The last point was not finished in 1998 and continues in 1999.

Test-bed operation was provided with operation control, data acquisition, and visible and infrared image acquisition system optical measurements.

The infrared camera system (AVIO 2100, Stirling-cooled) has been installed on a pole 36 m above the ground and only 40 m from the CESA-1 tower. Two different filters in the 5 µm and 3 µm range show the quartz window and the absorber surface through the quartz window, respectively, to give online thermograms (temperature distribution images) of the components during operation (Fig. 2.4.3). Due to a 4x-tele-converter lens and the short distance, the spatial resolution is in the range of centimeters. Special work has been done on the spectral response of the system and thus the evidence of the

a)



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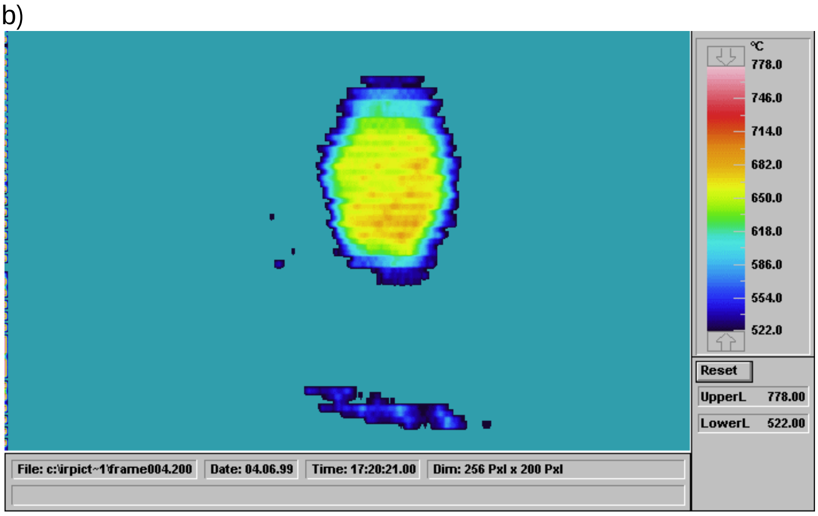


Figure 2.4.3 Flux and temperature distribution are examined in the REFOS tests. a) flux map of REFOS inlet aperture taken with modified PROHERMES system at PSA. b) temperature distribution inside the REFOS receiver, on the absorber surface, taken with the IR camera system and a 3.1 – 3.5 mm band-pass filter

resulting images.

The visible range slow-scan camera (Theta system) is the centerpiece of the so-called PROHERMES flux measurement system. It provides digital images of the moving white bar passing just in front of the entrance plane of the receiver module. These shots are corrected with certain methods inherent to the system and then pasted and calibrated. The result is a solar flux distribution map of the receiver entrance aperture and its surroundings that can be further evaluated for receiver performance calculations. The reporting period was characterized by set-up, calibration, programming and cross-checking of the needs for the REFOS tests as well as evaluation of picture series.

The REFOS project is prepared and led by DLR, though counting on increasing interest and support from the PSA during 1998 and in the beginning of 1999. The continuation in 1999 had to be suspended as a consequence of withdrawal of German financing. Nevertheless, the significance of this technology for the improvement of solar technology has been recognized and gives rise to hope on resuming this activity.

2.4.4 Computer Design Tools

The development of user-friendly computer codes for energy analysis of reflective concentrator systems (Enertracer and Fiat_Lux) and for the design, financial and performance evaluation of solar thermal power plants (Solwin) has received a significant dedication during 1998. The objective is to produce a new generation of computer codes able to replace the existing tools developed during the early eighties, and designed to the new operating systems and with more friendly graphic interfaces.

2.4.4.1 EnerTracer

EnerTracer is a 3D energy analysis code for reflective concentrator systems development of which was begun at the PSA in 1998. The basic idea of is to define a computational paradigm that is sufficiently abstract to be applied to a wide variety of reflective concentrator systems. Ray-Tracing Techniques and the Monte Carlo Method are being used to implement this paradigm. Incident radiation is defined by specifying the radiance at each point of the concentrator aperture. The following expression is used to determine the total power associated with the incident radiation flux on the concentrator-system aperture surface:

$$\Phi_{Sol} = \int\int\int\int L(u,v,\theta,\phi)\,\mathrm{sen}\,\theta\,\cos\theta\,du\,dv\,d\theta\,d\phi$$

Afterwards, the radiometric description of incident solar radiation is substituted by a statistical description defined using the probability density function:

$$p(u,v,\theta,\phi) = \frac{L(u,v,\theta,\phi)\,\mathrm{sen}\,\theta\,\cos\theta}{\Phi_S}$$

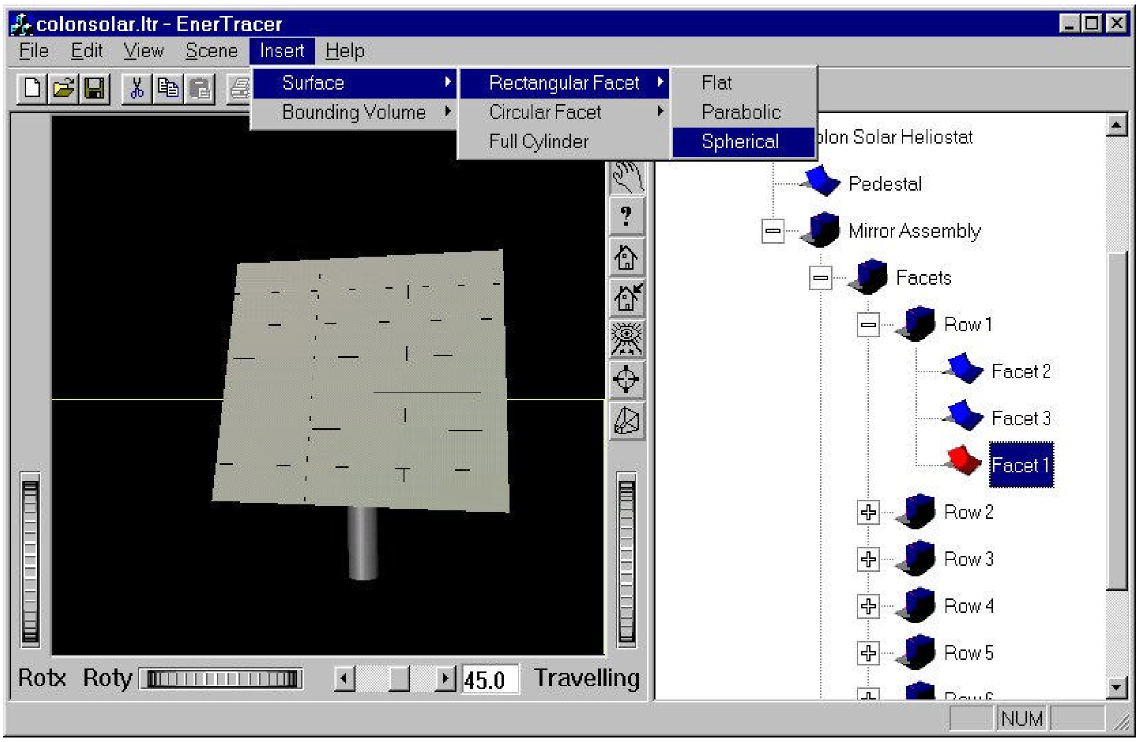


Fig. 2.4.4 The computer framework created for EnerTracer; example for the COLON SOLAR heliostat

Fig. 2.4.4 shows an example of the use of EnerTracer for the simulation of the Colon Solar Heliostat. EnerTracer development status can be summarized as follows:

- A first version of a program using Visual C++ for the Windows 9x and Windows NT operating system and Open Inventor was presented to the SolarPACES community in October, 1998.
- "Classes" have been developed for the most common concentrator surfaces.
- Literature on random number generators was reviewed and a suitable uniform generator passing the most rigorous tests for randomness and efficiency was identified.
- Algorithms to simulate the different 'sunshapes' proposed in solar literature have been developed.
- Ray-tracing and bookkeeping algorithms for surface energy characterization are under development.

2.4.4.2 Fiat Lux

The aim of the "Fiat_Lux" software tool of the PSA is the characterization of solar concentrators based on precise knowledge of the real sunshape.

The core of Fiat_Lux was developed using Matlab. The sunshape image is captured by a 14-bit resolution CCD imaging device and transformed into a matrix representative of the spatial distribution of the sun's intensity. From this matrix sunshape, a matrix of the flux distribution incident upon the receiver is obtained by matrix-manipulation technique consistent with the principles of geometric optics. The software allows the user to define the ideal shape of the mirror and superimpose on it a waviness model to simulate manufacturer and other mirror imperfections. This matrix is projected onto the receiver by a previously modeled mirror, following the law of reflection and assuming ray-cone approximation for every area element.

The analytical function for modeling individual mirror errors is:

$$z=f(x,y)+w_1(A_1,,e_1,)+ w_2(A_2,,e_2,)$$

where:

- f(x,y) is the geometrical term, tailored by users depending on the shape of the mirror (spherical, cylindrical, etc.) and
- w_1, w_2 are waviness terms, modeled by two sinusoidal functions.

During 1998, the kernel of the program was generated in Matlab and afterwards compiled to C++. The first version of the code has already been satisfactorily tested with several heliostats (GM-100, ASM-150 and COLON SOLAR) and dishes at the PSA (Fig. 2.4.5). Code validation activities have already begun. Deconvolution of concentrator errors could be reproduced by modeling non-ideal effects like waviness, canting errors and structural deformation from gravity loads.

2.4.4.3 SolWin

The objective of SolWIN is a software analysis tool to visualise the technical, economic and financial viability of solar thermal power projects. The software will be developed mainly to match the requirements of project developers and decision makers in the power sectors in order to facilitate and promote the market

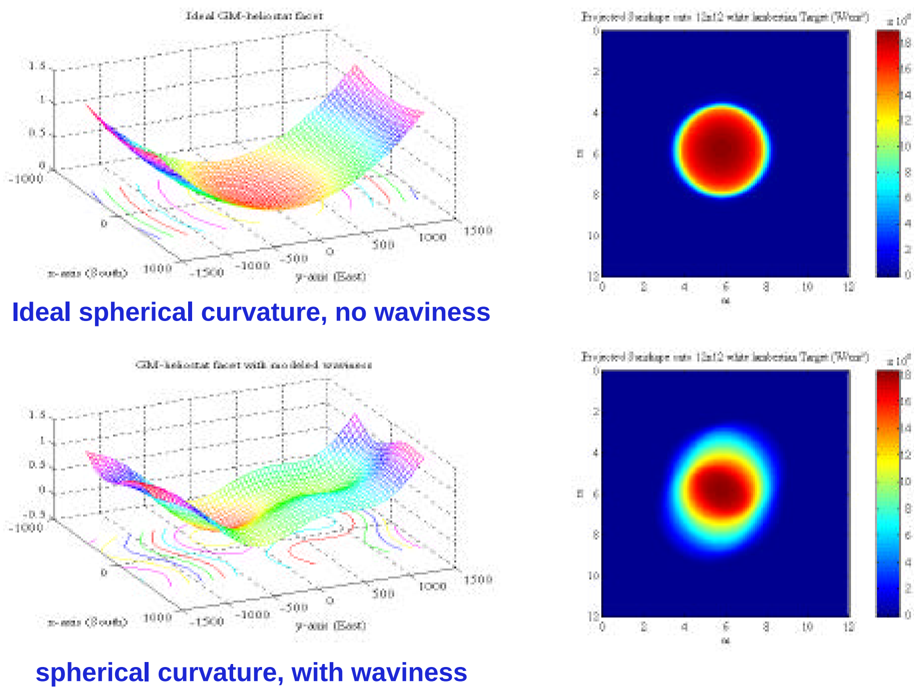


Fig. 2.4.5 GM-100 heliostat single facet simulation of real flux distribution onto the target.

introduction of solar thermal electricity generating technologies. The target group should be able to:

- analyze and evaluate hybrid solar-fossil electricity generation concepts
- analyze the solar potential of selected sites
- assess resource consumption of solar thermal power systems
- find least-cost solar power solutions
- develop financing schemes for solar thermal power plants

SolWin contains several editable databases to provide the user with information on different solar thermal technologies, fuels, meteo data, cost and financing data. Performance prediction models are calculating the produced kWh of each user-defined system, the approximate costs and the revenues generated during the entire project lifetime. The modules are based on a combination of physical equations and measured data from various existing projects.

Within the SolWin site module, DLR has implemented several models for estimating meteo data. The models employed information or existing GHI data. The ambient temperature or GHI data may also be created in a similar way. Furthermore, enhanced graphic interfaces were developed to handle and visualize meteo data. Apart from the DLR meteo database, SolWin can also use NREL TMY2 data. In Fig. 2.4.6, an example of the user interface of the meteo module is depicted. In the window on the left, the user can determine the kind of meteo

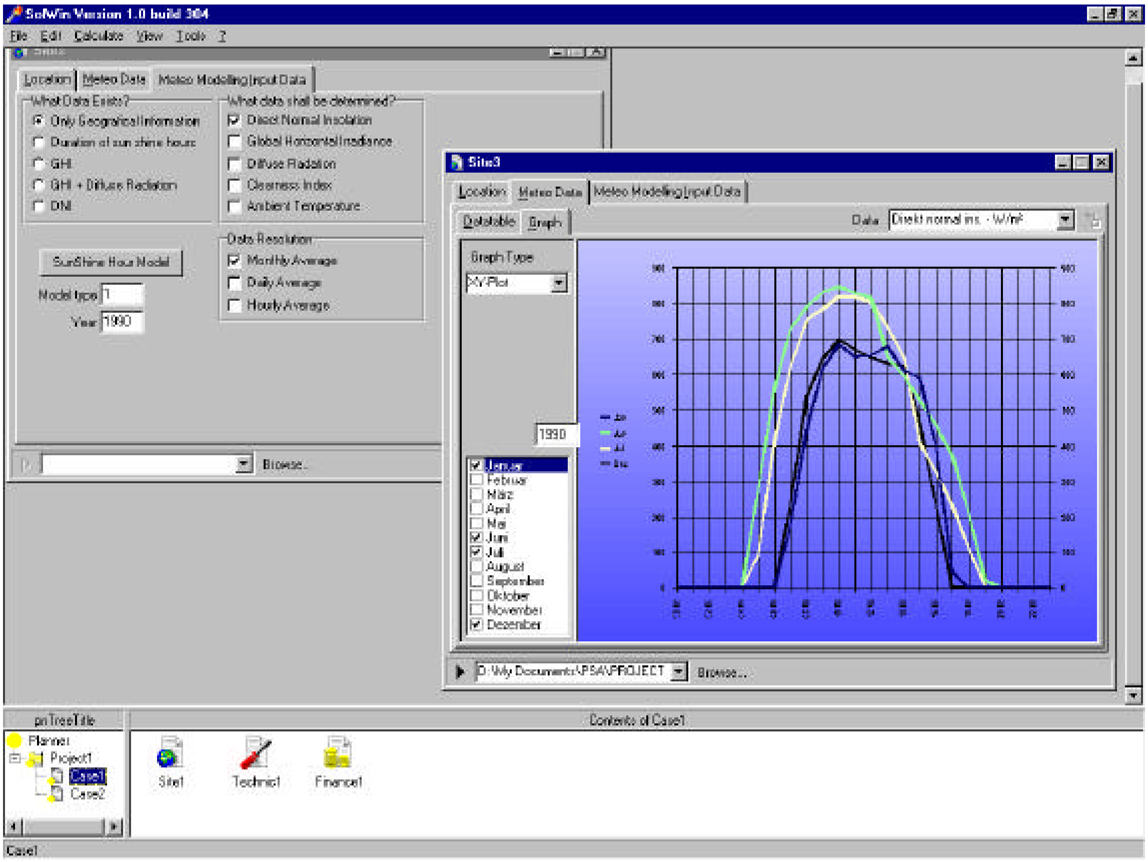


Fig. 2.4.6 User interface of the meteo module of SolWin

data that needs to be generated (e.g., normal direct insolation, ambient temperature, etc.) and then display the meteorological data generated in several types of graphic (XY-plots, Isoline, Histogram) or as tables of raw data in a separate window.

Within the scope of a scientific exchange program between DLR and SunLab, a parabolic trough model was developed and programmed by H. Price and T. Wendelin of NREL. R. Diver of Sandia and the DLR Distal team compiled a dish/Stirling system model during his stay at the PSA. Moreover, implementation into SolWin of the stand-alone tower version has begun. The existing project financing and cash flow model was improved and extended. The credit plan module was made more flexible, in order to give the user more choices to reproduce realistic project financing structures. In addition, insurance and tax features were implemented in the SolWin core.

2.4.5 TSA

PHOEBUS Technology Program Solar Air Receiver (TSA) testing in 1993 and 1994 successfully demonstrated the potential of this technology. In the following years the main goal was to optimize receiver and steam generator control. In 1995 and 1996 work on automatic aiming-point strategy programs were completed and several tests were performed. In 1996, 22 new TSA receiver absorber elements that had been tested for 120 hours in 1997 with improved temperature behavior, as well as further improvement in the manufacturing process, were implemented. In the same year, the ability of the system to produce electricity with the CESA-1 steam turbine was again demonstrated and the PSA personnel accumulated more experience in operating the system in grid-connected mode.

The majority of the REFOS tests planned for 1998 did not allow for part for another system being operated at the same time in the CESA-1 test facility. The REFOS and TSA receivers could not be operated at the same time since the platforms are too close together and it is therefore unsafe. Nevertheless TSA was operated daily for system demonstrations for visitors.

Since the Spanish Royal Decree was published in late 1998, the interest of industrial partners in proven technologies like that of TSA (Phoebus) is starting to grow again so that they can build a power tower plant to produce and sell electricity on the Spanish market. A new demonstration phase was planned together with industry for 1999 to convince industry of the performance and reliability of the open volumetric receiver concept.

2.4.6 Volumetric Receiver

A second series of Hit-Rec volumetric absorber tests were carried out in the CRS test bed in 1998. The Hit-Rec receiver is made of SiC pieces fitted on SiSiC cups. Its 37 modules have a total surface area of 0.49 m². The module support structure is a double-walled membrane cooled by a forced stream of air at ambient temperature. From the membrane, the slightly preheated air goes through the modules to the front, where it is then sucked into the absorber. The new module mounting concept makes replacement easier in case of failure.

The main goal was to reach high air temperatures and this was accomplished. The Data Acquisition System measured and recorded temperatures over 1000°C.

On the other hand, problems due to stretching because of inadequate cooling distribution on the membrane and fit of the modules caused several of them to break down and one module fell from its place, cracking some of the others.

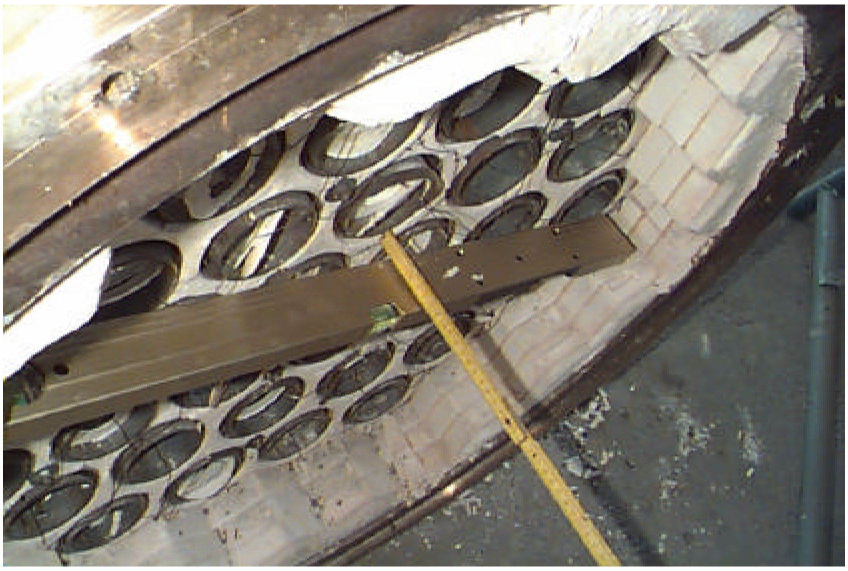


Fig. 2.4.7 Hit-Rec. Membrane deformation

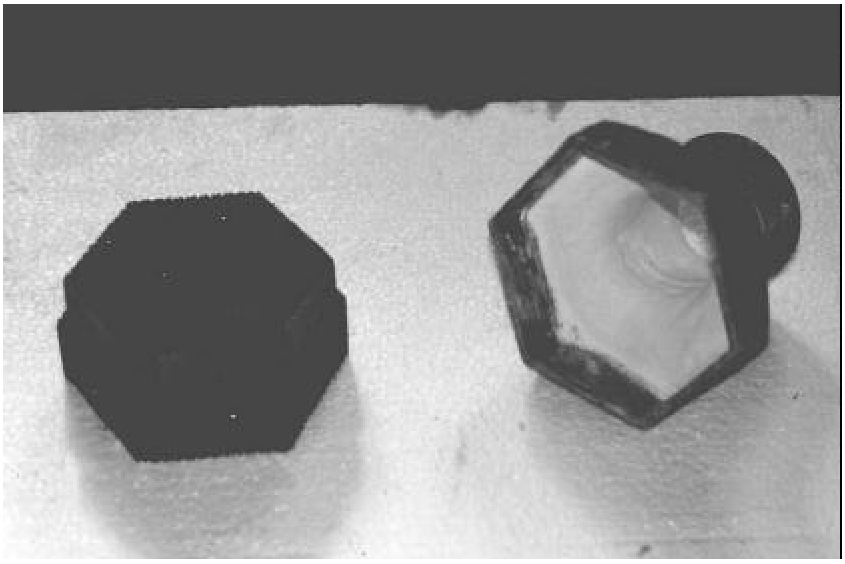


Fig. 2.4.8 Hit-Rec. Absorber piece and cup

2.4.7 Cold Finger Test

Another test campaign performed at the CRS test facility was the comparison of the calorimeters used for measuring incident flux in the Hit-Rec receiver, TSA receiver and a new gage used as a reference standard. The flux gages were mounted on refrigerated "cold fingers" placed just in front of the volumetric aperture.

The tests were performed around solar noon, focusing several groups from the east, west and center of the heliostat field step by step.

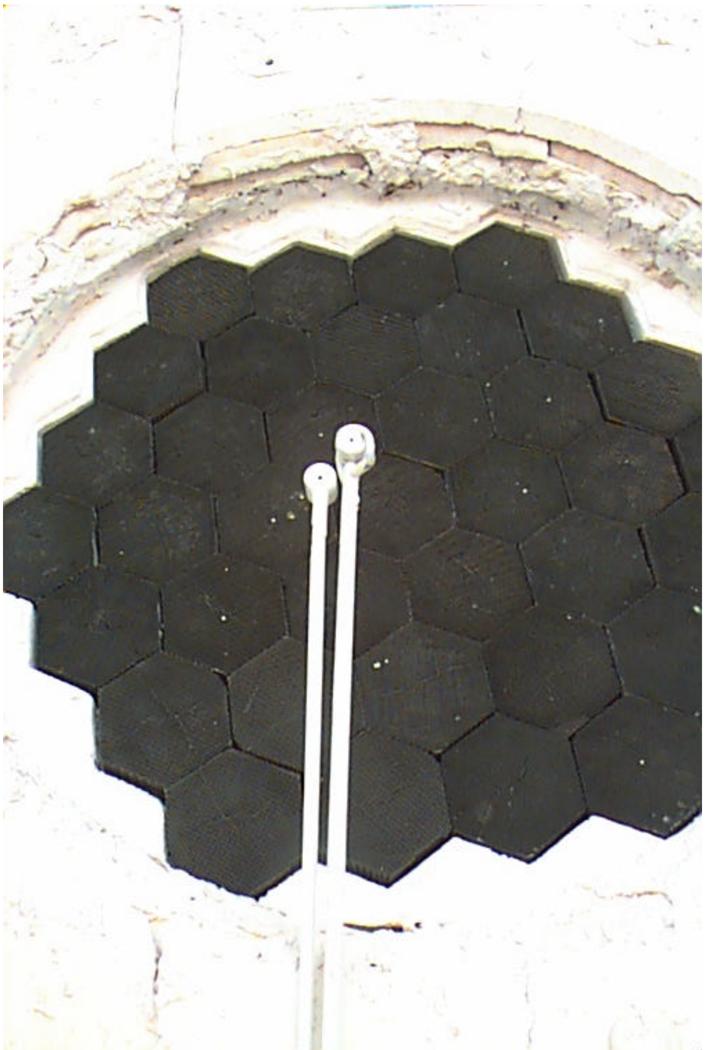


Fig. 2.49 Flux gages mounted on the cold fingers in front of Hit-Rec volumetric receiver

2.5 Solar Chemistry

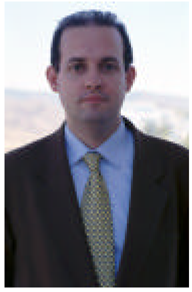
The dramatic increases in the cost of oil beginning in 1974 focussed attention on the need to develop alternative sources of energy. It has long been recognized that the sunlight falling on the earth’s surface is more than adequate to supply all the energy that human activity requires. The challenge is to collect and convert this dilute and intermittent energy to forms that are convenient and economical or specifically, in solar chemistry, to use solar photons in place of those from lamps. It must be kept in mind that today there is a clear world-wide consensus regarding the need for long-term replacement of fossil fuels, which were produced million of years ago and today are merely consumed, by other inexhaustible or renewable energies. Under these circumstances, the growth and development of Solar Chemical Applications can be of special relevance. These technologies can be divided in two main groups:

1. Thermochemical processes: the solar radiation is converted into thermal energy that causes a chemical reaction. Such a chemical reaction is produced by thermal energy obtained from the sun for the general purpose of substituting fossil fuels.
2. Photochemical processes: solar photons are directly absorbed by reactants and/or a catalyst causing a reaction. This path leads to a chemical reaction produced by the energy of the sun’s photons, for the general purpose of carrying out new processes.

It should be emphasized, as a general principle, that the first case is associated with processes that are feasible with conventional sources of energy. The second is related only to completely new processes or reactions that are presently carried out with electric arc lamps, fluorescent lamps or lasers.

From the outset, it was recognized that direct conversion of light to chemical energy held promise for the production of fuels, chemical feedstock, and the storage of solar energy. Production of chemicals by reactions that are thermodynamically ‘uphill’ can transform solar energy and store it in forms that can be used in a variety of ways. These processes generally start with substances in low-energy, highly-oxidized forms. The essential feature is that these reactions increase the energy content of the chemicals using solar energy. For such processes to be viable, they must fulfill the following requirements:

- The thermochemical reaction must be endothermic.
- The process must be cyclic and with no side reactions that could degrade the photochemical reactants.
- The reaction should use as much of the solar spectrum as possible.
- The back reaction should be very slow to allow storage of the products, but rapid when triggered to recover the energy content.
- The products of the photochemical reaction should be easy to store and transport.



Julián Blanco
Area Head

Sixto Malato, PhD

Christoph Richter, PhD

Barbara Millow, PhD

Pilar Fernández

The other pathway for the use of sunlight in photochemistry is to use solar photons as replacements for those from artificial sources. The goal in this case is to provide a cost-effective, energy-saving source of light to drive photochemical reactions with useful products. Photochemical reactions can be used to carry out a wide range of chemical syntheses ranging from the simple to the complex. Processes of this type may start with more complex compounds than fuel-producing or energy-storage reactions and convert them to substances to which the photochemical step provides additional value or destroy harmful products. The principles of photochemistry are well understood and examples of a wide range of types of synthetic transformations are known. Therefore, the problem becomes one of identifying applications in which the use of solar photons is possible and economically feasible. The processes of interest here are photochemical, hence, some component of the reacting system must be capable of absorbing photons in the solar spectrum. Because photons can be treated like any other chemical reagent in the process, their number is a critical element in solar photochemistry.

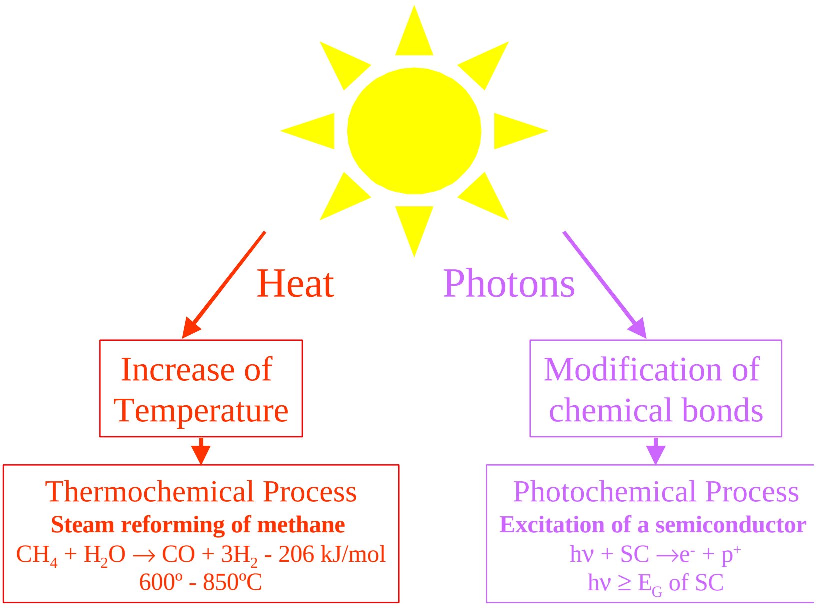


Fig. 2.5.1. Schematic view of Solar Chemical Applications

The Solar Chemistry Area of the Plataforma Solar de Almería (PSA) has been working with chemical applications of solar detoxification since 1990, in particular in photocatalytic water decontamination projects, both at a national and international level. The engineering experience acquired in developing solar detoxification systems has led to the installation at the PSA of the largest solar detoxification pilot plant facility in Europe. It has been very successfully used by many European research institutions to carry out EC-financed projects in which the Solar Chemistry Team has participated as either Coordinator or Partner.

In this context, a European industrial consortium has been created to design, manufacture and install in situ and set-up turnkey SOLARDETOX plants for the treatment of hazardous and non-biodegradable water contaminants using solar light. This

Consortium has performed comprehensive technological research and development to obtain a state-of-the-art technology validated by the construction of a full-size demonstration plant at one of the partner installations. Initial market analyses show a promising number of possible applications for this remarkable environmental technology, even in not-so-sunny regions such as northern Germany. These analyses also show that this technology could be fully competitive with conventional wastewater treatment processes.

2.5.1 Participation in the EC DGXII TMR Program (Solar Detoxification)

The treatment of contaminated water necessarily includes the design of an efficient photoreactor. Basic laboratory research on the process has mostly been performed with experimental devices in which efficiency was not as important as obtaining appropriate conditions that would permit reproducibility of the results and exhaustive knowledge of the effects of all the important parameters. This is correct when the goal is a fundamental knowledge of the process, but not always sufficient to attempt a change of scale. So, research at pilot scale is necessary for validating laboratory results. As the PSA is the only European centre for experimentation in the field of applied solar chemistry, it has been selected by the European Commission to provide European research groups access to solar pilot plants for demonstrating pre-industrial-scale feasibility of processes previously tested only at lab scale. In 1998, six research groups have used the PSA Detox Installations to carry out different research programs on this subject.

2.5.1.1 UMR CNRS C 6503, Université de Poitiers (France)

Several photoanodes adapted either to parabolic trough (PTC, Helioman) or to compound parabolic collectors (CPCs) were tested under outdoor conditions and it was found that a layer of TiO_2 photocatalyst deposited on a conducting substrate presents several advantages for the decontamination of water:

- No separation of the photocatalyst from the decontaminated water is needed.
- The photocurrent-potential dependencies measured either under global solar light (GSL) or concentrated direct solar light (CDSL) are very useful for rapid, simple evaluation of photoreactor performances. From the photocurrents measured continuously throughout the decontamination process, it is possible to obtain the amount of electricity involved and thus calculate the number of hydroxyl radicals to be entered in the mass balance.
- Better separation of charges occurs if photogenerated electrons are withdrawn by the application of a bias potential at the TiO_2/electrolyte interface, and this enhances the photooxidation of organic pollutants.

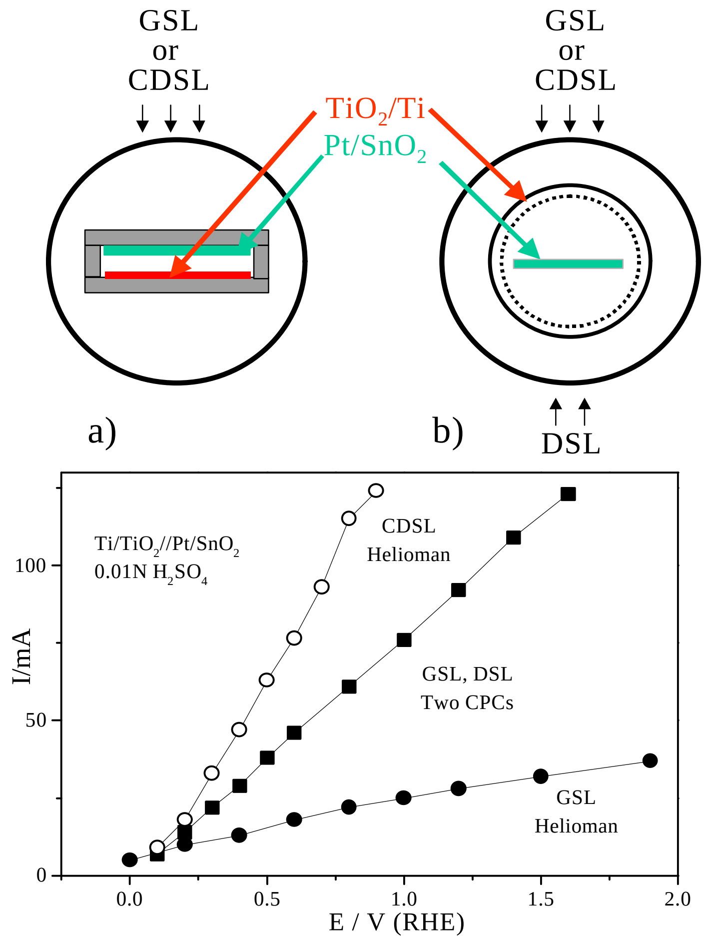


Fig. 2.5.2. Up: Schematic cross section of a) a one-compartment reactor, b) a two-compartments reactor. Down: Photocurrent-potential dependencies recorded for reactors with CPC's (■) or Helioman (❍●).

Among the various photoreactors tested, those having two compartments are of the most interest in practical applications such as water decontamination in solar plants. Indeed, the cylindrical photoanodes placed around an inner compartment are able to collect solar light at low concentration ratios, such as those provided by CPCs, efficiently. However, several problems remain to be solved before photo-electrochemical reactors can be built for use in solar plants: porous large-area conducting substrates have to be found to deposit TiO_2 and electrode materials such as Pt/Nb or reticulate vitreous carbon, which are more efficient than conducting glass but also more expensive, must be tested. Careful estimation of the investment needed for the construction of practical photoelectrochemical reactors, compared to the investment required for TiO_2 slurries from which the photocatalyst must be separated, is required. At the same time, more resistant reactors have to be designed to avoid mass transfer problems due to low flow rates.

2.5.1.2 Laboratoire CNRS "Photocatalyse, Catalyse et Environnement", Ecole Centrale de Lyon (CNRS, France).

Two different types of experiments were performed by this research group at the PSA in 1998. The degradation of 4-chlorophenol (4-CP) was used as a model in both cases:

- Comparison of various titania samples
- Solar photocatalytic degradation using the synergistic effect between titania and activated carbon.

Comparison of various titania samples.

Among various physical characteristics such as particle size, structure or active site density, which may intervene in photocatalytic activity, the influence of the surface area appeared to be of prime importance. For smaller surface-area catalysts, there is a decrease in the readsorption rate of intermediate products and consequently in the overall photodegradation rate. By contrast, for larger surface-area catalysts, final rate of disappearance of total organic carbon (TOC) was observed to be slower because of very low pollutant coverage which favors electron-hole recombination. Comparison of the kinetics of decontaminating water at PSA and in laboratory experiments indicated the same kinetic order (apparent first order) for 4-CP disappearance and the same apparent quantum yield. However, fewer intermediate products and faster disappearance of TOC were observed in the PSA solar pilot reactor, which, moreover, worked with a lower optimum concentration of suspended titania. This was ascribed to the photoreactor design.

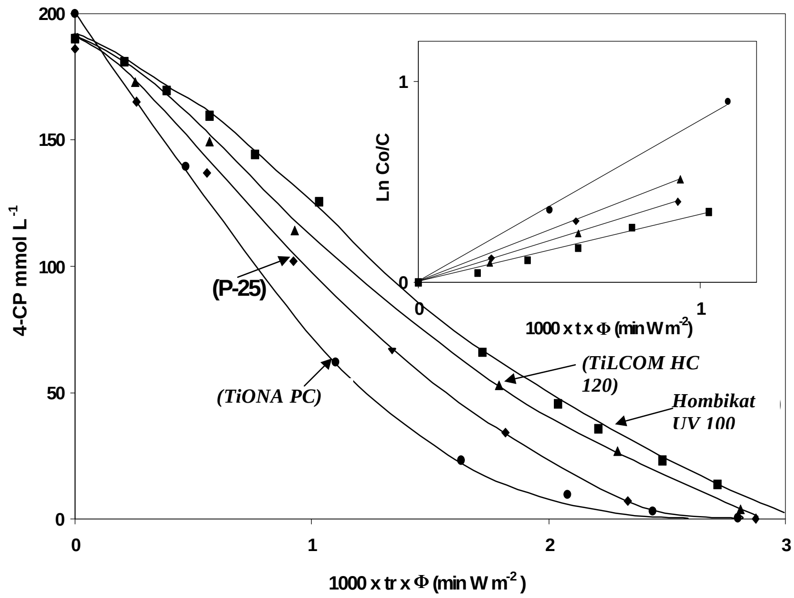


Fig. 2.5.3. Disappearance of 4-CP as a function of solar exposure in presence of P-25, TiONA PC 10, TiLCOM HC 120 and Hombikat UV 100 catalysts. The insert shows the linear transformation Ln Co/C = f(t_R x F).

Solar photocatlytic degradation using the synergistic effect between titania and activated carbon.

The photocatalytic degradation of 4-chlorophenol was performed in contact with a suspended mixture of titania and of activated carbon (AC). Non-additive adsorption capacities were observed when the two solids were mixed. This was ascribed to strong interaction between the two solids. Synergy was observed with a 2.4 factor increase in the first order rate constant at lab scale. With pure titania, the same main intermediate products (hydroquinone and benzoquinone) were found but in much smaller quantities and with a much shorter lifetime. The synergy effect was ascribed to extensive adsorption of 4-chlorophenol on AC followed by transfer to titania where it is photocatalytically degraded. When extrapolating these experiments by a 12 500 volume factor to the PSA solar pilot plant, an identical synergy factor of 2.4 was found, thus confirming the transpositivity of laboratory experiments to large solar setups. The synergy effect was not disabled when the double-phase photocatalyst was reused. This combined photocatalytic system appears to be a new way to treat diluted used water more efficiently and in a shorter time, which could be of interest in producing drinking water in dry sunny areas.

2.5.1.3 Laboratoire de Chimie Industrielle, Université de Metz (France).

The preparation of TiO_2 supported on glass fibre by sol-gel method was demonstrated. The photocatalytic activity of this supported catalyst (TiO_2-FG), both in a laboratory reactor and PSA CPC reactor, was evaluated. It has been demonstrated that the same catalyst can be reused several times. Photocatalytic activity of supported catalysts in benzamide was good. However, the evolution of Total Organic Carbon (TOC) in a test of TiO_2-FG was very slow. It follows that the degradation process is not the same as with the classic P25 TiO_2.

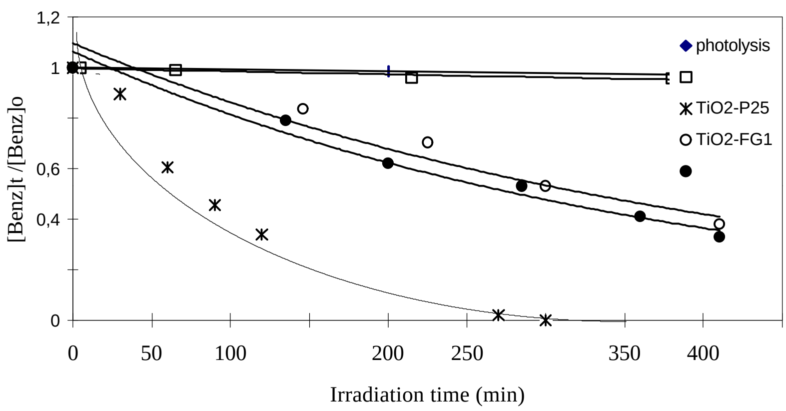


Fig. 2.5.4. Disappearance of benzamide with TiO_2 supported on glass-fibre and TiO_2-P25 in CPC experiments.

2.5.1.4 Dipartimento di Ingegneria Chimica dei Processi e dei Materiali, Università di Palermo (Italy).

The photocatalytic oxidation of free cyanide ions was carried out in aerated aqueous suspensions containing polycrystalline TiO_2 (anatase) irradiated by sunlight. The influence of the presence of an organic compound (phenol) or of a strong oxidant (H_2O_2) on the photoprocess was also studied. The dependence of the cyanide photo-oxidation rate on the following parameters: (i) cyanide concentration; (ii) amount of catalyst; and (iii) phenol concentration was investigated. Under these experimental conditions, the kinetics of cyanide photo-oxidation is independent of the initial cyanide concentration and of the amount of catalyst, while it is affected by the concentration of phenol and by the presence of H_2O_2. The results of this work indicate that the heterogeneous photocatalytic method can be successfully used for eliminating cyanide ions from wastewater with natural sunlight as the radiation. The photoreaction proceeds at a measurable rate until the complete disappearance of cyanide ions. The main oxidation products of cyanide ions are cyanate, nitrite, nitrate and carbonate ions.

At mild photo-process oxidation conditions the nitrogen mass balance in the dissolved compounds is not satisfied in the course of cyanate photooxidation, thus indicating the formation of some volatile species (see Fig. 2.5.5). Under strong oxidation conditions, however, the nitrogen mass balance is closely determined by the addition of H_2O_2 to the solution. The efficiency of the cyanide oxidation process decreases in the presence of a competitive oxidation reaction regarding an organic compound (phenol) present in the reacting medium. The kinetic model of Langmuir-Hinshelwood describes the photoreactivity results obtained with cyanide and cyanide-phenol solutions well.

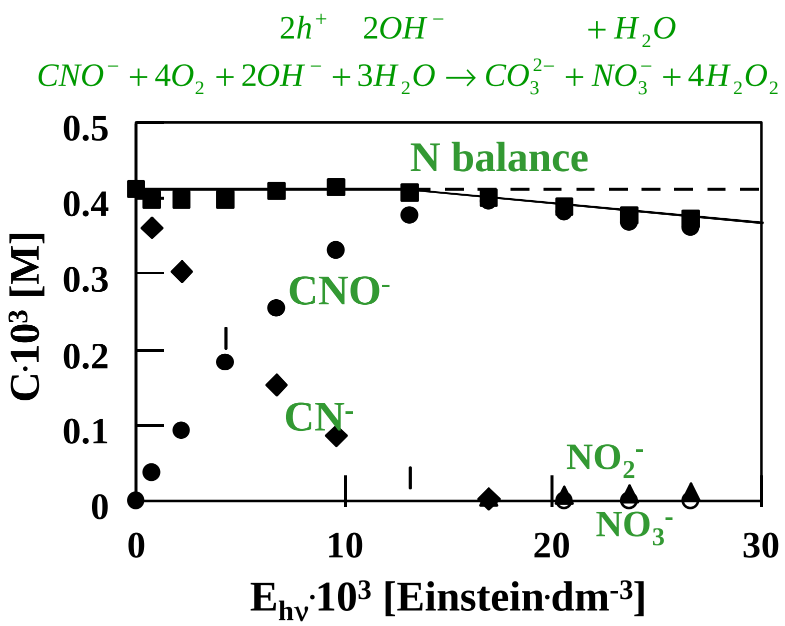


Fig. 2.5.5. Concentrations of cyanide, cyanate, nitrite, nitrate, and nitrogen balance versus the cumulative photonic energy, E_{hn}. Initial cyanide concentration: 0.41 mM.

2.5.1.5 Institute of Environmental Engineering, Laboratory of Biological Engineering, Swiss Federal Institute of Technology (EPFL, Swiss).

The degradation in TiO_2 suspension of different phenolic substances was studied in the CPCs to try to assess the structure-reactivity relationship. For this purpose both electron-donating (-OH) and electron-withdrawing ($-NO_2$, -COOH, $-SO_3^-$, -Cl) substituents at "para" position of the hydroxyl group were selected. p-hydroquinone (R-OH), p-nitrophenol ($R-NO_2$.), p-hydroxybenzoic acid (R-COOH), p-hydroxybenzenesulfonate ($R-SO_3^-$), p-chlorophenol (R-Cl) and phenol (R-H), where R is -PhOH, are representatives of some common and hardly biodegradable industrial compounds. The primary and ultimate degradation of the phenolic compounds in the presence of TiO_2 and H_2O_2 or in the absence of H_2O_2 were measured following the decrease of the compound concentration (HPLC) and Total Organic Carbon (TOC) as a function of accumulated energy (per unit of volume, KJ/L) incident on the reactor. For all experiments, the transformation of phenolic compounds can be described assuming a first order reaction, as seen in Fig. 2.5.6. The initial reaction rate (slope of the curve) for each compound shows the following reactivity trend:

$R-Cl > R-SO_3H > R-H \sim R-COOH \sim R-NO_2 > R-OH$.

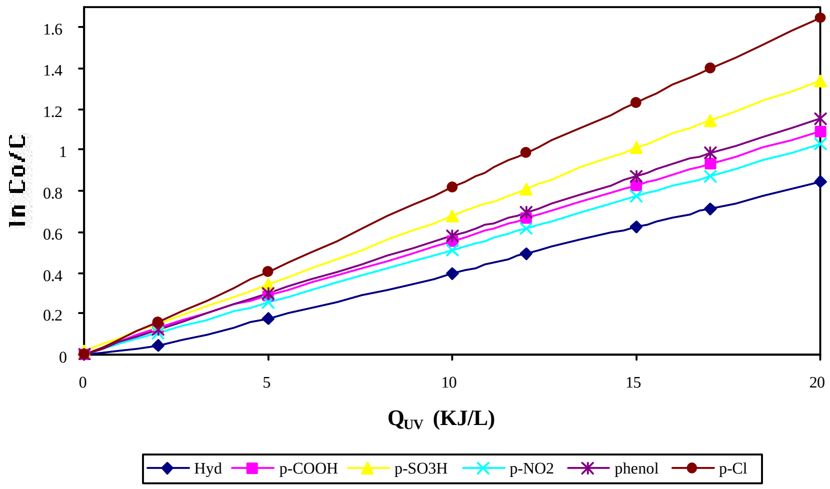


Fig. 2.5.6. First-order diagrams for the photodegradation of phenolic compounds (0.4 mM) as a function of accumulated energy in presence of TiO_2 (0.2 g/L).

Studies based on the compound characteristics, such as electron density, hydrophobicity, polarizability, adsorption on TiO_2 surface, etc., are in the moment carrier out at EPFL laboratories in order to obtain a quantitative estimation of the photocatalytic degradation of phenolic compounds. Furthermore, experiments of degradation of p-NTS (p-nitrotoluene-o-sulfonic acid), AMBI (5-methyl-6-amino-2-benzimidazolon) and two herbicides (Metobromuron and Isoproturon) in the HELIOMAN and CPC collectors were carried out in order to evaluate kinetic constants at different degradation processes (Fenton, TiO_2 and TiO_2 + H_2O_2)

and compare the photocatalytic process in different photoreactor systems.

2.5.1.6 Institut für Physikalische-und Umwelt-Chemie an der Universitat Bremen (Germany).

The photocatalytic oxidation of the pesticides pirimicarb and imidacloprid was studied in solar-irradiated TiO_2 suspensions at pilot-plant scale. The effect of additional TiO_2-concentration (ranging from 0 to 1000 mg/L) and pH (pH 3, 7 and 10) of the solution on the decomposition rates were examined. Addition leads to an increase in the reaction rates of both pollutants. pH dependence is also obvious, but dissimilar for the two pesticides (see Fig. 2.5.7). It may be concluded that solar irradiation of the pesticides pirimicarb and imidacloprid in titanium dioxide catalyst suspensions is a generally practicable technology. Based on these results, acid solution conditions are preferred for photocatalytic oxidation. To confirm this result, more lab-scale research will be done. On one hand, the ratio between photocatalysis at different pH will be determined and on the other, the amounts of pesticides adsorbed on the photocatalyst surface at various pH will be specified to provide more precise information about photocatalytic oxidation of these pesticides.

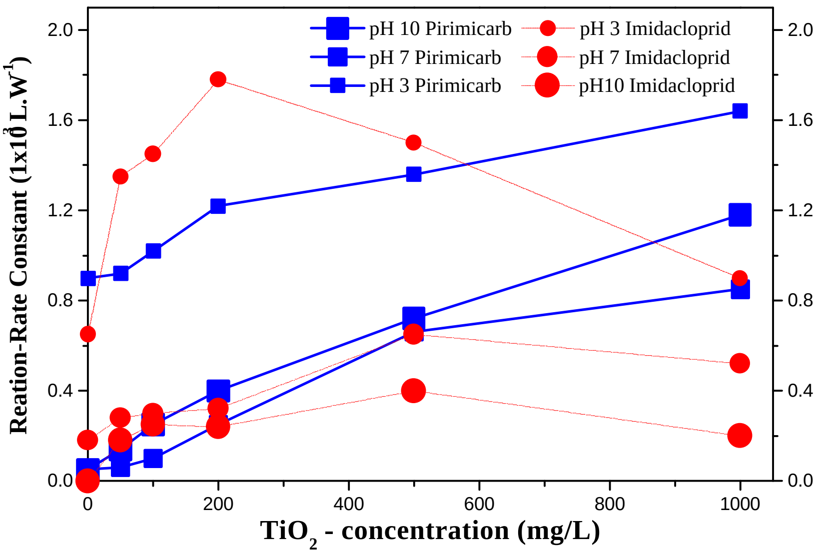


Fig. 2.5.7. Dependences of the reaction rate constants of the photocatalytic oxidation of pirimicarb and imidacloprid on the pH value of the solution and the TiO_2 concentration.

2.5.2 Recovery of Olive Mill Waste Water by Photocatalytic Detoxification and Disinfection (LAGAR)

The objective of this European Union project (approved in 1997 and begun in September, 1998) is the development of the best (e.g. cheapest) possibility of using sunlight for wastewater treatment with photochemical detoxification technology at pilot plant scale, for the mineralization of recalcitrant phenolic contaminants typically found in the soluble organic fraction of olive mill waste water (OMW). The following Project Tasks were undertaken During 1998:

- Task 2: Characterization of the OMW to be used in the photocatalytic experiments.

- Task 3: Treatment of OMW in the actual PSA pilot plants by different photocatalytic procedures (TiO_2 and Photo-Fenton).

OMW was taken directly from the waste-water effluent of a small olive mill in Tabernas, Almería (Spain). All the analyses of OMW were made on fresh samples (a few days after collection or frozen since then). The parameters analysed were:

COD:	86847 mg/L
Dissolved Phenols:	4400 mg/L
TOC:	33251 mg/L
pH:	5.1
Suspended solids:	23 g/L
Solid Residue:	69 g/L
Relevant anions:	phosphate 712 mg/L, chloride 495 mg/L sulfate 103 mg/L nitrite 5.5 mg/L.

Optical characterization is summarized in Fig. 2.5.8. Chemical treatment of wastewater by UV-irradiation, oxidants and/or catalysts (Advanced Oxidation Processes,) can achieve complete mineralization of the pollutants to CO_2. Combinations of an inexpensive biological process and an advanced oxidation process as a preliminary treatment are very promising for OMW as, although it has a high concentration of organics, most of them are biodegradable. Therefore, complete mineralization is not really necessary. The aim of this project is the destruction of the toxic compounds (mostly phenols) but without mineralization of the total organic content.

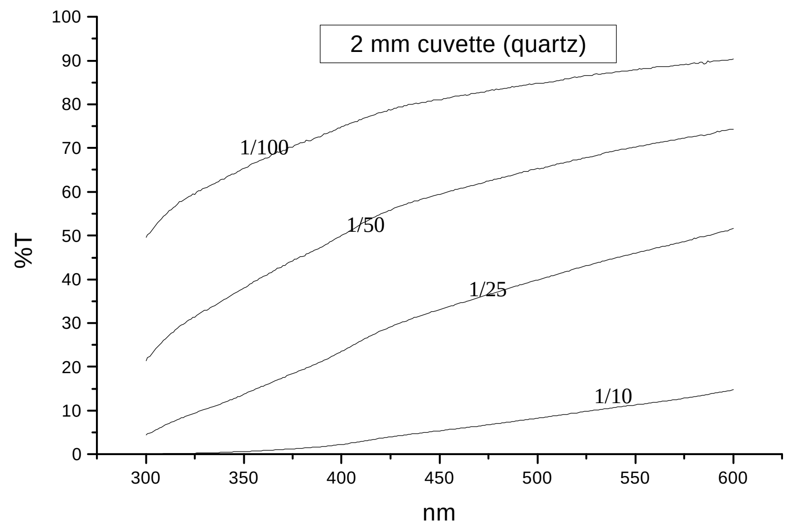


Fig. 2.5.8. Transmission spectra of OMW through 2 mm pathlength at different dilution ratios.

The active species responsible for the destruction of the OMW contaminants is in many cases the hydroxyl radical (•OH) with its very high oxidation potential (+2.8 V vs. NHE). It attacks almost all organics, but it especially favors unsaturated compounds in an aqueous solution. This unstable, and therefore very reactive, radical can be generated by various techniques:

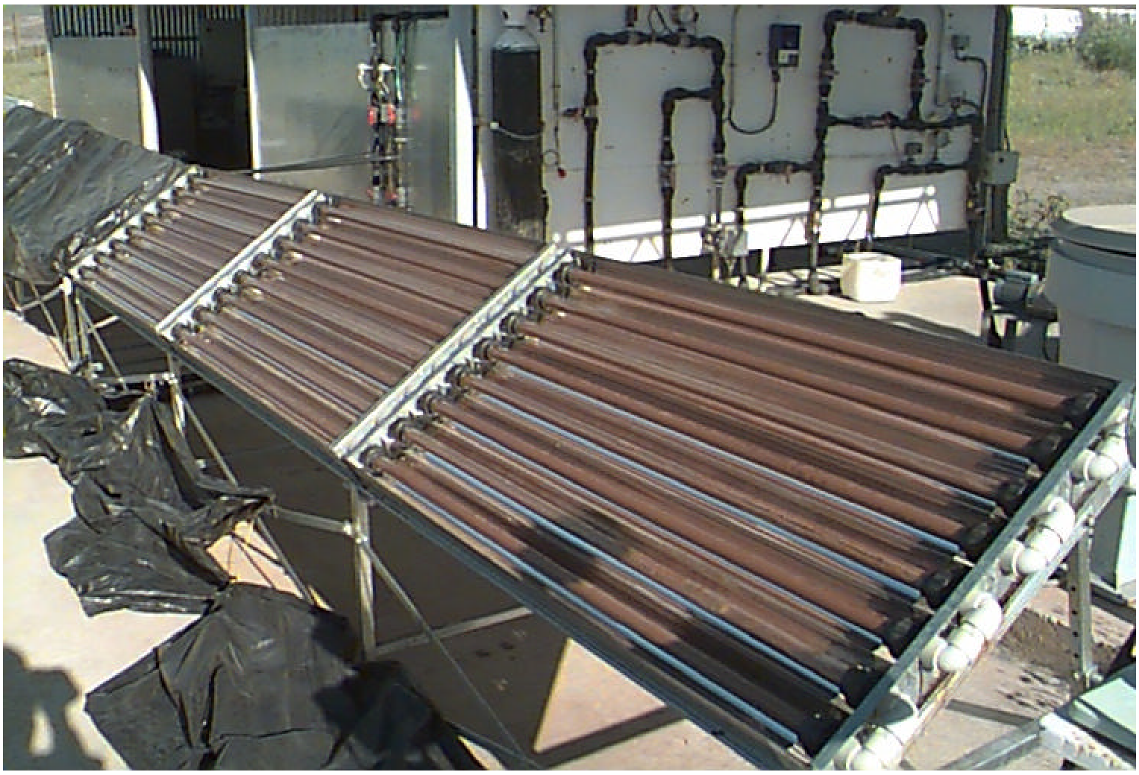


Fig. 2.5.9. CPC picture taken at the PSA during a typical experiment with OMW.

- TiO_2. Excitation of this semiconductor by irradiation of light with wavelengths below 390 nm is a method for $^{\bullet}OH$ radical production.
- TiO_2 + Persulfate. The effect of persulfate on many organic compounds has been long known. At high temperatures (90-130 ºC) it is capable of oxidizing them completely in a few minutes. A similar effect is obtained when electrons are generated in an aqueous solution which produces sulfate radicals from persulfate. So, reaction rate increases because the recombination of e-/h+ decreases considerably.
- Photo-Fenton Reaction. There are several natural reactions which help to decompose waste compounds. Iron, the fourth most abundant element in the earth's crust, plays a leading role in these ecological cycles, mainly as a photocatalyst with the sun as excitation light source. Among others, the Photo-Fenton reactions take place in atmospheric water droplets, for instance, and are also applied effectively for artificial treatment of waste-water.

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + {}^{\bullet}OH$$

$$Fe^{3+} + H_2O + hn \rightarrow Fe^{2+} + H^+ + {}^{\bullet}OH$$

Unfortunately the high power demand for the UV-lamps decreases the attractiveness of AOPs. Therefore, substituting the UV-irradiation by sunlight appears desirable. This is possible for the three processes mentioned. Two different variables have been chosen for the comparison of the photocatalytic treatments applied: Dissolved Phenols and COD. In Fig. 2.5.10 the COD behavior is shown.

Photo-Fenton reagent is clearly more effective than titanium dioxide with or without persulphate. Iron 5 mM with hydrogen peroxide 20 g/L (constant concentration) is the most effective for COD degradation between the different Photo-Fenton experiments carried out. In any case, the Photo-Fenton conditions have not been optimised for the moment. As it can be seen in Fig. 2.5.11, phenols are easily degraded with lower iron concentration (1 mM).

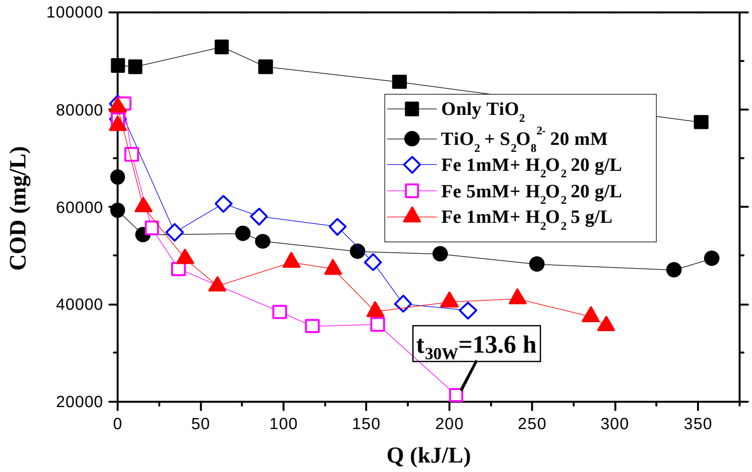


Fig. 2.5.10. OMW Photocatalytic treatment with TiO_2, TiO_2+persulphate and Photo-Fenton reagent COD behaviour.

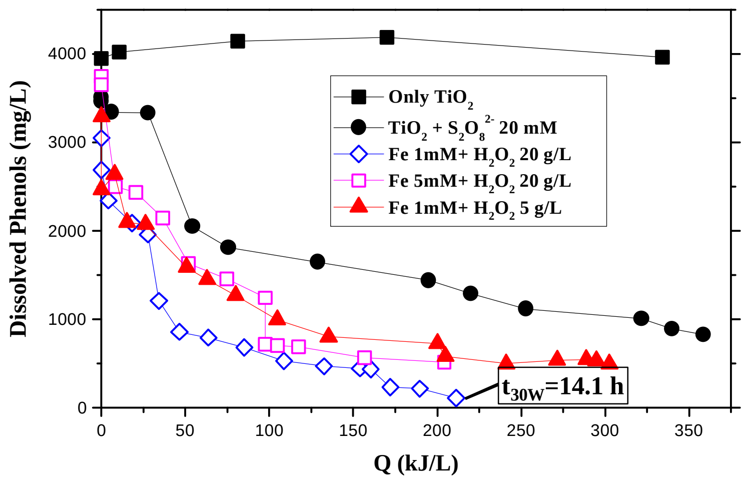


Fig. 2.5.11. OMW Photocatalytic treatment with TiO_2, TiO_2+persulphate and Photo-Fenton reagent. Dissolved phenols behaviour.

OMW has been successfully treated with Solar Energy at pre-industrial scale. The Photo-Fenton reaction was the most suitable of the photocatalytic methods used, however more experiments are necessary to optimize the process and a photoreactor will therefore be designed for the best possible handling of the Photo-Fenton reaction in later LAGAR Project Tasks.

2.5.3 Solar Detoxification Technology in the Treatment of Industrial non-Biodegradable Persistent Chlorinated Water Contaminants (SOLARDETOX)

The "Solar Detoxification Technology in the Treatment of Industrial non Biodegradable Persistent Chlorinated Water Contaminants (SOLARDETOX)" project is funded by the European Commission under the BRITE-EURAM III Program. The project consortium is made up of 8 project partners: a solar collector manufacturer (AO SOL, Portugal), components manufactures (SCHOTT, Germany; ENEL, Italy), a user of the technology (HIDROCEN, Spain), and an environmental & engineering consulting company (ECOSYSTEM, Spain), with the assistance of three photocatalitic research groups recognized worldwide (from University of Torino, Italy, DLR, Germany and CIEMAT, Spain). The 3-year project, coordinated by CIEMAT (Centro de Investigaciones Energéticas Medioambientales y Tecnológicas), started in June 1997.

The direct industrial objective of all this research is to develop a solar detoxification system for the treatment of industrial emissions (at medium/low concentrations) of recalcitrant hazardous organic water contaminants, including complex mixtures, from almost any chemical activity, using solar radiation as the energy input. Specifically, the project addresses industrial non-biodegradable chlorinated hydrocarbon solvents present in water, as from the manufacture of fine chemicals, printing, area cleaning, pharmaceutical manufacturing, painting of car, dry cleaning, textile and paper coatings, manufacture of coating materials, etc.

2.5.3.1 Objectives

The main focus and innovations in this project are specific technological developments in solar photocatalysis. The objective is to make the solar detoxification technology commercial. This includes demonstrating the feasibility of photocatalytic treatment of typical persistent non-biodegradable chlorinated contaminants in water found in the effluents from production of chemical.

C_1 and C_2 non-biodegradable chlorinated hydrocarbon solvents (NBCS), such as methylene chloride, trichloroethylene, tetrachloroethylene, chloroform, methyl chloroform, etc., have not been replaced in industrial chemical process reactions until now. Furthermore, large amounts of water contaminated with NBCS are still untreated and urgently need further purification. Due to the fact that they are not biologically degradable, they are a hazard for water resources, especially drinking water. Traditional removal methods used in industrial process water, such as stripping, adsorption by activated carbon, thermal or chemical oxidation methods, have important disadvantages or limitations in the treatment of low concentrations of organic pollutants.

The basic idea of the project is the development of a solar detoxification system, based on the simple, inexpensive and efficient non concentrating solar collector technology which is also able to destroy most of the persistent NBCS at low concentrations. Once the system is ready for industrial use, typical applications are expected to occupy only a few hundred square meters of solar collector field.

The main objective is the optimization of technical and economic aspects of real solar detoxification technology (SOLARDETOX) application. This main project goal could be subdivided into the more specific scientific, engineering and strategic objectives.

Scientific objectives

- Assessment of the performance and best working conditions for the catalyst powders developed compared with the efficiencies of commercial products (Degussa P25), in the treatment of chlorinated solvent compounds.
- Assessment of the degradation process mechanisms of the.
- Evaluation of photonic efficiencies.
- Determination of formation of side products.
- Kinetic modeling of the process from degradation data.

Technological and engineering objectives

The engineering objectives are the focus and also the main innovations in this project. Since the existing solar detoxification technology began with minor modifications of solar thermal technology, specific technological developments are lacking:

- Glass reactor with high solar UV transmissivity.
- Solar collector upgrading design.
- Catalyst upgrading and supporting.
- Highly efficient UV reflective surface.
- Demonstration of technical and economical feasibility under real conditions.

Strategic objectives

The strategic objectives of the project may be summarized as follows:

- A well-defined system by standardization of optimum component designs (i.e., materials, diameters, thickness, suppliers, etc.) and quality assurance, in order to minimize production and erection costs.
- A reasonable turnkey system cost.
- Low system operating costs in order to become competitive with standard hazardous waste transport costs.
- A consortium made up of industrial and institutional partners.

This process and its associated technology are fully devoted to hot environmental subjects and the results will be immediately translated into environmental benefits and sustainable development. All prospective studies show that environmental technologies and the environmental market itself will be very relevant in the next century and of key importance to the creation of jobs.

2.5.3.2 Scientific and Technological Project Achievements

Some of the most relevant scientific and technological achievements are the following:

Basic chemistry

The UNIVERSITY OF TORINO (Italy) studied the basic chemistry of the solar detoxification degradation of previously mentioned chlorinated solvents.

Degradation experiments were carried out to determine the type of catalyst and the best operating conditions to be used with real mixtures. From these, it was observed that the disappearance of Total Organic Carbon (TOC) closely follows that of the most concentrated compound in the solution, namely $CHCl_3$. The evolution of chlorides closely matched the disappearance of TOC, but over long degradation times. When TOC is not completely abated, the residual organic molecules do not contain bound chlorine. Thus, for the purpose of decontamination, it is not necessary to obtain complete conversion to CO_2.

The final products of degradation are CO_2, HCOOH, HCHO, Oxalic acid, glyoxilic acid, glyoxal (see Fig. 2.5.12), depending on the degradation time (Calza, Minero and Pelizzetti, 1997). Toxicity related to chlorinated compounds disappears, as Cl^- is completely degraded.

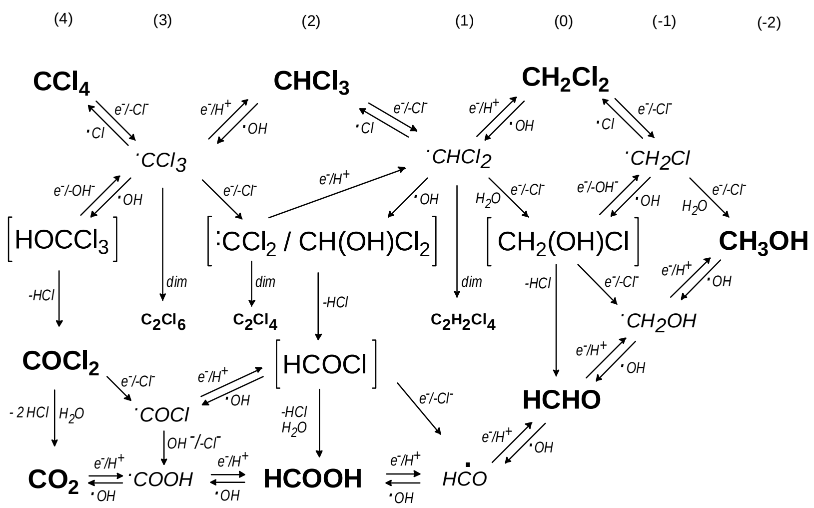


Fig 2.5.12. C_1 chlorinated compounds degradation pathways (Calza, Minero and Pelizzetti, 1997)

TiO_2 Catalyst

A significant improvement in catalyst efficiency compared to P-25 Degussa titania was obtained at ENEL laboratories (Italy) by synthesizing TiO_2 powders with an innovative process based on the pyrolysis of suitable reactant vapors induced by a CO_2 laser beam. This improvement is attributable both to the higher specific surface area of the laser-powders and to better crystallization obtained with suitable thermal treatments. Degussa P25, considered in the literature to be the best titania photocatalyst, is also produced through a vapor-phase method (flame pyrolysis) but its surface area is considerably smaller (50 m^2/g) than that of the laser powders. Moreover P25 particle dimensions are non-uniform and the crystalline structure is about 30% rutile.

TiO_2 laser powders tested at solar experimental photocatalytic plants in slurries have better efficiencies in comparison with P25 titania, mainly when suspensions at high TiO_2 concentrations (1 g/l) are used (Fig. 2.5.13).

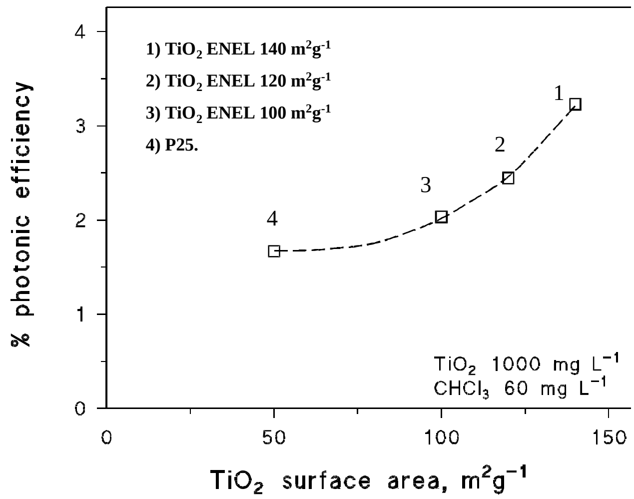


Fig. 2.5.13 Trichloroethylene photocatalytic degradation: photonic efficiency of different ENEL catalysts and Degussa P25

UV reflective surface

In order to improve the efficiency of non-concentrating solar collectors for photocatalytic applications, a new mirror with increased UV reflectivity has been developed by CIEMAT. The idea is to increase reflectivity within a narrow wavelength range, including the appropriate UV range (300-400 nm), by optimizing the optical length of a TiO_2 + SiO_2 interface stack used to manufacture a reflective mirror for solar collectors, which would then have up to 95% efficiency in the UV range of the solar spectrum. For this purpose a layer of one highly refractive material (TiO_2) is alternated with another with a low refractive index (SiO_2), both with a quarter-wave optical thickness, as shown in Fig. 2.5.14. Aluminum is applied using the Sol-Gel technique with the appropriate metal alcoxides.

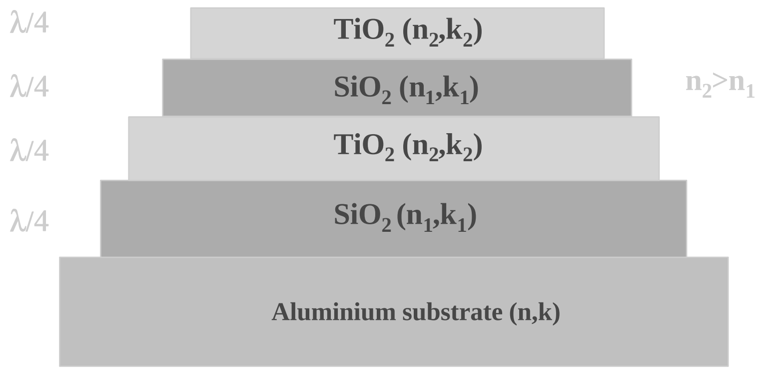


Fig. 2.5.14. Sol-gel-enhanced UV-reflectance interference stack mirrors

The German company, SCHOTT-ROHRGLAS, addressed the improvement of glass tubular reactors for solar photocatalytic applications. Two undesired effects reduce the performance of a glass reactor for solar detoxification: increased absorption in the solar UV-range between 300 and 400 nm and a further decrease of UV-transmissivity during operation due to the damaging impact of solar radiation in the same wavelength region (UV-solarization).

Both effects are caused by polyvalent ions changing their charge. The influence of Fe-ions in the glass is especially harmful, changing their charge from Fe^{2+} to Fe^{3+} by photo-oxidation with photons of a wavelength lower than 400 nm (Fig. 2.5.15). Furthermore, the oxidized Fe^{3+} ion absorbs in the UV. In order to increase long-term performance of the detoxification reactor, two different ways to attain higher UV-transmissivity and prevent UV-solarization have been examined: reduction of the iron content in the raw material and reduction of iron(III)-content by a melting process under reducing conditions.

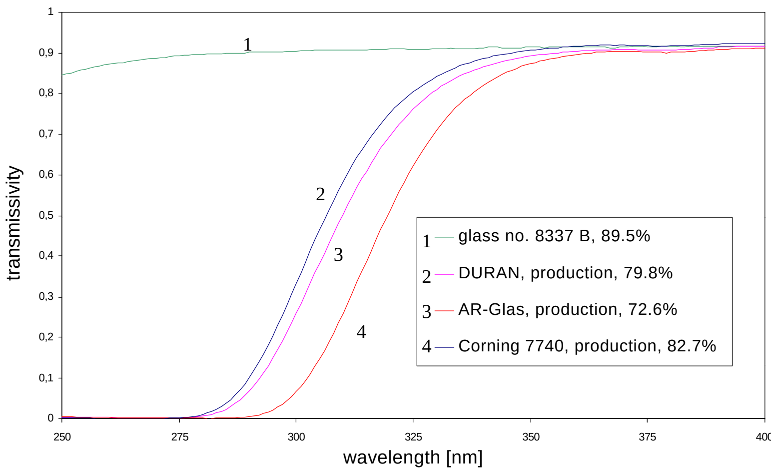


Fig. 2.5.15. Transmissivity spectrum of different special glasses

In conclusion, it may be affirmed that the enhancement to transmissivity in the region of 300-400nm can only be reached by strongly reducing iron content to 50 ppm.

Solar collector engineering

INETI and AOSOL have identified construction, structural, mechanical and optical problems in non-concentrating solar collectors systems. CPC collectors were constructed based on the following final design data:

Acceptance angle:	90º
Truncation angle:	90º
Internal absorber radius:	14.6 mm
External absorber radius:	16.0 mm
Optical gap:	1.4 mm
Sunlight concentration ratio:	1.0

The CPC consists of 16 parallel 1.5-m-long tubes with a highly reflective anodized aluminum reflector on a galvanized supporting plate. At the end of each collector tube there is a connection to the adjacent tube forming a row of collectors connected in series which is the complete module. In the prototype plant, each parallel row has 21 collectors. The modules are E-W orientated with a slight structural tilt (1%) to keep the CPC troughs dry and avoid accumulation of rain water. Fig. 2.5.16 shows the first collector support structure erected with different possible angles of tilt.

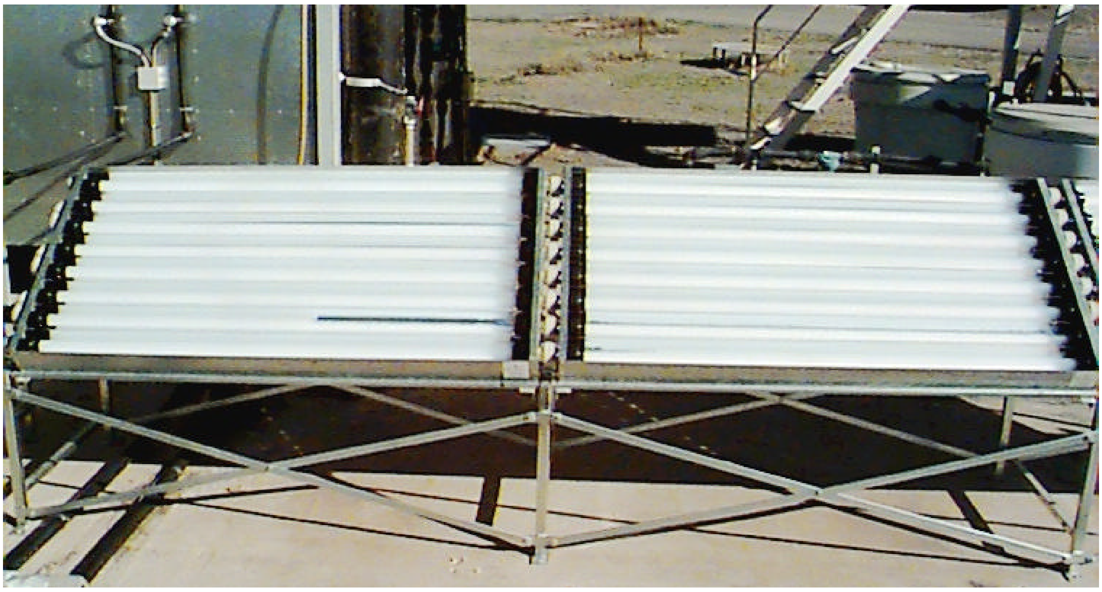


Fig. 2.5.16 Modular CPC structure designed for easy assembly.

TiO_2 slurry catalyst recuperation

In spite of the possible advantages of a supported catalyst configuration, slurry systems are much more efficient, resulting in a considerable reduction in the final treatment cost. So the process of recovering the catalyst from slurry for later reuse has also been studied at CIEMAT in cooperation with the University of

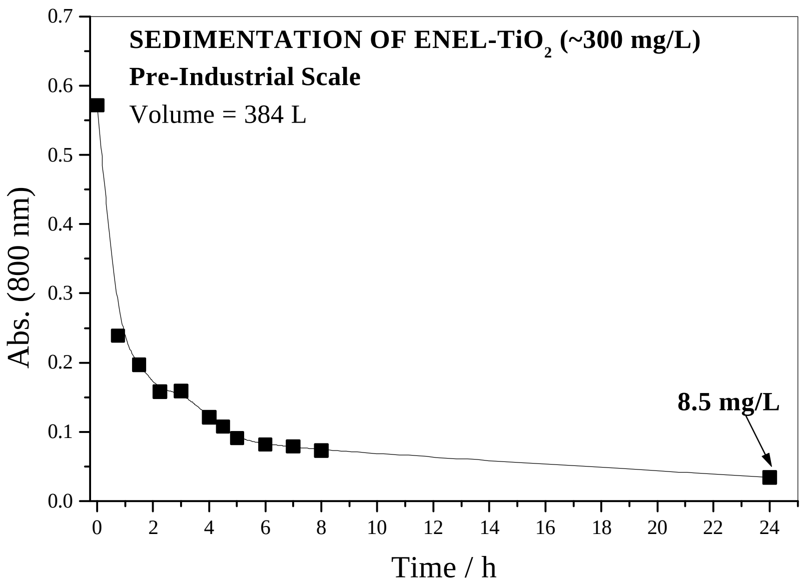


Fig. 2.5.17. Sedimentation experiment of ENEL-TiO_2 catalyst.

Almería. Catalyst recuperation was achieved by induced accelerated sedimentation of TiO_2 particles after characterizing the colloidal stability of catalyst particles in aqueous suspension.

To assess this method and its transfer from lab to pre-industrial scale, a pilot plant was erected at the PSA for testing catalyst recuperation by sedimentation and reuse after degradation experiments with TiO_2-ENEL and P25 suspensions. Fig. 2.5.17 shows the progression of absorbence over time during one of the experiments performed. This figure demonstrates that after about five hours of storage, almost all the particles have been deposited at the bottom of the tank. The photocatalytic degradation test had a total of 384 L of suspension. A sample taken after one night yielded a nearly negligible catalyst concentration (around 8.5 mg/L) as represented by the final point in Fig. 2.5.17. This small remaining fraction of catalyst can easily be recovered by microfiltration due to the low TiO_2 concentration.

This method of TiO_2 catalyst sedimentation and recovering is currently pending patent.

Toxicity assessment after photocatalytic treatment.

Toxicity tests with standardized ecotoxicity systems are useful in aqueous waste evaluation because chemical and physical tests alone are not enough to assess the effects on aquatic biota. Some ACUTE toxicity tests were employed for solar photocatalytic degradation of pure halogenated compounds and toxicity of Chloroform (CCl_3H) and Perchloroethylene (C_2Cl_2) was found to have been greatly reduced after Solardetox treatment, based on Microtox ® and Daphnia Magna tests (Fig. 2.5.18).

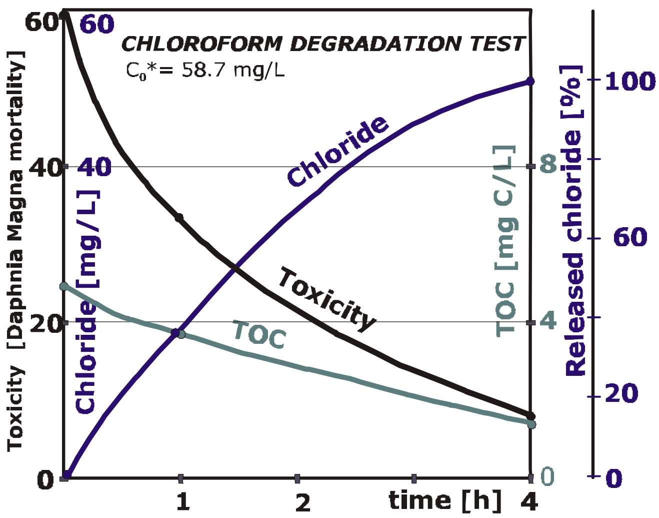


Fig. 2.5.18 Toxicity evolution during photocatalytic degradation of chloroform, using Daphnia Magna microcrustaceous.

2.5.3.3 Technology Demonstration: Pilot Plant

Two types of prototypes were built in duplicate for testing at the PSA and DLR: one without catalyst to be used with slurries and another with an immobilized catalyst. Four non-biodegradable chlorinated solvents (NBCS), chloroform ($CHCl_3$), dichloromethane (CH_2Cl_2), trichloroehylene (C_2HCl_3) and tetrachloroethylene (C_2Cl_4), were tested in concentrations of 20, 200, 50 and 50 mg/L, respectively. The efficiency of the ENEL-TiO_2 catalyst, as well as many other process parameters, were studied by degrading mixtures of the 4 compounds. The appearance of chloride measured as [Cl^-] in (mg/l) can be used as a parameter to determine the degradation of the NBCS.

Degradation of the single compounds in the two different prototype reactor units is illustrated in Fig. 2.5.19, where the rate of degradation is plotted as a function of the amount of energy supplied by solar irradiation (UV-range of the solar spectrum), per volume of the illuminated reactor unit

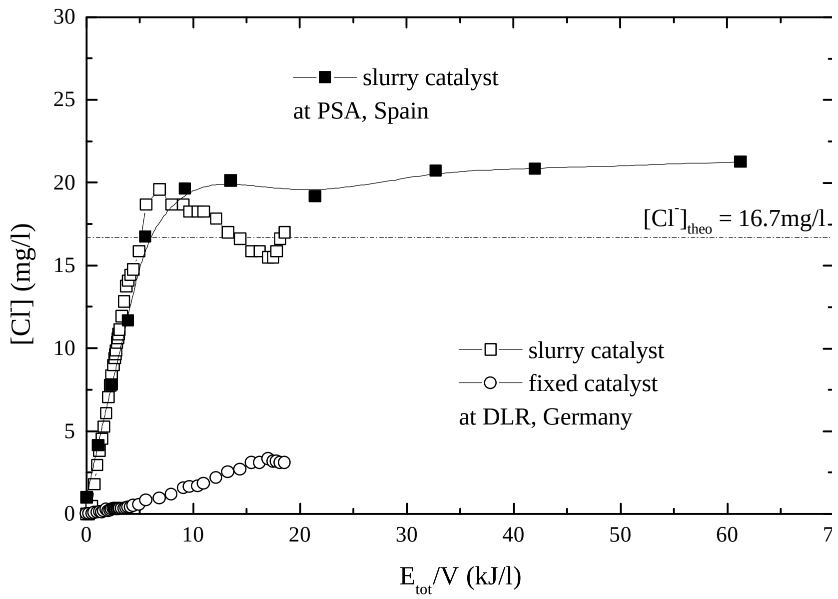


Fig. 2.5.19 Degradation of 20mg/l CH_2Cl_2 at DLR, Germany (open symbols) and at the PSA (solid symbols) as a function of accepted solar energy per liter.

A complete pilot plant will be designed and erected (summer 1999) at the installations of HIDROCEN (Spain) (Fig. 2.5.20). This 100-m^2 collector aperture plant will be designed by ECOSYSTEM to treat 2 m^3 of water contaminated with the selected NBCS compounds, in approximately two hours (depending on solar irradiation), in a batch system. This plant, intended as a demonstration of what a commercial plant would be like, was designed with fully automatic systems for minimum operation and maintenance requirements.

The main items of the plant designed are: TiO_2 recovery; buildings, foundations and pits (civil engineering); pumps, piping and fittings; hydraulic system; automation and control; reservoir tanks; engineering; electrical and mechanical installation. Main plant parameters are: i) 2 Modules (21 collectors each) in parallel rows; ii) total collector aperture area: 100 m^2; iii) total volume of the circuit: 800 L; iv) total volume of the plant: 2000 L; v) catalyst use configuration: slurry; vi) completely sealed and air injection.

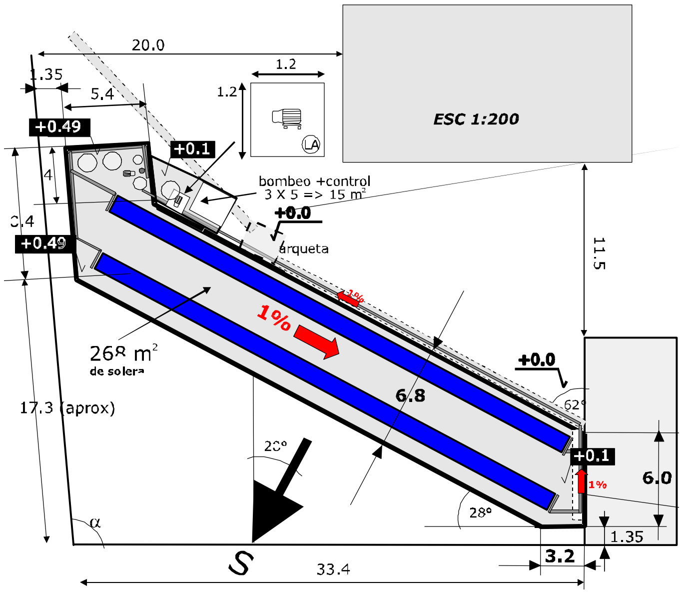


Fig. 2.5.20 Demonstration plant layout. Solar collector field aperture area = 100 m². CPC solar collectors are located in two parallel rows of 31 m length each.

2.5.4 Collaboration within the European Commission TMR Program (TMR-SOLFIN)

Some Fine Chemicals (substances produced in small amounts (<100 tons/year) but which have high prices (>$100/kg)) are currently produced by photochemical synthesis, using electric lamps as the light source. In some cases, sunlight could serve as well, thus avoiding the wasteful fossil-fuel→electricity→lamp production chain. Therefore, growing effort has been exerted during the last decade to mutually adapt modern solar technology and the chemical engineering of photochemical synthesis. Within this context, the PSA Solfin Facility, funded since 1996 by the CEC Program for Training and Mobility of Researchers, gives investigators in preparative photochemistry the possibility to test their reactions with solar light. A great variety of synthetic reactions have been tested and promising candidates for further optimization can be identified. At the same time, young graduate research chemists learn about the feasibility of direct application of solar radiation for photochemical synthesis.

As the main summarizing result, the efficiency of a relatively simple nonconcentrating CPC collector system for performing preparative synthetic reactions on a small and medium scale using solar radiation was clearly demonstrated. The great majority of the reactions could be performed smoothly and easily with the solar photoreactor, in many cases yielding a high percentage of turnover of the initial material during a time comparable or in some cases considerably faster than with traditional laboratory UV-lamps. The latter seems surprising at first sight, given the relatively low percentage of UV-radiation in the solar spectrum, but can be explained by the continuous emission of the sun in the UV region compared to the line emission of a typical UV-lamp.

The total photochemically useful spectrum available is therefore very similar under solar conditions, as shown in Fig. 2.5.21.

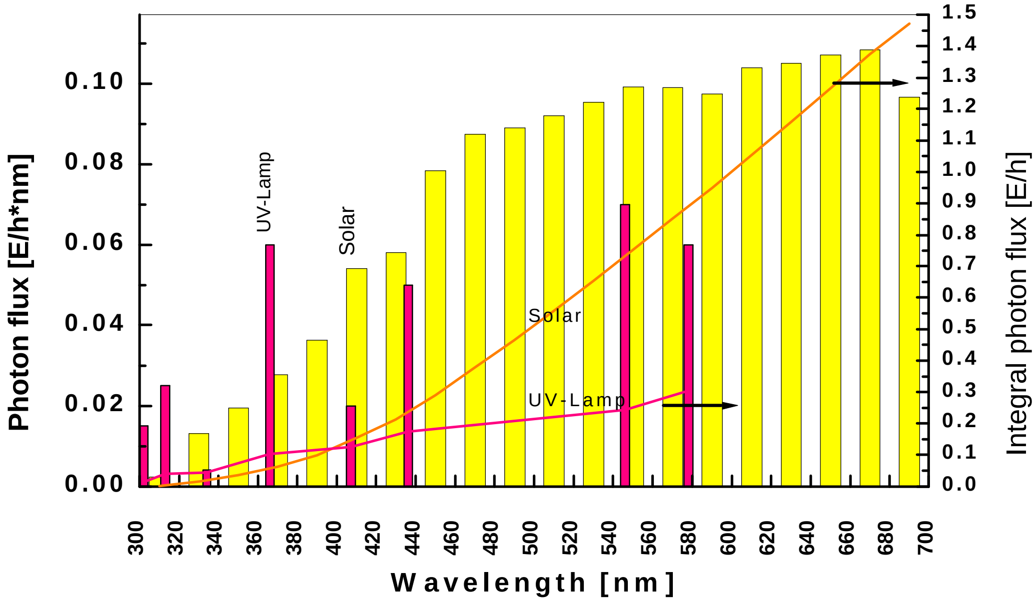


Fig. 2.5.21 Photon flux available from a medium-pressure laboratory UV-Lamp and in a solar photoreactor with 0.2 m^2 aperture. Left axis: Spectral photon flux (Emission lines of UV-lamp; flux in 20 nm range of solar spectrum). Right axis: integrated photon flux.

Five European photochemical research groups from England, Germany, Ireland and Italy received funding from the TMR Program to perform the tests summarized briefly below.

2.5.4.1 Dept. of Chemistry, University of Reading (England)

The experiments in sunlight-induced regio- and stereo-specific ($2\pi + 2\pi$) cycloaddition of arylethenes to 2-substituted-1,4-napthoquinones were continued, with special attention to the effects of temperature and concentration of the initial material. 2-Acetoxy-1,4-napthoquinone undergoes photochemical regio- and stereo-specific ($2\pi + 2\pi$) addition to styrene and 1,1-diphenylethene with high yields. Cyclobutane formation essentially occurs quantitatively in sunlight

A conversion of more than 96% was achieved in 4-6 hours exposure depending on the concentration of the 2-acetoxy-1,4-napthoquinone. Furthermore, the adducts obtained directly from removal of the solvent from the reaction mixture were highly pure: in particular, the minor by-products using artificial light were not evident in the high-resolution 1H NMR spectrum of the raw material produced with solar irradiation. It was also evident that the concentration of quinone can be increased to 6% w/v without any adverse effects on the reaction rate: this has the advantage of increasing the quinone absorption cut-off point from 370 nm to 430 nm (at 1.5 absorbance) in the region of strong increase in solar emission and so producing higher yields of cyclobutane adducts in shorter exposure times. The photoaddition reactions are also not affected by temperature increases up to 60°C so that cooling of the water containing solar-irradiated solutions is not essential.

2.5.4.2 Inst. f. Organische Katalyseforschung an der Universität Rostock (Germany)

Pyridine derivatives are of considerable interest in academia and industry, for example, as building blocks for drugs or basic chemicals. They can be obtained by Co^{I} catalyzed cocyclization under normal pressure and room temperature by supplying the reaction with photon energy. This photocatalyzed methodology allows a broad spectrum of mono- or higher (up to penta-) substituted pyridines to be synthesized under ambient conditions. Either alkyl-, alkoxy-, amine-substituted nitriles or nitriles with double bonds or alkynylnitriles may be cyclized with ethyne or variously substituted alkynes or diynes.

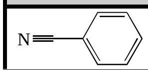
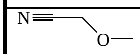
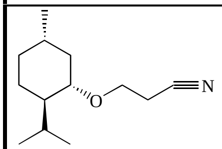
Besides aryl- and alkyl-, alkoxy-substituted nitriles are also suitable for cocyclization with ethyne. [CpCo(cod)] as well as other precatalysts substituted on the Cp ring can be used. In order to study whether synthesis under solar photochemical conditions can be run successfully in water, even with different nitrile compounds, nitriles with various substituents reacted with ethyne with very satisfying results as shown in Table 2.5.1.

2.5.4.3 School of Chemical Sciences, Dublin City University (Ireland)

During their July visit, a number of additional arylidenecyclopentanone oxime ethers/acetates were irradiated using the Solfin solar reactor. Photolysis was carried out with oxime ether/acetate solutions (1.4x10-2 M, 2.5-3 g of oxime derivative) in 99.8% pure UV-VIS-grade methanol (1200 cm^3). Three different compounds were tested:

2-(2-Napthylidene)cyclopentanone oxime methyl ether: This reaction was complete after 600 min. The GC trace showed smooth degradation of the initial isomer and formation of the other three geometric isomers, followed by their degradation and

Table 2.5.1 Chemoselectivity in the cycloaddition of ethyne with different nitriles in water with 2-5 vol% toluene

Nitrile	Mol (nitrile)	Mol [cpCo(cod)]	Time [min]	turnover of nitrile [%]	yield of benzol [%]
	0.1	0.001	480	91	2.4
N≡—$(CH_2)_{10}$—	0.76	0.008	280	19	0.3
	1.6	0.008	90	12	1.3
	0.75	0.0075	295	52	1.2

evolution of the product. Isolation and purification gave a 62% yield of cyclised product.

2-Furfurylidenecyclopentanone oxime acetate: After 480 min. the GC analysis showed decay of the starting isomer, formation of the 3 other isomers and then formation of the cyclised product. The GC of the product mixture shows 81% conversion of the starting geometrical isomer. A 64% product yield was isolated.

2-(2-Pyridyl) ethenylcyclopentanone oxime acetate did not cyclize as the other oxime acetates had done. After about 60 minutes, the initial isomer had been consumed and a single product formed. This was isolated as a brown gum and its NMR spectrum shows it to be an isomer of the initial material. Further solar irradiation of this product over 1000 minutes leads to its smooth conversion to another single product, as shown by GC analysis. NMR of this product shows it to be another of the geometric isomers which could be isolated as a white solid with a 58% yield.

2.5.4.4 Dip. di Chimica e Centro di Studio su Fotoreattività e Catalisi del C.N.R. Università degli Studi di Ferrara (Italy)

Tests of some inorganic photocatalysts such as TiO_2, polyoxotungstates and iron(III) porphyrin complexes in the oxidation of hydrocarbons by O_2 under solar light were performed. They can work efficiently with interesting results which well correlate to laboratory experiments with Hg medium pressure lamp.

Fig. 2.5.22 shows results of TiO_2-catalyzed oxidation of cyclohexane. In pure cyclohexane the formation of ketone predominates over that of alcohol. It also shows the formation of both cyclohexanol and cyclohexanone when the suspended TiO_2 is irradiated in a more polar solvent. The overall rate of formation of

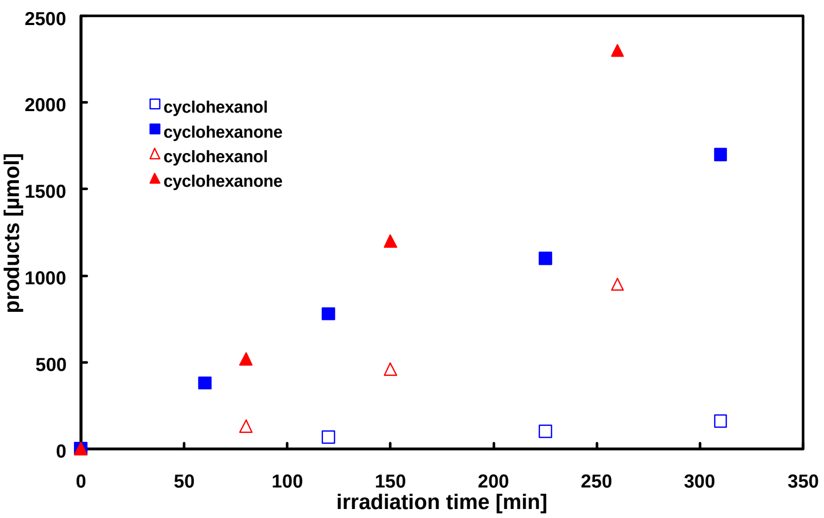
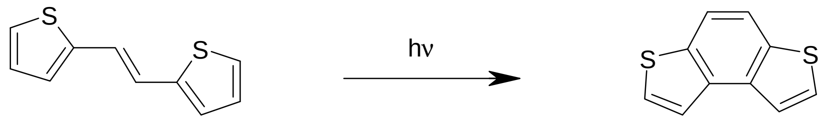


Fig. 2.5.22 Effect of the reaction medium on the solar assisted oxidation of cyclohexane on TiO_2 suspensions in pure cyclohexane (square symbols) and in cyclohexane/dichloromethane 1/1 (triangle symbols) respectively.

alcohol and ketone increases in the solvent mixture, in particular that of cyclohexanol. These results are in a very good agreement with those obtained with a UV-lamp. The nature of the solvent can control surface reactions through a modification of adsorption-desorption equilibrium of reagents and intermediates.

2.5.4.5 Dipartimento di Chimica del Politecnico, Milano, (Italy)

The fundamental photochemical step for the synthesis of a class of helicenes was investigated under solar conditions. These heterohelicenes belong to a family of molecules that can be prepared with good yields by the photoinduced cyclodehydrogenation of appropriate 1,2 diheteroarylethylenes. The helicenes are formed of ortho-condensed aromatic or heteroaromatic rings.



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SCHEME 1

When these reactions were run in the Solfin reactor they were completed in a shorter time (generally 2 h, compared to >10h) with chemical yields similar to the ones obtained in the Rayonet reactor in the laboratory.

2.6 Materials treatment

Included in the EU DG-XII "Training and Mobility of Researchers Access to Large Scale Facilities" programme, the High Flux Concentration Facility Solar Furnace (HCF) was used by four European research groups for testing ceramics and metals.

The "Ecole National Superieur de Mines de Paris" studied the thermal behaviour of different refractoriy materials subjected to thermal shock, while tests by the National Tecnichal University of Athens focused on cladding steels and cast iron using predeposited ceramic powders. The production of metal carbides and carbonitrides is the goal of the Portuguese "Instituto Superior Tecnico de Lisboa", and the Finnish Helsinki University of Tecnology tested tool steels exposed to thermal cycles in the PSA Solar Furnace

Diego Martínez
Area Head

José Rodríguez

2.6.1 High Flux Concentration Facility (Solar Furnace)

The many possibilities the sun's high quality energy offers in the field of very high temperatures and flux densities motivated construction of the PSA Solar Furnace. In operation since 1991, it has been devoted to materials treatment in the framework of the European Union "Training and Mobility of Researchers" program.

The main components are the Heliostats, parabolic concentrator, louvered shutter and test table.

Four heliostats reflect the sunlight onto the concentrator, which in turn concentrates it on the focus, at the test table, 7.45 m in front of the concentrator. Concentration of sunlight is regulated by a louvered shutter placed between the heliostats and the concentrator. A movable test table holds the specimens in the focal spot.

The heliostats have a flat, non-concentrating, reflective surface of 53.61 m^2 per heliostat that reflects collimated solar rays horizontally and parallel to the concentrator. They are computer controlled to track the sun continuously and have a 90% reflectivity.

The 11.5-x-11.2-m louvered shutter is compose of 30 slats arranged in two columns. The slats are moved by a stepping motor with 15896 positions between 0º (open) and 55º (closed).

The parabolic dish concentrator consists of 89 spherical, sandwich-type facets (0.91 x 1,21 m) and has a total reflecting area of 98.5 m^2, 94% reflectivity and focal length of 7.45 m.

Specimens to be tested are placed on the mobile test table (0.6 m x 0.7 m), a platform having movement on three axes: X= 850 mm (east-west); Y= 600 mm (concentrator axis) and Z= 450 mm (up-down).

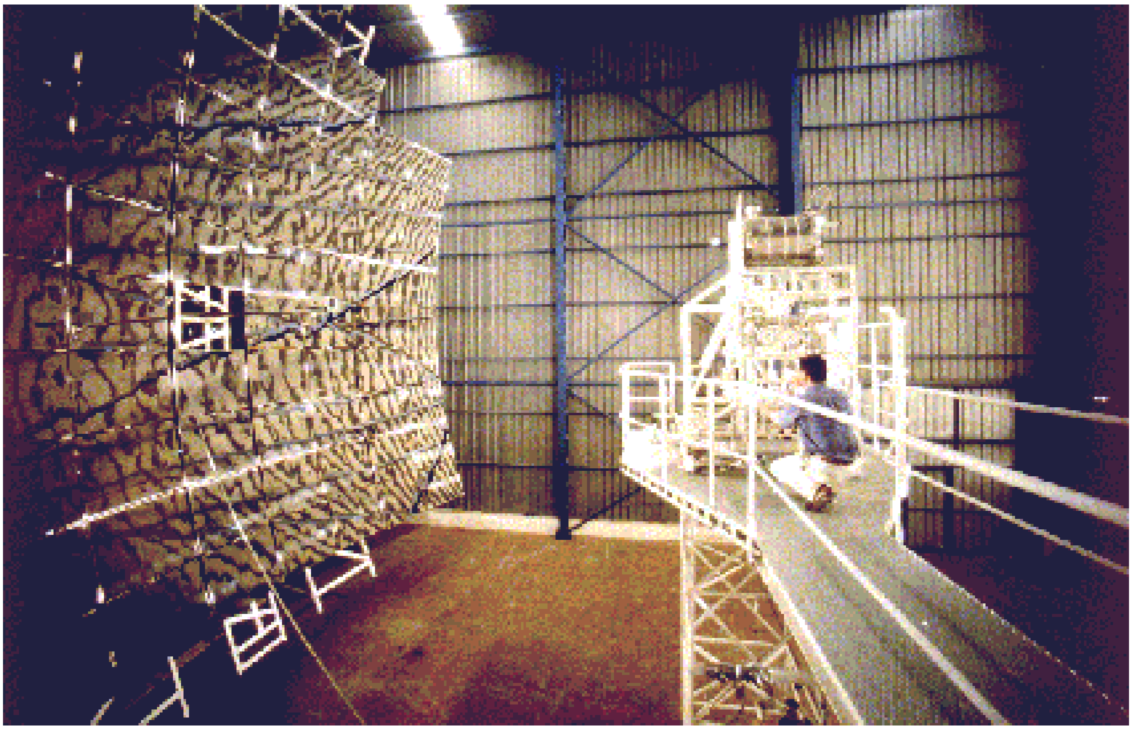


Fig. 2.6.1 Concentrator and vacuum chamber

2.6.1.1 Tests carried out in the Solar Furnace

The materials treatment experiments accomplished in the HCF are included in the European Union DG-XII “Training and Mobility of Researchers-Access to Large Scale Facilities” program, which last from January, 1996 to December,1998.

Different metallic and ceramic materials have been exposed to the high flux focal spot in the PSA Solar Furnace at ambient pressure conditions and in controlled atmospheres of Ar or N_2 inside the MiniVac (mini vacuum chamber)

Ecole National Superieur de Mines de Paris.
Michel Boussuge, Responsible Scientist

The ENSM de Paris studied thermomechanical loads in some industrial refractory materials, such as alumina-mullite, alumina-spinel and magnesia, by subjecting them to thermal shock in the PSA Solar Furnace. These materials are to be used as core-catchers in future European pressurized-water reactors, which, in case of a severe nuclear accident, would retain the melted radioactive core material.

The specimens (50-mm diameter and 230 mm high) are water cooled to assure a temperature of 20 ºC on the base and they are wrapped in alumina wool to ensure uniaxial flow. Four thermocouples are inserted in the center of the samples at different distances from the surface to obtain a vertical temperature profile.

The samples at the focus are subjected to strong thermal shock as the shutter opens 100% in a few seconds. This shutter position is maintained until the surface of the refractory is melted or for times ranging from 30 minutes to 5 hours.

Fig. 2.6.2 Sample and diaphragm reflected in tilted mirror

National Technical University of Athens.
Dimitris I. Pantelis, Responsible Scientist

The surface modification of metal alloys by forming coatings with pre-deposited ceramic powders was studied by an NTU Athens research group in cladding experiments with different kinds of steels and cast iron.

Several types of steel, cast iron and TiN and Ni alloys were tested in Ar or N_2 streams at 2 bar in the MiniVac (mini vacuum) chamber, which has a quartz window to allow the concentrated light to go through and is connected to a gas system.

The specimens were treated at temperatures ranging from 1200ºC to 1400ºC with exposure times of 3 to 30 minutes. Three different ceramic powder coatings were used: Al_2O_3, SiC and WCCo (Cermet).

Compared to conventional processes, melted zones are deeper and larger surfaces can be treated.

Instituto Superior Tecnico (IST) of Lisbon.
Luis Guerra Rosa, Responsible Scientist

The IST experiments attempted to prepare refractory carbides and carbonitrides from compacted powder mixtures of metal and carbon. The specimens were submitted to the concentrated solar radiation for 30 minutes in ambient pressure or in 2-bar N_2 or Ar in the MiniVac. These carbides and those obtained by conventional methods were then compared.

The 1-cm-diameter, 0.5-cm-high specimens are composed of a mixture of active carbon a(C) or graphite (G) with either of the following metals: Si, W, Ti or Mo. In a following test campaign, Zr, Cr, V and Nb were the metals employed.

The samples, held on an alumina support, are placed inside the MiniVac and exposed to the focus at about 1600ºC for 30 minutes.

The results obtained up to now show that the thermodinamic stability of TiC_x and TiN_x are comparable while Si and W carbides seem to be more stable than the respective nitrides. In the case of Mo in Ar atmosphere, two phases can be observed, MoC_{1-x}, which appears to suggest that a certain type of photochemical reaction is induced due to the special spectral composition of the solar spectrum.

Helsinki University of Technology (HUT)
Seppo Kivivuori, Responsible Scientist

The purpose of the HUT Test campaign is to investigate the effect of thermal shock on steels and coatings subjected to the high flux focal spot in the PSA Solar Furnace.

The experiments performed by HUT have focused on thermal fatigue testing on tool steels.

Cylindrical specimens, 25 mm in diameter and 45 mm high, are subjected to twelve thermal cycles at temperatures ranging from 500ºC to 750ºC by mean of a fast shutter which, in less than one second, alternately exposes the samples to the focus and shades them.

Three different surface treatments were studied, TiN, chromium and gas nitriding; and four sample types, with the last coatings mentioned and one just quenched and tempered.

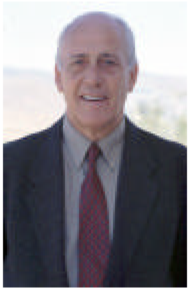
3 Supporting Services

3.1 Operation & Maintenance

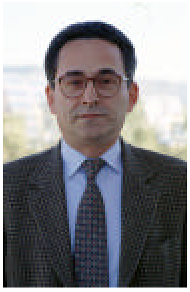
The Operation and Maintenance team, which depends directly from the Directorate in the CHA-PSA organization, provides most of the experience, know-how and manpower for carrying out the experiments in close cooperation with the Area Heads and other PSA teams. The main tasks are the **operation** of facilities and **maintenance** and **construction/modification** of project setup.

Activities in 1997 were carried out on schedule. The DISS project received special attention, laying power and water supply lines and electrical assembly trays.

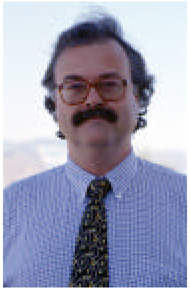
Within the General Infrastructure, the O&M team replaced the elevation worms in 80 CESA-1 SENER heliostats.



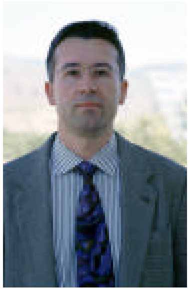
José Antonio Rodríguez
Head of O&M



Antonio Valverde



Javier León



José Rodríguez García

3.1.1 Summary of Hours of Operation

The PSA facilities in 1998 were operated for as long as the assembly of new projects allowed. The programs of work have been carried out with small deviations from the plan. Table 3.1 *Summary of Operation Hours 1997-1998,* shows the hours project were operated by facility for the last two year.

Table 3.1 Summary of Operation Hours 1997-1998

CESA-1	**Hours-1997**	**Hours-1998**
Collector	2193	1870
TSA	434	60
ASM-150	174	129
GM-100	574	1227
Turbine	39	12
GRAAL	87	*
REFOS	46	198
CRS	**Hours-1997**	**Hours-1998**
Collector	1577	1586
Cor-Rec	112	*
RAS	32	*
Hit-Rec	82	105
DCS	**Hours-1997**	**Hours-1998**
ACUREX	677	690
Desalination	672	332
Detoxification	1101	1153
ARDIS	576	*
HTL (LS-3)	113	518
HFC	**Hours-1997**	**Hours-1998**
Collector	1605	1477
Shutter&T.	1572	1474
North Dish	1053	665
Center Dish	1276	1092
South Dish	1134	138

*) Project ended in 1997

3.1.1.1 CESA-1 Facility

Replacement of the old SENER heliostat elevation mechanisms by commercial ones, which started in the last quarter of 1997, was completed by the end of this year. The number of heliostats out of service was reduced to 3% of the total field.

A new automatic offset adjustment control was developed and tested in collaboration with the University of Seville. Final installation of this software will be done during 1999.

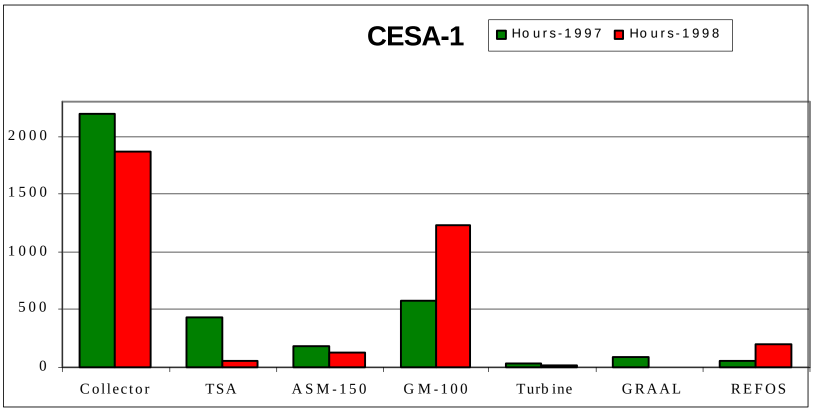


Fig. 3.1 Comparative hours of CESA-1 test facility operation

Heliostats

The two PHOEBUS-type heliostats, ASM-150 and GM-100, and the Colon-Solar heliostat were operated in several test campaigns.

TSA Project

The TSA project was operated for only 60 hours mainly due to the installation and testing of the REFOS project (combined-cycle receiver system) in the CESA-1 tower test facility. The personnel required to operate the TSA system for electricity generation was reduced, especially due the automatic aiming-point strategy program, because once the receiver is started up, unattended heliostat field operation is satisfactory.

TSA operation for electricity generation was insignificant because of the difference in sizes between the steam generator and steam turbine designs.

REFOS

The first secondary concentrator test phase was performed this year. A cold-water calorimeter was installed for measuring the power at the exit of the secondary concentrator.

The open-loop cooling system used for HERMES and the closed-loop cooling system of the GAST project were adapted to dissipate the collected energy.

3.1.1.2 SSPS Facility

Central Receiver System (CRS)

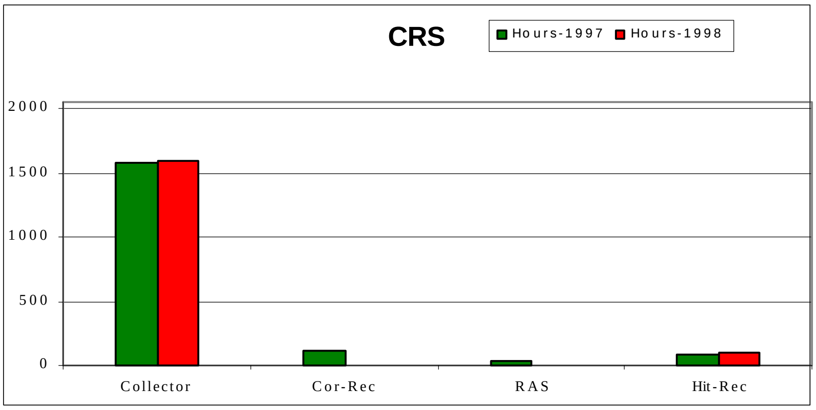


Fig. 3.2 Comparative hours of CRS test facility operation

Volumetric Receiver Project.

One absorber, the Hit-Rec receiver, mounted in 1997, was operated all year. High air temperatures were reached with steep temperature gradients in order to arrive at nominal conditions quickly. Problems with movement of modules continued and several solutions were studied for improving system behavior.

Distributed Collector System (DCS)

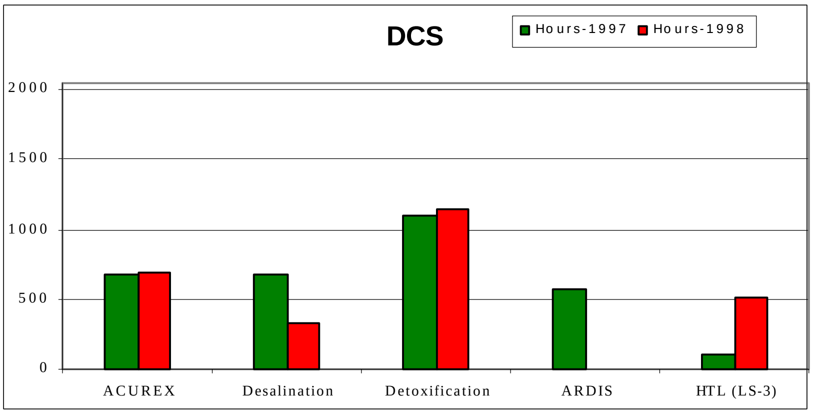


Fig. 3.3 Comparative hours of DCS test facility operation

ACUREX

One more year, the field was mainly devoted to the UE TMR program, in its last period. The foreseen test campaign was fully developed. The test along the year were distributed between the following organizations, Universities of Norway, Strathclyde, Coimbra, Nova, Oulu, Ruhr, Seville and Instituto de Engenharia de Sistema e Computadores (INESC) (HORUS program), checking in all cases the response of the oil system under the actuation of different controls. The main problems were due to small leaks in some flexible hoses, which were substituted by new elements. A certain amount of the energy collected by the system was used for water production.

Heat Transfer Loop (LS-3)

The HTL has been during this year in regular operation, fulfilling part of the test camping included in the project PAREX. Some problems with the oil pump caused a delay in the normal developing of the tests. The main goal was calculate the efficiency of the loop for different factors as irradiance, working oil temperatures and even, different wind speed conditions. Several focusing tests were carried out, using laser procedures and by shadowing methods. It was also checked the incidence of an end reflector, made of Aluminium, in the global efficiency improvement.

Desalination Plant

The Desalination Plant was included in the EC-TMR program and was operated regularly during the year. The principal user was the University of Ulster. Apart from this, continual production of distilled water fed the PSA Detoxification, TSA and DISS Projects and was used for more general purposes such as washing mirrors and cooling water. Several acid cleanings, dipping individual cells in special baths, had to be done, since scaling on the outside of the evaporator tube bundle grew in spite of anti-scaling products added routinely during operation and maintaining lower-than-nominal temperatures.

3.1.1.3 High Concentration Facility (HCF)

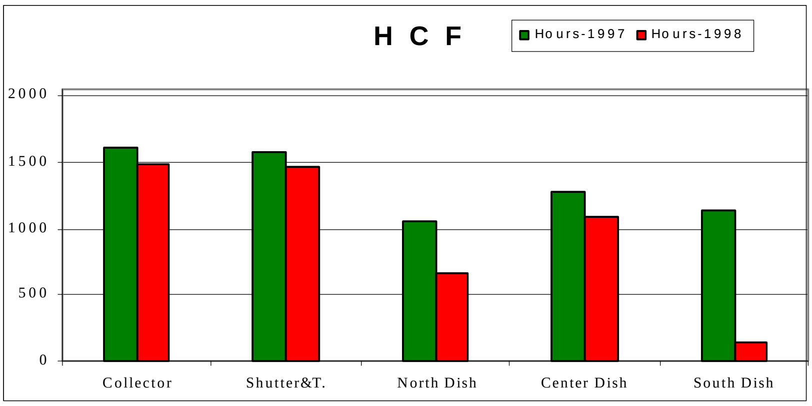


Fig. 3.4 Comparative hours of HCF test facility operation 1997-1998

Solar Furnace

Four European research groups carried out tests in controlled Ar or N_2 atmospheres and ambient pressure conditions on several kinds of ceramic and metal samples in the framework of the EU's DG XII "Training and Mobility of Researchers – Access to Large-Scale Facilities" program.

- The Ecole de Mines de Paris tested three different refractory materials (alumina-mullite, alumina-spinel and magnesia) by subjecting them to thermal shock for 30 to 300 minutes on the horizontal plane. The 50-mm diameter and 250-mm high specimens were exposed to the concentrated radiation at 100% shutter aperture. A diaphragm –reconcentrator placed on top of the samples provided a more homogeneous flux distribution on the exposed surface and prevented heating the side of the samples.

- The Instituto Superior Tecnico of Lisbon produced carbides and carbinitrides employing a non-graphitic (amorphous) active carbon as the carburising medium. Thirteen tests were performed inside the mini vacuum chamber (MiniVac), each including eight samples consisting of compacted pellets composed of a mixture of each one of the following metals: Si, W, Ti, Mo, Zr, Cr, V and Nb, with active carbon a(C) or graphite (G). The samples were subjected to concentrated radiation for periods of 30 minutes at about 1600 ºC in Ar or N_2 streams inside the MiniVac
- Experiments by the National Technical University of Athens focused on surface hardening and cladding of different kinds of steel, cast iron, aluminium and TiN and Ni-based alloys on the horizontal plane. The specimens were exposed to the concentrated light at temperatures ranging from 1200 ºC to 1400 ºC inside the MiniVac for exposure times of from 3 to 30 minutes in Ar or N_2 streams at 2 bar. Three different powders were used for cladding: Al_2O_3, SiC and WCCo (Cermet)
- The Helsinki University of Technology tested thermal fatigue of tool steels. During the test, the 25-mm ∅ x 45-mm high specimens were submitted to 12 thermal cycles, ranging from 500ºC to 750ºC, in which the samples were alternately exposed to the concentrated radiation and shaded. Three different surface treatments were tested: samples with TiN coating, and nitride coating and quenched. Samples were then cooled down by a flow of air at about 1 bar

DISTAL

Routine operation of the three DISTAL-I dishes continued, accumulating more than 6600 kWh gross power and about 1900 operating hours in 1998. Since project startup in 1992, a they have totaled more than 106 600 kWh gross power produced and over 27 900 operating hours.

DETOXIFICATION

The Detoxification project was devoted mainly to performing experiments in the framework of the TMR program and the Solardetox project.

The Collector Loop and CPCs were used to carry out experiments for the following institutions:

- University of Bremen experiments on contaminants such as Imidacloprid and Piramicarb.
- CNRS Lyon tested 4-clorophenol, Nitrobenzene and Chlorobenzoic acid.
- University of Palermo: CN^-+phenol.

- University of Metz: 4-clorophenol, Phenol, Nitrogen, Hidrobenzoic acid, P-clorophenol, P-nitrophenol and Phenol.
- The University of Poitiers used an electro-mechanical reactor as a catalyst, with 4-clorophenol and Phenol as contaminants.

The catalysts used were TiO_2, Granulate Active Carbon (GAC) and TiO_2+AC, except for the University of Poitiers where the catalyst was an electro-mechanical reactor.

3.1.2 Maintenance

José Manuel Molina

The PSA ***General Maintenance Plan*** (**GPM**), in effect since 1994, was revised and followed with satisfactory results, as expected, especially due to the guaranteed continuity from the previous year of the service contract with the GYMSA Company.

Maintenance activities are illustrated in Figs. 3.5 to Fig. 3.8.

Fig. 3.5 summarizes and analyses the distribution of work done under the GMP since 1993. Construction activities tended to increase as in former years, at the expense of preventive and corrective tasks.

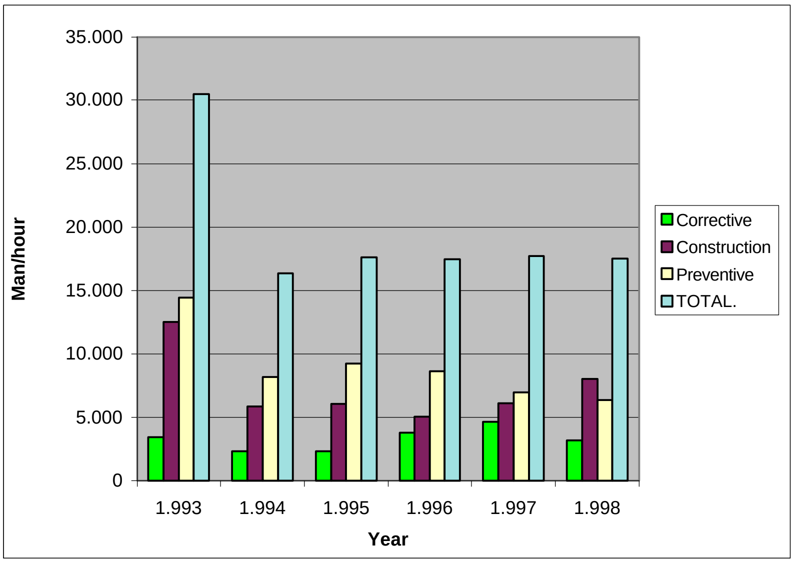


Fig. 3.5 Distribution of work done under the GMP since 1993

Fig. 3.6 presents the distribution of work by activity in 1998 versus 1997, keeping in mind that all project maintenance work, as well as general installation, is included under "construction". As shown, more time was devoted to construction in 1998 than 1997.

Fig. 3.7 shows the distribution of the maintenance workload history devoted to "General" by preventive, corrective and construction work. "General" contains virtually all preventive maintenance work done for infrastructure as well as the three test facilities. Indirect labor is not included.

Fig. 3.8 is the historical distribution of the Project maintenance workload.

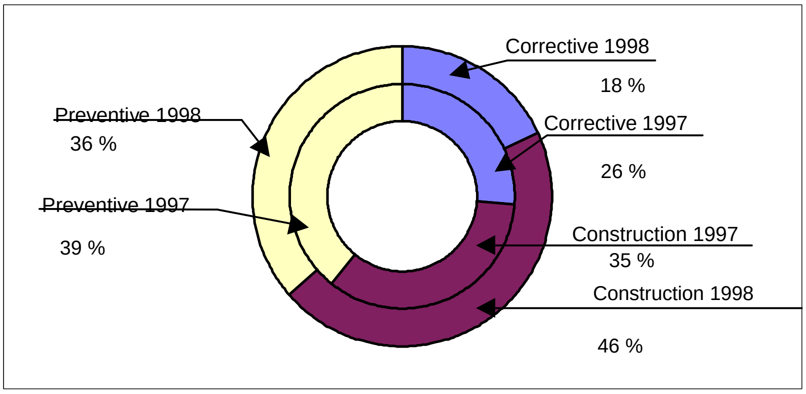


Fig. 3.6 Distribution of work by activity in 1998 versus 1997

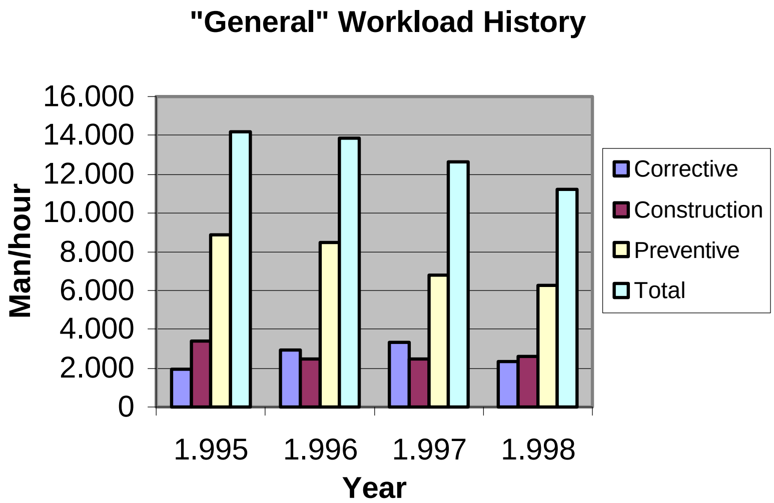


Fig. 3.7 Historical distribution of "General" maintenance workload by preventive, corrective and construction

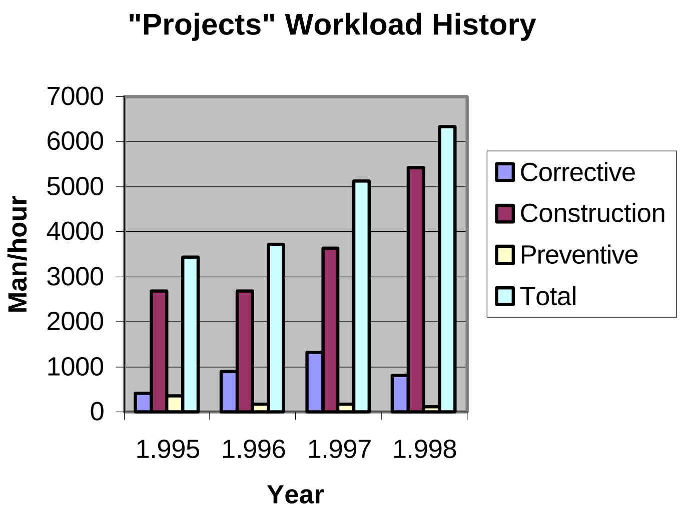


Fig. 3.8 Historical distribution of the project maintenance workload

General

Installation of optic fiber line connecting DISS building and the warehouse with CESA 1 facility, finishing the net of internal communications.

Study of requirements to be able the erection of the new fittings in the Meteorological Station

3.1.2.1 Projects

CESA 1

- Replace the elevation worms in 80 SENER heliostats CESA 1 facility.
- Paint the structures of 100 heliostats as the first step in their renovation.
- Installation of new water supply line from Desalination Plant to CESA-1.
- Several modifications in the flux measuring cell.

HELIOSTATS

- Modification of the GM-100 steel facet-structure supports
- Checking and mounting of COLON SOLAR new drive motors.
- Installation of COLON SOLAR facets.

TSA AND REFOS

- Installation of cold finger.
- Erection of the IR control camera and its electrical-signal cables.
- Installation of the receiver shield protection, erection of the compressed air supply and the receiver water-cooling systems

CRS

Mounting and dismantling of absorber in CRS tower.

SOLAR FURNACE

Installation of a titled mirror on the test table and modification of the table.

DETOXIFICATION

- Erection of new test collectors and its mechanic and electric system
- Erection of the test collector and its mechanic and electric system for ExpoAgro in a platform.
- Modifications as required in test loop.

DISTAL II

Installation of counterweights on the support structure.

LECE

- Installation of air conditioning in CESPA IV cell.
- Mounting and dismantling a variety of windows.
- Planting and looking after plants at CESPA III cell.

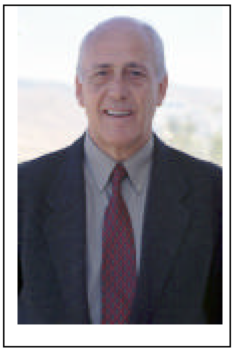
DISS

- Installation of a new water cooling system in pump P-23 and modification of pump P-10.
- Installation of power and lighting systems in the DISS control building and B.O.P., such as electric switchboards in Low Voltage room. Erection of the electrical and control trays in the DISS loop.
- Installation of the earthing network and lightning protection system.
- Installation of a raw and demineralized water supply systems from CESA 1 to the facility.
- Installation of a communications network connected to the PSA network.

3.2 Engineering Activities

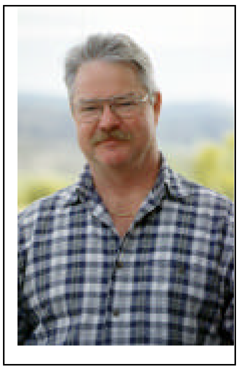
The PSA Engineering Department supports all areas and their projects and in general services, such as flux measurement, instrumentation and control, computer services, safety and drafting. Ten scientists and technicians with the support of two doctoral students make up the department.

Andreas Holländer (Area Head)



José Antonio Rodríguez Povedano

Due to cancellation of Annex I of the Cooperation Agreement by the German Ministry, the Steering Committee decided in May to change the department structure before the end of 1998. In summer, 1998, the most important part of DISS test loop was erected and all available work and resources were allocated there. Therefore, Jose Antonio Rodríguez Povedano took over general department issues and the Area Head, Andreas Holländer, was dedicated full-time to the DISS project. Beginning in 1999 he will take over the coordination of the DLR-PSA parabolic trough department.



Dieter Weyers

Angel Soler

Most of the resources were allocated to the erection, cabling, testing, implementation of control and startup of the DISS test loop. All 11 collectors were assembled, aligned and cabled. Over 1,000 special argon welds were supervised. Key components like vessels, deaerator and pumps were commissioned. All the control systems were installed, connected and tested. All the alarm signals were installed and checked.

Francisco Martín

Furthermore, the computer pool was improved and all computers now have PII processors, communicating each PSA work place with the rest of the world. The recently developed "Optimas image system" with 12-bit CCD camera was used for the evaluation of the REFOS receiver which represents an important step forward in the evaluation of heat flux measurements. The infrastructure was complemented with the erection of DISS and allocating the corresponding money.

3.2.1 Computer and Information Services

Rosario Domech

Today, in any type of company and, in particular, research centers like the PSA, this service is vital to its operation and represents an indispensable tool for reaching overall institutional goals as well as those of the various projects and activities carried out at it.

The PSA Computer and Information Services include a wide variety of activities from software development to information infrastructure, local and external communications, which are fundamental to the center due to its many component buildings and facilities and distance from the two parent institutions (CIEMAT, Madrid and DLR, Cologne).

In 1998, the objectives indicated in the Computer and Information Services Plan prepared at the end of 1996 were consolidated and the enormous effort invested in infrastructure throughout 1997 was completed, with the resulting approach to the final user.

The main tasks of the Computer and Information Services can be grouped as:

Juan Antonio Camacho

a) Computer infrastructure

A1. Computer pool
- Acquisition of new network server
- Replacement of 486s as PCs and upgrade to Pentium II

A2. Local PSA Network
- Extension of the local PSA network to the DISS installations over optical fiber and twisted pair
- Extension of the local PSA network to the store and workshop over optical fiber and twisted pair
- Replacement of student offices cabling with twisted pair

Jaime Aranda

b) Software development

B1. Control and data acquisitions systems. Development of software for PSA project operation
- LS-3
- Solfin
- Acurex

B2. Business information systems. Development of software for PSA management and access to general information about it
- Economic control system (SIPSA).
- Automation of the PSA Library

- System for accounting hours worked by personnel to the various projects

c) Computer Systems

- Implementation of the RAS (Remote Access Service) so that personnel can work in remote sessions.
- Updating to Windows 98 on most of the office computers
- Updating to Microsoft Office 97 on most of the office computers
- Management of physical maintenance as well as all of the PSA computer pool.
- Study of the impact of the year 2000 on PSA facilities

Statistics

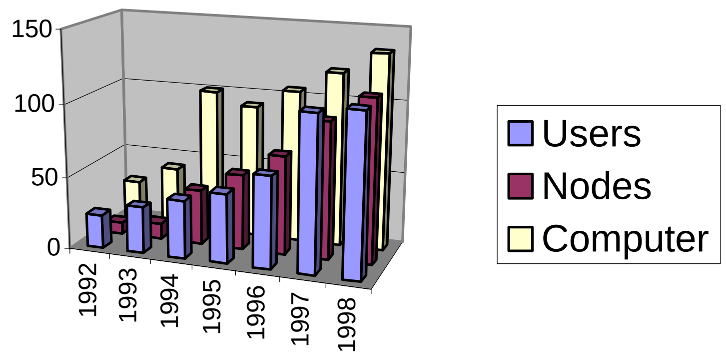


Fig. 3.9 Local Network

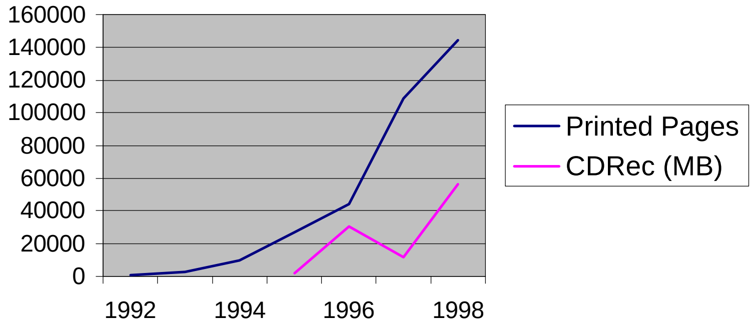


Fig. 3.10 Other Services

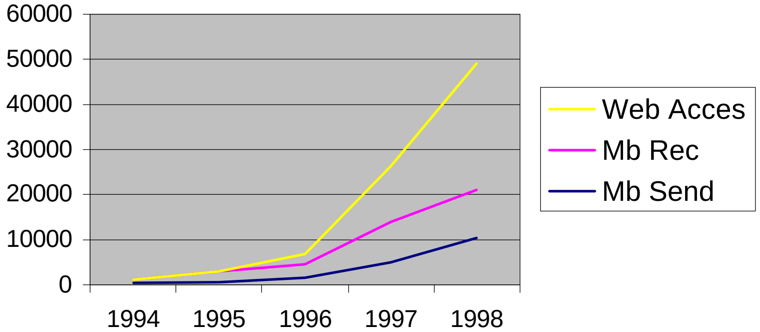
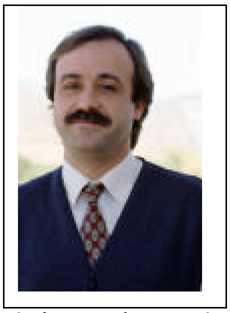


Fig. 3.11 External Communications

3.2.2 Design, Control and Instrumentation



Ginés García Navaja

Andrés Egea Gea

The main work carried out during 1998 in the PSA about Designed, Control and Instrumentation tasks, was the implementation and start up of the local controllers on the DISS collectors and the assembly supervision and start up of the DISS instrumentation and control elements.

Fig. 3.12 DISS instruments assembly

These local controllers have been development and manufacture by PSA using the same LS-3 loop philosophy to avoid the solar sensor to control the collectors. These units compute the solar position using a new and powerful algorithm and they read the real position of the collector axe using an optical encoder.

Fig. 3.13 DISS Local Controller assembly

During the year, the communication and protocol between eleven of these units and central control unit, located inside of DISS control room, was very successfully tested with the participation of Bailey Hartmann & Braun Company. A special software driver has been development to command the DISS collector field with a standard market control system.

Another task was performed this year under a collaboration agreement between the University of Almería and the PSA for the design of a new advanced radio modem to be used in wireless heliostat field communication. Under this agreement, a new electronic power driver to manage a highly efficient adjustable-speed direct-current motor was designed, built and tested with excellent results.

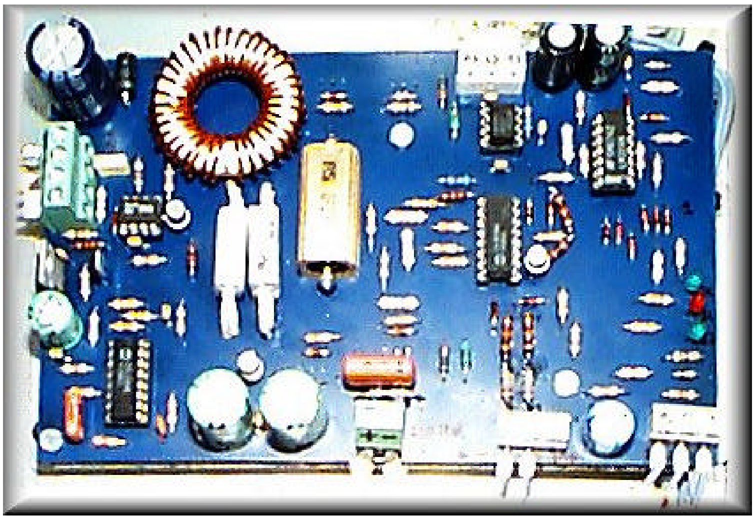


Fig. 3.14 New DC motor driver card

At the end of the year, one 70m^2, "T" classical glass-metal heliostat has been adapted to include all these new components to work using the stand-alone concepts. The PV system is able to drive two sun-tracking DC motors between 5 to 24Vdc, 0 to 15A. The heliostat communicates with the control room at 400 m distance by using a radiomodem working with 9600bauds. The heliostat is sensorized with anemometer, wind switcher, light sensor and ambient temperature.

During 1998, the whole autonomous configuration and hardware procurement and installation were completed. In 1999, extensive testing will serve to evaluate the reliability of the concept.

Fig. 3.15 Autonomous Heliostat

3.2.3 Flux measurement activities

In order to evaluate the performance of solar concentrating devices like receivers, single heliostats or a complete heliostat field, the PSA now has three different flux measurement and beam characterization systems available:

- The pioneer 8 bit VAX-based HERMES II
- The new 14 bit PC-based video flux measurement system PROHERMES
- The Theta-1 system, consisting of a 12-bit CCD camera and specialized software under DOS

PROHERMES flux mapping

Rafael Monterreal

Anselm Kröger-Vodde

In order to evaluate the performance of solar concentrating system components like receivers or heliostats, the PSA has prepared the PROHERMES flux mapping system.

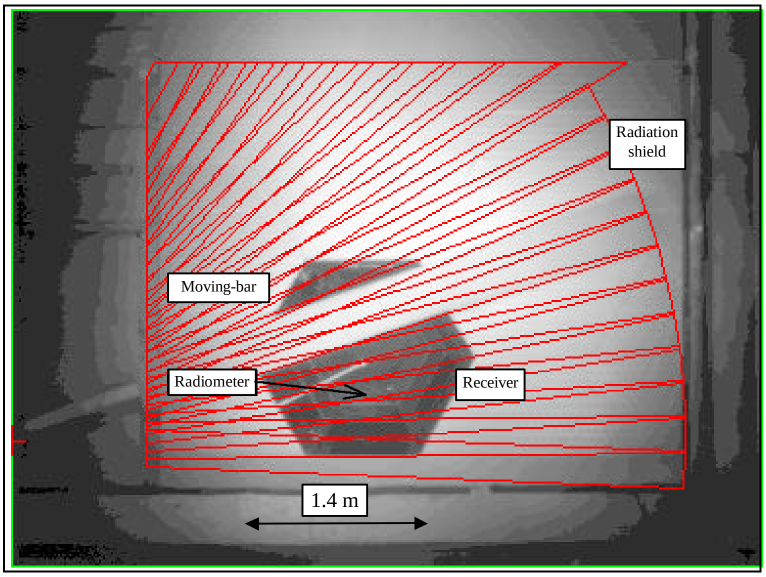


Fig. 3.16 PROHERMES snap shot with scan in the fuzzy recognition process of the moving-bar in front of the REFOS-receiver. Only target pixels are included in the evaluation.

Based on a 14-bit CCD slow-scan camera, the customizable OPTIMAS image-processing soft-ware and previous experience with the HERMES system, a flexible flux mapping system, has been designed to measure on a receiver aperture plane or special test targets. In both cases the camera is directed towards a white diffusely-reflecting target. This indirect method of analysis of re-radiation from the target permits easy evaluation of flux distribution maps. Grey-level conversion to physical power density units is made with calibrated radiation sensors. Figures 4.show a view of the application on the REFOS receiver and a screen shot of the evaluation algorithms.

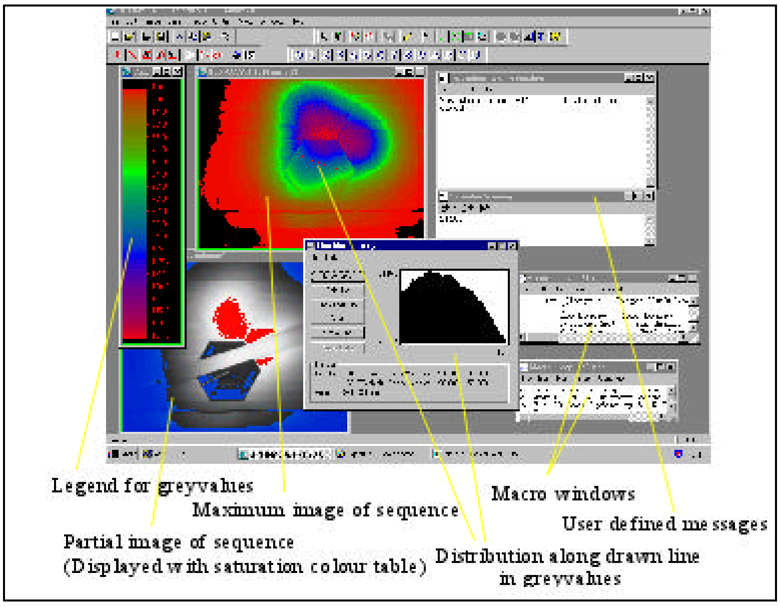


Fig. 3.17 PROHERMES evaluation procedure in Optimas®, applied to the REFOS secondary concentrator

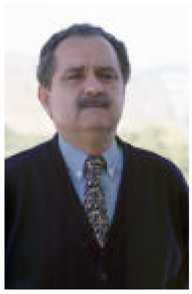
3.2.4 Infrastructure

3.2.4.1 General

General work carried out in 1998 to improve existing infrastructure was:

- Part of the roof of Building 14 was waterproofed
- The interior of Building 17 was remodeled.
- Air conditioning in Building 17 was improved
- A new dining hall was put in Building 15

The Annual meteorological report was prepared for the National Institute of Meteorology Station No. 6321 0.

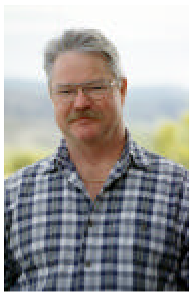


Bernabé Calatrava

3.2.4.2 DISS Project

Much general and civil engineering work had to be done for the DISS Project:

- A basic study of safety and hygiene en compliance with national law (R.D.1627/97)
- Coordination of Safety and Hygiene during the Project
- Supervision and coordination of civil engineering:
  - Main B.O.P. building
  - Leveling of area around the B.O.P.
  - Outdoor lighting.
  - B.O.P. electrical (grid and U.P.S. lines) and water connections.
  - Equipment was mounted on platforms prepared for them.
  - Foundations and structures for electrical panels, piping and wiring for power and communications were prepared.
  - Design and supervision of the B.O.P. parking lot.



Dieter Weyers

– Design and supervision of the outbuilding for recirculation pump and accessories.
– Design and construction of pipeline overpasses

Eckhart Lüpfert

3.2.4.3 Refos Project

The Refos Project installation was also prepared in 1998, which involved:

- Design and erection of the receiver and other equipment support structures
- Design and assembly of the heat exchanger.
- Design and installation of heat exchanger pipelines.
- Design and installation of primary-loop water recirculation pumps (receiver / exchanger), including electrical control panel.

4 Education, Training and Scientific Cooperation

4.1 Scholarships and Grants

At PSA we believe that one of the most effective ways to foster public awareness of the 'solar option' as a mid-term clean energy source, is to give university students an opportunity for close contact with it while acquiring working experience. That's why the PSA student program activities are maintained, and even increased, every year.

Again this year, the basis of the PSA student program has been the tripartite agreement signed by CIEMAT, DLR and the University of Almería (UAL) for five one-year doctoral grants and seven training grants lasting from a minimum of 6 months to a maximum of one year. Total student time at the PSA was 129 months. The total PSA student program investment was 12 860 000 PTA plus a contribution of 1 000 000 PTA by UAL.

The objective of the doctoral grants, which are renewable for a maximum of three years, is for the students selected to obtain a doctoral degree. A yearly progress report is required for the extension of their grants.

All these grants are published in the Official Bulletin of the government of Andalusia (BOJA) and candidates are selected by a joint CIEMAT-DLR-UAL commission following standard university procedures.

Besides this main agreement with the UAL, some other agreements with EC 'Leonardo de Vinci' offices, mainly in Germany, have been arranged, thus enabling up to 21 more students to come from Germany and France. The total of 'Leonardo' student time was 94 months this year, costing 1 880 000 PTA.

The distribution of student man-months at the PSA by area can be found in the chart below (Fig. 5.1).

Diego Martínez
Area Head

Christoph Richter

Cruz María López

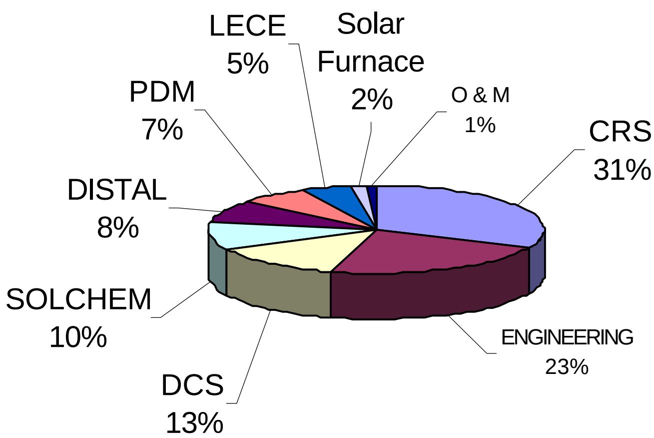


Fig. 4.1 Distribution of student man months by area

The table below lists students hosted at the PSA during 1998.

Table 4.1 Students at the PSA in 1998

Name	Country	Duration of Stay	PSA Area
Diego Alarcón	ES	12	CRS
Anselm Krogger-Vödde	DE	12	CRS
Rainer Kistner	DE	12	CRS
Walter Knechtel	DE	6	CRS
Brigitte Schwarz	DE	6	CRS
Jesús Fernández	ES	6	CRS
Stefan Franzen	DE	4	CRS
Marc Roger	DE	6	CRS
Christoph Koeppen	DE	6	CRS
Loic Rousseau	FR	2	CRS
Wolgang Glahn	DE	3	CRS
Francisco Soler	DE	6	DISTAL
Miriam Borowietz	DE	3	DISTAL
Carsten Reusch	DE	9	DISTAL
Ulrich Bartmann	DE	2	DISTAL
Luis Ramos	ES	4	Solar Furnace
Javier de Luis	ES	9	LECE
Virginie Besseyre	FR	2	LECE
Winfried Ortmanns	DE	6	DCS
Ralf Kemme	DE	6	DCS
Harald Horn	DE	3	DCS
Andrea Schneider	DE	4	DCS
Loreto Valenzuela	ES	12	DCS
José Zamora	FR	2	O & M
Pilar Fernández	ES	12	SOLCHEM
Julia Cáceres	ES	6	SOLCHEM
Mª Carmen Cerón*	ES	6	SOLCHEM
Nils Heining	DE	6	PDM
Alejandro Avellán	ES	6	PDM
Carolin Wagner	DE	4	PDM
Miguel Angel Rubio	ES	12	ENGINEERING
J.Andrés Pérez*	ES	12	ENGINEERING
Steffen Ulmer	DE	6	ENGINEERING
Martin Ostkopp	DE	12	ENGINEERING
Nuria Novas	ES	12	ENGINEERING

*These two grants were finally transferred to 1999.

The third way for young researchers to come to the PSA is through EC 'Marie Curie' grants. There is currently one German doctoral student at the PSA in the DISS project with such a grant. It is our desire not only to keep this door open but promote additional such long-term cooperation.

The first step in this direction concerns the presentation within the EC-DGXII's 'Fifth Framework Programme' of a 'Research Training Network' proposal called 'EuroTURN' whereby ten top-class European energy research facilities arrange internships abroad for over 20 young researchers in a coordinated infrastructure.

~~6~~4.2 Training and Mobility of Researchers Program

~~6.1~~4.2.1 The Access Program

The 'Training & Mobility of Researchers Program' (TMR) is the modified continuation of the 'Human Capital and Mobility' program (HCM) and its aim is to promote, through the stimulation of training and mobility of European researchers, a qualitative and quantitative increase in human resources for research within the Community and its Associated States (Iceland, Lichtenstein, Norway and Israel).

It is managed by the European Commission's Directorate General XII for Science, Research and Development and comprises four activities:

- *Research Networks* to promote transnational cooperation on research activities proposed essentially by the researchers.
- *Access to Large-Scale Facilities* to facilitate the access of researchers to existing large-scale facilities that are essential for high-quality research.
- *Training through Research* to foster better utilization of high-level researchers in the Community.
- *Accompanying Measures* for dissemination and optimization of the results of activities.

As one of the main PSA goals is to promote the use of solar thermal energy throughout Europe, it has long participated in 'Access to Large-Scale Facilities' programs, as a good way to disseminate the advantages of the 'solar option' within the European scientific community.

PSA participation began in January, 1990, when it joined the 'Large Installations Plan' (LIP) of the Second Framework Programme. (1990-Mid 1993). This line of work has been extended through the 'Human Capital and Mobility' (1994-1995) and currently, the TMR (1996 - 1998).

The EC-DGXII TMR contract with CIEMAT was for the period from 1996-1998, so this was the last year of the program at the PSA. This means that all the efforts aimed at compliance with all the contractual commitments have been completed and there have been no activities concerning either publication of access possibilities or selection of future users. Access given is shown by facility and country in Tables 4.2 and 4.3.

It is clear that TMR users found the Detox Loop, SOLFIN, Acurex Field and the Solar Furnace the most attractive.

In addition to access, some other related activities were carried out:

3rd General Users Meeting

All 29 groups and individual researchers selected were invited to this meeting held at the PSA on February 19th and 20th. The main objectives were discussion of the access schedule and a first visit to the facility. The PSA and the program itself were presented

FACILITY	WEEKS OF ACCESS IN 1998
CESA-1	3
DETOX LOOP	9
SOLFIN	12
ACUREX FIELD	13
SOLAR FURNACE	18
DISH/STIRLING	1
DESAL PLANT	9
L.E.C.E. CELLS	4
TOTALS	69

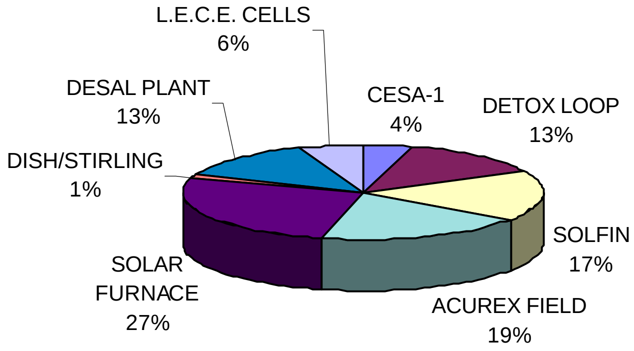


Fig. 4.2 Access in 1998 by facility

in a plenary session, followed by parallel sessions in which the users met their project leaders and other users of the same facility during the year.

The Second TMR-Users Workshop

The object of this activity, begun in 1997, was to give users the opportunity to meet after their test campaigns and present their results to each other for discussion. The 1998 Workshop was held on November 10th and 11th in Aguadulce, a coastal village near Almería. About 40 researchers attended the event. It was split in three parallel sessions, the largest of them on 'Solar Chemistry', the second, 'The Control of Solar Thermal Applications', and the third, entitled 'Other Applications' dealt with materials testing, dish/Stirling systems, CESA-1, LECE and the desalination plant so that all User research at the PSA was covered.

As a general statement, it may be said that, not only were there *no major difficulties in the execution of the contract,* this third year was the most fruitful, with the most access awarded. Users were also able to profit from more activities within their access grants.

COUNTRY	WEEKS OF ACCESS 1998
GERMANY	5
SPAIN	1
FRANCE	14
ITALY	11
FINLAND	9
GREECE	9
PORTUGAL	7
IRELAND	3
UNITED KINGDOM	6
NORWAY	4
TOTAL	69

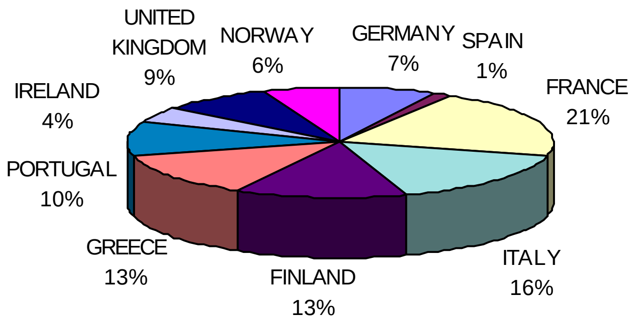


Fig. 4.3 Access in 1998 by country

Fig. 4.4 Official opening of the 2nd Users Workshop

Table 4.2 below summarizes evolution of access by PSA facility during the three years of the project

Table 4.2 3-year summary of access

FACILITY	WEEKS OF ACCESS IN 1998	WEEKS OF ACCESS IN 1997	WEEKS OF ACCESS IN 1998	TOTAL OF WEEKS
CESA-1	---	1	3	4
DETOX LOOP	10	13	9	32
SOLFIN	10	14	12	36
ACCUREX FIELD	14	10	13	37
SOLAR FURNACE	9	10	18	37
DISH/STIRLING	2	1	1	4
DESALINATION PLANT	3	2	9	14
LECE CELLS	2	6	4	12
SOLAR DRYER	1	---	---	1
TOTALS	**51**	**57**	**69**	**177**

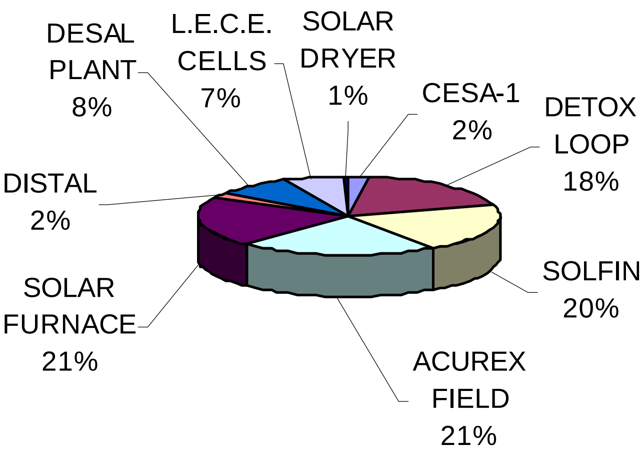


Fig. 4.5 Total access by facility

6.24.2.2 The Mid-Term Review

By EC-DGXII contract, a Mid-Term Review had to be organized. The purpose of this event is to review program progress so that any measures necessary to improve it could be taken. A panel of independent experts was recruited by the Commission to carry out this task.

The review was divided into three activities:

- To help the Panel evaluate the success of the program, a questionnaire was distributed among the Users to find out their opinions concerning some aspects of the program, such as the information provided on application, use of facilities, scientific support in setting up the experiments, the intellectual environment, logistic support at the facility, reimbursement of travel and accommodation expenses and also an overall appreciation of the services provided. It must be said that the Users gave the PSA a very high rating.
- The Panel Chairman visited the PSA on September 30th to establish contact with the facility and the Users on site. He visited all the PSA test facilities and also had a private meeting with the Users.
- The Panel of experts held a Technical Audit, consisting of a report and its presentation to the Panel in a dedicated session, in Cardiff (UK), opportunity which was also taken to hold the regular Round Table meeting on October 28th. Among others, the following aspects of the program were evaluated: publication of access, User selection process, of on-site User support, scientific output of the Users at the facility, amount of access provided and overall program management. The PSA was given very good reviews in the Panel's report, particularly stressing the high number of access proposals received and the very good selection process, the considerable effort made to publicize access in the scientific community and the additional stimulating intellectual environment provided by the organization of several workshops and a summer school.

6.34.2.3 The Summer School

This year, the PSA organised a 'Summer School', another TMR program activity under Activity 4, '*Accompanying Measures'*, which proposed three different options for 'meeting fora', Euroconferences, Summer Schools and Training Courses, to provide a flow of knowledge among young and experienced researchers.

The 1998 PSA Summer School initiative, entitled '*Solar Thermal Energy: The Clean Way for Electricity Generation and Produce Chemicals Production'*, was approved and partially funded by the European Commission.

The Summer School was intended to be fifty-fifty purely academic and training. It was composed of two week-long courses, the first from July 13th to 17th, entitled '*Solar Thermal Electricity Generation*' and the second, from September 21st to 25th, entitled '*Industrial Applications of Solar Chemistry*'.

A European dimension, meaning that the teaching staff as well as students must come from as many different European countries as possible, was a major characteristic required by the EC, as well defined by its rule that no more than 1/3 of the students may come from the same country.

Another of the requirements was that it had to be organised in a closed environment with the infrastructure necessary for informal contact and discussion among the participants as well as between participants and staff. A nice little hotel on the Coast of

Fig. 4.6 Some teachers and students in the September Summer School coursesession

Almería was therefore chosen as the venue for accommodation and theoretical lectures.

Most of the students attending did so with EC financial assistance covering their travel and accommodation expenses, as well as 50% of the course fees. These students were mainly from four target groups established by the European Commission:

young researchers,
women researchers,
researchers working in less-favored regions and
industry or assimilated institutions.

The daily schedule programmed two lectures in the morning and after lunch, a 45-minute bus ride to the PSA facilities where practice sessions were held, returning to the hotel late in the afternoon for round tables where the speakers, the PSA staff and the students exchanged ideas, experience and knowledge on the topic of the course.

Both courses were attended by over 20 students each, widely distributed among the EU countries. Besides, the target groups of DGXII were very well represented, with over 60% women and 50% from less-favored regions.

Furthermore, a book is to be published by CIEMAT to make the information compiled for the instruction of those students who were able to attend the course, available as a comprehensive reference on solar thermal electricity generation to anyone interested in this clean energy source.

5 Summary of 1998 Meteorological Data

5.1 Introduction

Andreas Holländer

Miguel Angel Rubio

The main PSA weather station has undergone very comprehensive reorganization and renovation this year. A complete set of high-quality sensors, covering all the main meteorological variables needed at the PSA, such as direct and global solar radiation, wind speed and direction, air temperature, relative humidity, precipitation and atmospheric pressure, has been installed.

Although these new sensors represent an improvement in the measurement quality, during their installation there was no data collection and, as a consequence of this there are some gaps in the database. For this report, the missing data have been partially substituted by modeled data, but there are still some gaps in the graphs.

Measurement and calibration of the sensors are according to World Meteorological Organization Standards. It should be made clear that the measured data by the PSA are not considered official Meteorological Institute data, but nevertheless, all the equipment follows their rules.

Values are transmitted every two seconds and extreme and average values are recorded every five minutes. Mean hourly and mean daily values are also recorded. Apart from the PSA meteo station, an independent station of the Spanish Instituto Nacional de Meteorología that measures sun, air temperature, relative humidity, precipitation and atmospheric pressure, is also located at the PSA.

In the near future a time server using a GPS system will be implemented, and also an Internet Server, which will be able to distribute the measured data around the world.

5.2 Evaluation of Meteo Data 1998

5.2.1 Direct radiation conditions

Fig. 5.1 shows that direct radiation levels were not very high during the time period observed. The highest levels of direct radiation were received at the beginning and the end of winter and during the summer. The peaks at the beginning of the year are due to the good weather enjoyed in March and April. At the end of the year the weather was also quite good and that fact is reflected in the high beam irradiance values.

During the winter, the sky in Tabernas is more transparent due to the lower levels of aerosols, which is the reason that the direct radiation is higher then. The hourly maximum direct irradiance of 1 002 W/m^2 was measured on April 12th. This year there were 3 053 hours with an average direct radiation over 175 W/m^2, an important threshold for solar thermal power plants. This is more than the previous year.

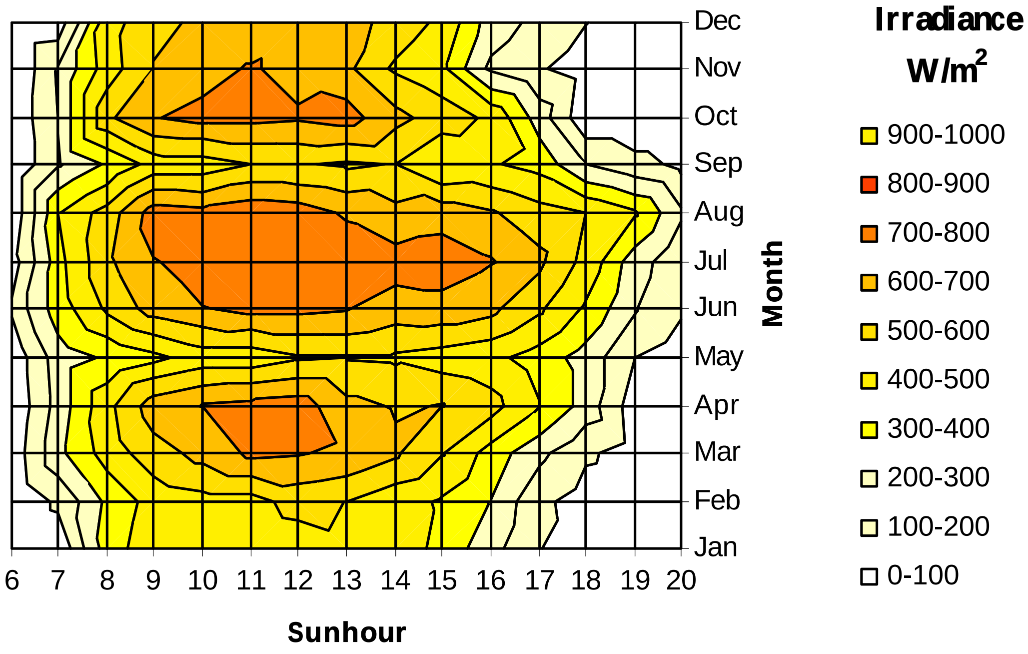


Fig. 5.1. Average monthly values of Direct Radiation at Tabernas

5.2.2 Global radiation conditions

Fig. 5.2 demonstrates distribution of annual global radiation during 1998. Maximum global radiation was reached in summer, with values over 900 w/m^2 at midday, and sometimes over 1 000 W/m^2. The peak of 1 051 W/m^2 was measured on the 25th of May, a lower value than last year. In April, high values over 800 W/m^2 were also reached due to the good weather conditions.

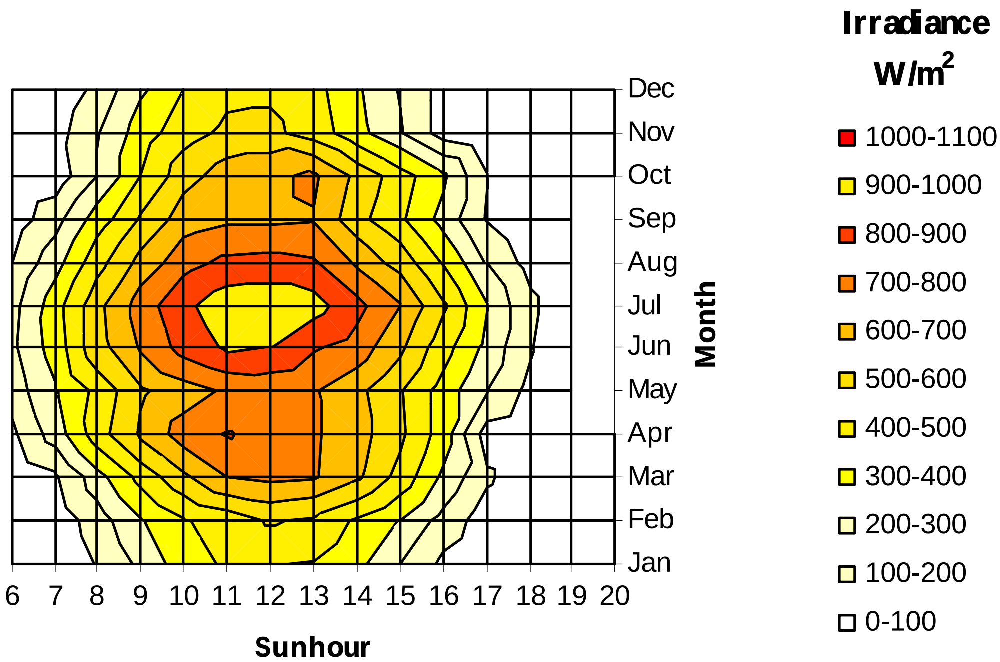


Fig. 5.2 Average monthly values of Global Radiation at Tabernas

5.2.3 Temperature data

The diagram in Fig. 5.3 shows the hourly average temperatures. Comparing the air temperature at ground level and global radiation, it was find that they are correlated. The coldest time of the day is the early morning from 6 to 8 a.m., and the maximum temperature is at about 4 p.m. in the afternoon.

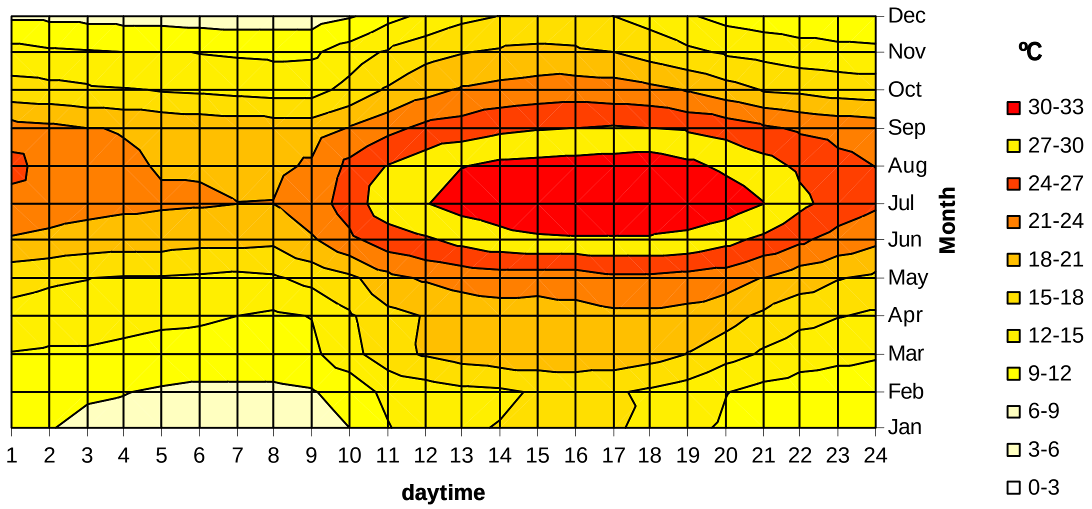


Fig. 5.3. Average monthly values of temperature at Tabernas

The minimum temperature of -2.0ºC, was measured on the 22nd of December. The maximum of 39.2°C was reached on the 11th of August. This year the range of the temperatures was slightly wider than last year. The average temperature in 1998 was about 16.1ºC, a little lower than the year before. The following graph shows the minimum, average and maximum values for each month.

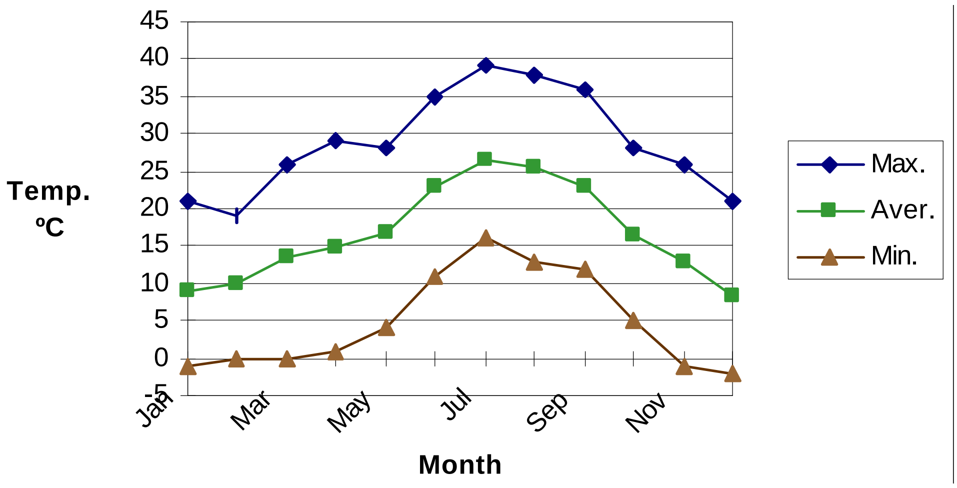


Fig. 5.4. Extreme and average values of temperature in 1998

5.2.4 Distribution of Relative Humidity

Observing Figure 5.5, the relative humidity in the air is related to the temperature. The driest period was also the period with the highest temperatures, at around 4 p.m. in summer. Midday in August was extremely dry with average values of around 20%, probably due to the high temperatures. The lowest relative humidity recorded at the station was 15.2% on the 31st of July.

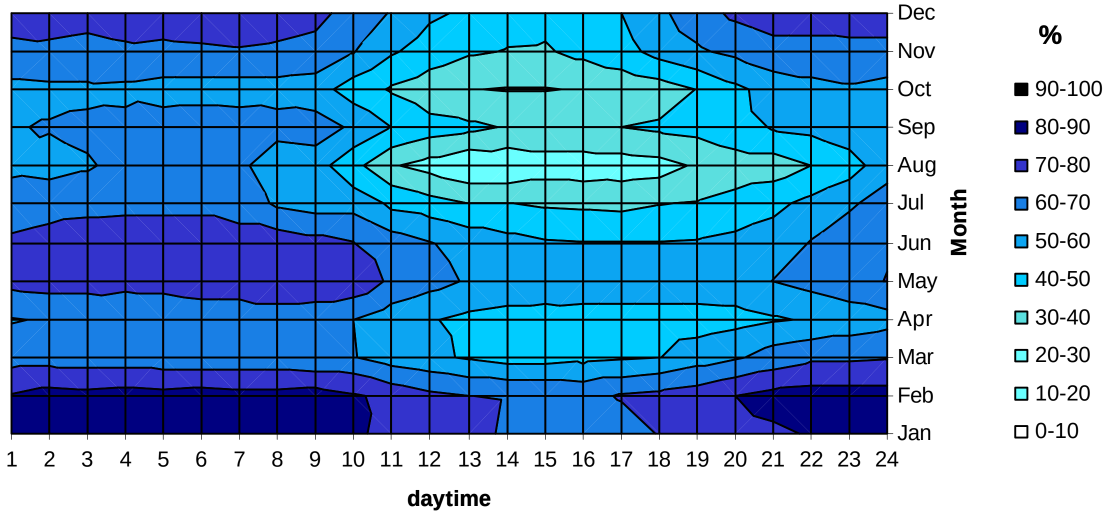


Fig. 5.5. Average monthly values of relative humidity at Tabernas

5.2.5 Wind distribution

Fig. 5.6 presents the distribution of wind speed during the year. No strong winds are measured before noon and the strongest winds occur from 3-6 p.m. The windy season is during the summer, from the end of June to the beginning of September. May was an unusually calm month this year. The highest wind speed was 19.6 m/s on the 10th of April.

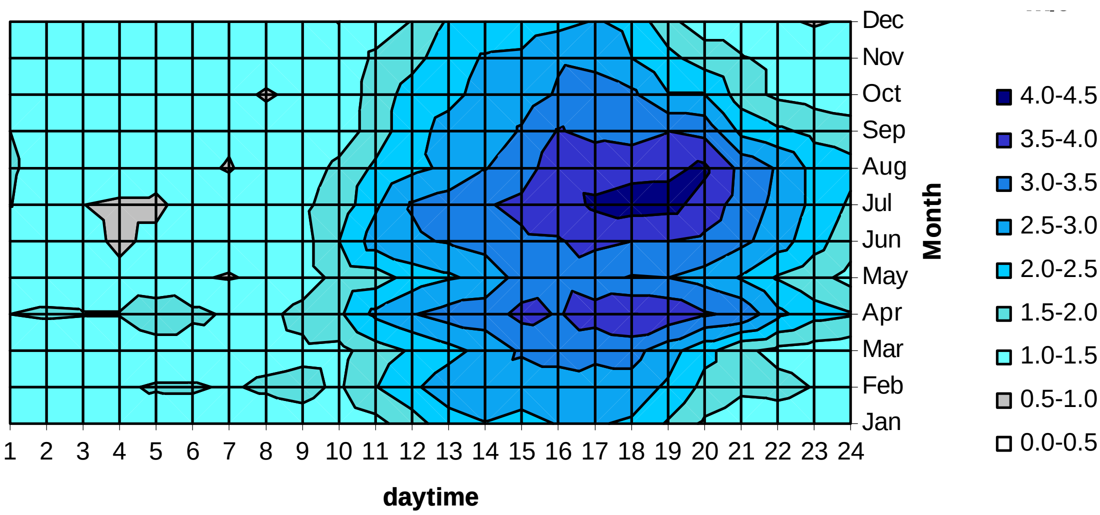


Fig. 5.6 Average monthly values of wind speed at 2 meters in Tabernas

In the following graph, the relative frequency of the direction of the wind is shown. Almost 40% of prevailing winds blow out of the northeast and east, and 25% are from the Southwest. This has been a constant pattern at the PSA since the meteo station was erected. The most probable reason for this is the location of the surrounding hills.

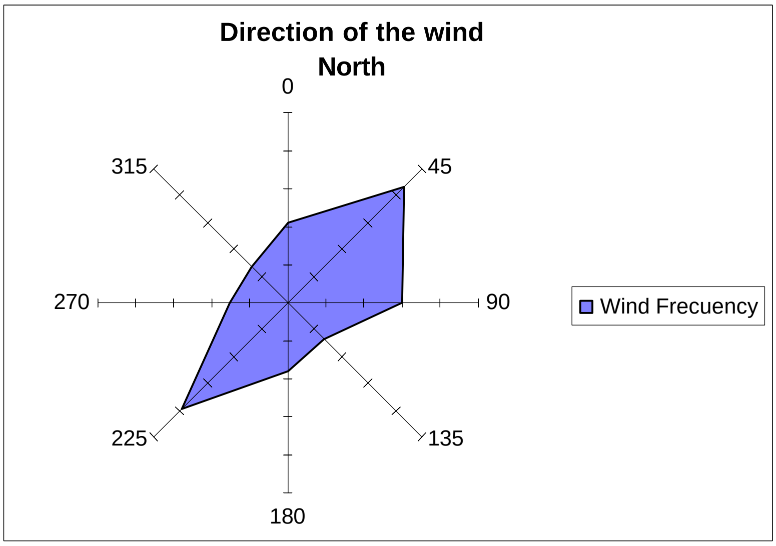


Fig. 5.7 Wind direction distribution at 10m in Tabernas

APPENDIX 1

PROJECT DESCRIPTIONS

Autonomous Heliostat

Test Engineer: Ginés Garcia

Participants:

- CIEMAT
- DLR
- Universidad de Almería

Duration: **From**: : June 1998

To: December 1999

Funding: 10 Million PTA

Source: PSA Basic Budget

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998			0,2	0,2	
1999			0,5	0,5	

Objectives:

To develop and evaluate the technical and economic feasibility of a wireless stand-alone heliostat prototype working in fully autonomous mode.

Description:

The 70-m^2, glass-metal COLON SOLAR heliostat was adapted to include all the stand-alone concepts. The development is jointly performed by the Instrumentation Team at the PSA and the Univ. of Almería, and includes many improvements stemming from their own experience with the different generations of heliostats operated at the PSA: The PV system is able to drive two sun-tracking DC motors from 5 to 24 Vdc and 0 to 15 A. Three new electronic cards were developed for the autonomous heliostat: A new DC motor driver card, a control card based on the PSA GA2696A card and a card for the advanced radio modem. The heliostat communicates with the control room 400 m away by safe-transfer radio modem at frequencies of 400-800 MHz and 9600 baud. Messages and data transmission are encrypted. The heliostat is provided with anemometer, wind switch, light sensor and temperature. With this information the heliostat is able to operate autonomously and decide whether to enter into stow under low battery loads. The local control continuously monitors the reference parameters and measures the most representative consumption and electrical values producing a self-diagnosis log file in case of failure.

Status:

During 1998, the entire autonomous configuration and hardware procurement and installation were completed. At the end of the year, the heliostat was adapted to include all these new components to work using the stand-alone concepts, with the only exception of the advanced radio modem that is being developed by the Univ. Almeria and is expected for 1999.

Plans for 1999:

Assembly will be completed early in 1999 and from April to November, a full qualification campaign will be carried out. Tests will be performed in two different phases. Phase I will include functional tests, communication tests and routine operation with the preliminary photovoltaic system and radio modem as designed. This phase will give information on autonomy ranges and consumption in different operation modes and emergency protocols. During August, the heliostat will work without assistance.

Phase II will include an advanced and cost-effective radio modem developed by the University of Almería. Optimization of hardware, appropriate dimensioning of the PV system and cost analysis of the autonomous concept will be assessed.

BRITE-EURAM III Solardetox Project (Solar Detoxification Technology to the Treatment of Industrial Non Biodegradable Persistent Chlorinated Water Contaminants)

Project Leader: J. Blanco

Test Engineers: S. Malato and P. Fernández

Participants: **Participants:**

CIEMAT / DLR
HIDROCEN S.L., Spain
SETSOL, Energias Renovaveis, Portugal
Torino University, Italy
SCHOTT-ROHRGLAS, Germany
CISE, Italy
ECOSYSTEM, Spain
INETI, Portugal

Duration **From**: 1997
To: 2000

Funding: 1.9 million ECU

Source: UE DGXII/Consortium

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998	0.2	0.3	0.1	1.5	1
1999	0.2	0.2	0.1	1	1

Objectives:

The main focus and innovations in this project are specific technological developments in solar photocatalysis. The objective is to develop the solar detoxification technology to a commercial level and make the photocatalytic treatment of typical persistent non-biodegradable contaminants in chlorinated water found in effluents from chemical production processes feasible:

- High UV transmissivity glass reactor (up to 90 %, 1 mm wall thickness) in the solar UV range (310 to 400 nm)
- Solar collector upgrading design to minimise land required avoiding losses by collector shadows.
- Catalyst upgrading and supporting
- Highly UV reflective surface (up to 95 %)
- Demonstration of technical and economical feasibility under real conditions.

Description:

C_1 and C_2 Non-Biodegradable Chlorinated Hydrocarbon Solvents (NBCS), such as methylene chloride, trichloroethylene, tetrachloroethylene, chloroform, methyl chloroform, etc, are difficult to replace because they influence process reaction and are compatible with most substrate materials. Traditional removal methods used in industrial process water such as stripping, adsorption by activated carbon, biological treatment, thermal or catalytic oxidation and chemical oxidation have important disadvantages or limitations in the treatment of low concentrations of organic pollutants (from 20 to 50 ppm). Now industry is minimizing or eliminating solvents to cut down on the cost of hazardous waste disposal as well as chemical emissions. Emission Limit Values (ELV) are based on the Best Available Techniques (BAT) recognized as feasible from a technical and economic point of view and reasonably accessible to the operator. As multimedia regulations continue to be placed into effect, the approach to environmental management where treatment methods simply transfer contaminants from one medium to another becomes an increasingly unstable option.

The basic idea of the project is the development of a Solar Detoxification System, based on the simple, inexpensive and efficient non-concentrating solar collector technology (such as the compound parabolic collector and flat collectors with tubular photoreactors) which seems the best technological solution for Solar Detoxification Systems as static collectors can capture the diffuse UV sunlight as well as the direct beam (the diffuse component can make up 50% of the available UV light, even on a clear day, and the UV available on a cloudy day may be no less than half that on a clear day). When solar UV radiation is used, the beauty of the Solar System, which can destroy many of the most "difficult" persistent organic pollutants, is its intrinsic simplicity. It is cost-effective, easy to use, and requires a minimal capital investment. The technology is also ecological, as all the components are very simple, common materials.

The reaction takes place when UV radiation photo-excites a semiconductor catalyst in the presence of oxygen. In these circumstances hydroxyl radicals, OHº, are generated which attack oxidizable contaminants producing a progressive break-up of molecules into carbon dioxide, water and diluted mineral acids.

In addition to assessing its capacity for destruction, field demonstration attempts to identify any pre- or post-processing requirements, potential operating problems, and capital and operating costs. As the existing Solar Detoxification technology comes from the solar thermal technology with just some minor modifications, the state of the art still requires specific technological developments which could significantly increase the present efficiency.

Status:

The project was approved in 1996 and formally begun in June 1997.

Main activities achieved in 1998 period are the design and construction of collector proto types, which have been tested within the last part of the year. Main decisions fining the necessary hardware boundary conditions have been taken. Thus, the following items have been fulfilled:

- Collector engineering, design, construction and building-up have been performed by CIEMAT, AOSOL and INETI.
- Specific Tests have been carried out at prototype systems constructed in PSA (Spain) and DLR (Germany).
- The production of glass tubes by SCHOTT.
- The supply of the new pyrolaser catalyst has been made by ENEL (3 Kg).
- CIEMAT proposed a modification of the work program to include the construction of a small mobile pilot plant. This proposal was approved by the European Commission.

Plans for 1999:

Main activities planed for the next period are:

- Optimization of collector design to cost reduction will be performed by AOSOL
- Optimization of glass tubes by SCHOTT.
- ECOSYSTEM will decide, in cooperation with all the partners, the HIDROCEN pilot plant details.
- Production of the pyrolaser catalyst will be made by ENEL (2 Kg).
- Construction of the HIDROCEN pilot plant.
- Starting of the test campaign at Hidrocen.

COLÓN SOLAR
Integration of Solar Thermal Energy into an existing oil-coal-gas Power Plant

Project Leader: Manuel Blanco

Participants:

CIEMAT, Madrid
DLR, Cologne
AICIA, Sevilla
Sevillana de Electricidad Sevilla
ENDESA, Madrid
Electricidade de Portugal, Lisbon
ABB
INABENSA, Sevilla
Babcock Wilcox Española, Madrid
PROET, Lisbon

Duration: **From**: 1997
To: 1998 (Phase I)

Budget: 41.7 M ECU

Source THERMIE
Utilities (Sevillana, Endesa)

Objectives:

To integrate Solar Thermal Energy into an existing oil-coal-gas Power Plant (Cristobal Colón) at Huelva (Spain) using a CRS to boil part of the water, repowering to improve the efficiency with and without sun and during low-load periods with an annual fuel savings upwards of 14% and a reduction of CO x, NO x, SO_2 emissions to the atmosphere.

Description:

The main goal to be achieved in the Colón Solar is the integration of solar thermal energy into a conventional electricity plant. A new hybrid plant is proposed. Central receiver technologies have been chosen, as they seem to be the most promising technology for large-scale power plants. In addition, integration into a combined cycle enables higher thermodynamic efficiencies. The solar plant produces saturated steam for the whole system in a Brayton-Rankine combined cycle.

The solar system considered is a north-field central receiver system with a nominal power of 21.5 MWt under nominal conditions (solar noon and 860 W/m²) and a field of 489 heliostats, each with 70 m² reflective surface.

The site selected is an old conventional plant at Polígono Industrial Punta de Sebo (Huelva-South West of Spain). Good weather conditions, the availability of the land required for the heliostat field and easy access to fossil fuel supply are several of the main reasons for this choice.

Status:

By the end of 1997, Phase I, which consisted of detailed engineering of the solar part and the necessary modifications to the conventional plant, including specifications for bidding by suppliers, was well advanced, and during 1998, was successfully completed. A prototype heliostat was installed and tested at the PSA with outstanding results.

Plans for 1999:

The project has been indefinitely postponed due to takeover of the main project partner, Sevillana, by ENDESA.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Related
1998	0.2	0.1	1	1.7
1999	---	---	---	---

DISS-Phase I
(Direct Solar Steam in Parabolic Trough Collectors)

Project Leader: E. Zarza

Participants:
- CIEMAT
- DLR
- ENDESA
- INABENSA
- FLAGSOL
- ZSW
- SIEMENS
- UNION FENOSA
- IBERDROLA

Duration: **From**: January 1996
To: November 1998

Funding: 7 MECU

Source: DG-XII
Partners

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998	3	1	2	1.5	2
1999	3	2	2	1.5	2

Objectives:

The objective of the DISS project is to develop a new generation of Solar Thermal Power Plants using parabolic-trough collectors, producing high pressure steam in the absorber tubes and thus eliminating the oil currently used at the SEGS plants to transfer heat from the solar field to the conventional power block. In order to increase the competitiveness and efficiency of this new type of solar power plant, the DISS RD&D project includes not only the development of the new Direct Solar Steam technology, but also improvement of the solar collectors and overall system integration.

Description:

The nine SEGS plants currently supplying 354 MWe peak power to the California grid using the technology developed by the LUZ International company since the early 80's represent state-of-the-art solar parabolic-trough thermal power plants. LUZ was able to continually increase efficiency while reducing costs of the SEGS plants. Unfortunately, these efforts were insufficient to withstand the reductions in conventional fuel costs and tax subsidies and the company collapsed in 1991. By that time, however, LUZ had identified a number of improvements that could reduce the cost of electricity generation by 30%. These improvements were grouped into three categories:

1. Solar Collector improvements
2. Replacement of oil heat transfer medium by direct steam generation (DSG) in the solar collector absorbers
3. Overall system improvements

In 1989, LUZ began an R+TD program to develop and implement all these improvements. Unfortunately, this program was aborted by the collapse of LUZ.

From a technical stand point, the most critical part of these improvements is the development of direct solar steam generation in the parabolic-trough collectors. This is due to the two-phase flow (water-steam) in the absorber tubes of the collectors, which involves some technical uncertainties that must be clarified before the implementation of a commercial plant using this technology. Some of these unknown factors are:

- Solar field control
- Process stability
- Materials and components

Since DISS objectives cover not only development of the new process (direct solar steam generation) but also the potential improvements identified by LUZ, parallel activities on system integration and collector improvements are being performed simultaneously with the design, implementation and operation of the PSA test facility.

Direct steam generation also has a certain number of technical problems that require real-scale experimentation and evaluation for cost assessment. To find the solutions to these problems, the laboratory facilities currently available (HIPRESS, Siemens-KWU) are insufficient. A specific real-scale test facility is required, and this is an essential job for the success of this project. A key point of this project is therefore the design and implementation of such a real-scale test facility at the PSA.

Status:

The detail design of a life-size DSG test facility was finished and the facility was implemented at the PSA in 1998. The solar field of this test facility is composed by a single row of parabolic trough collectors, North-South oriented and with a total length of 550 m. The concentrating parabolic reflectors of the DISS collectors are similar to those implemented at the SEGS plants in California (i.e.LS-3 design). Only minor modifications have been introduced in the steel structure in order to meet the special requirements demanded to the DISS collectors (i.e. heavier absorber pipes and possibility to incline the tracking axis of the collectors up to 8º, in steps of 2º).

The PSA DISS test facility has been designed to have a great operational flexibility, thus offering the possibility to test the three DSG basic processes (i.e. once-trough, recirculation and injection) in a wide range of operational parameters. New selective coatings for absorber pipes have been investigated as well as several ways to enhance the heat transfer at the absorber pipes (i.e. micro grooves and inner porous coatings). A dynamic simulation model for the DSG test facility implemented at the PSA has been developed and used to predict the performance and behavior of the test facility under different working conditions.

All these activities were included in the first phase of the project, which finished on November 30, 1998. The European Commission has given financial support to the project trough the Non-Nuclear Energy Program (contract no. JOR3-CT95-0058).

Plans for 1999:

The second phase of the DISS project was started on December 1, 1998, with a duration of 33 months. In 1999 and 2000, the test facility implemented at the PSA in 1998 will be used to study under real operation conditions the existing technical uncertainties with regard to the DSG processes. The three DSG processes (Once-through, recirculation and injection) will be investigated and experimentally evaluated at the PSA to find the optimum process or combination of processes for DSG commercial power plants. In parallel with this investigation, new absorber pipes and reinforced mirrors will be tested during the next years, and the configuration for a first DSG demonstration plant will be prepared.

DISTAL II/EURODISH
(Cost Reduction for Dish/Stirling Systems)

Project Leader: P. Heller

Test Engineer: W. Reinalter

Participants:

SOLO Kleinmotoren, Germany
MERO System, Germany
Klein + Stekl, Germany
Schlaich, Bergermann u. Partner, Germany
Inabensa, Spain

Duration: **From**: June, 1998
To: January, 2001

Funding: 275 Mio. Ptas (total project)
50 Mio Ptas (PSA)

3.75 M Ptas (PSA 1998)

Source: PSA Basic Budget
CEC-DGXII

Objectives:

The objective of this project is to develop new innovative components and manufacturing/erection procedures and associated tools which reduce cost for dish/Stirling systems to below 5 000 ECU/kWe.

Description:

The dish/Stirling system is acknowledged to be the most efficient technology for converting solar radiation into electricity. Overall system efficiencies of between 20% and 30% have already been achieved by several early prototypes. For early market penetration in remote area and island installations, system costs have to be below 5 000 ECU/kWel for production of 100 to 500 units (1 to 5 MWel) a year. This will be achieved in the following ways:

- Component cost reduction
- Development of a new concentrator manufacturing procedure
- Improvement of Stirling engine
- Development of a cost-effective erection procedure
- Remote monitoring and protected control via World Wide Web (WWW)
- Test of pre-commercial units as reference systems

Status:

First tests of improved components were conducted late in 1998. These tests use the DISTAL II facility as a test bed. New engine components as well as a new water-cooled cavity were installed for pre-qualification. Testing of the concentrator tracking system were started.

Plans for 1999:

Component tests will be carried out during the system development phase. One unit of the DISTAL II facility will be equipped with a new tracking system control cabinet.

Man Power/Year:

Year	Main.	Oper.	Project Relat.
1998	0.1	0.5	0.2
1999	0.2	1	1

EUROTROUGH
(low cost EUROpean parabolic TROUGH collector)

Project Leader: E. Zarza

Test Engineers: F. Schillig, E. Lüpfert

Participants:

Instalaciones Abengoa, S.A.
Schlaich, Bergermann und Partner GbR
Fichtner GmbH & Co KG
PILKINGTON Solar International GmbH
DLR
CIEMAT
Centre for Renewable Energy Sources CRES

Duration: **From**: 08/1999 **To**: 01/2001

Funding: Total $2.4 M

Source:

European Commission (50%),
Project Partners (50%)

Objectives:

The most active industrial solar thermal partners in Europe joined forces in this industrial project to develop an advanced, low cost European parabolic-trough collector for process heat and electric power generation.

- development of a new light-weight collector design including construction, drive, control and concentrator technology weighing under 30kg/m²
- mass manufacturing, transport and assembly concept for economic implementation of parabolic trough collectors in small and medium application ranges starting with a few MW
- fully automated operation, minimum O&M
- reduction of solar collector costs below $200/m²
- attain worldwide leadership in renewable energy systems

Status:

Experience from former installations has been compiled, the new collector structure is being developed, wind-tunnel tests have been prepared, and test equipment procured.

Plans for 1999:

Completion of detailed design of the steel structure, tracking unit design and testing, prototype test plan, environmental impact study and cost assessment.

Man Power/Year:

Year	Main.	Oper.	Project Relat.	Techn.
1998	0	0	1	0
1999	0	0	2.7	0.3

HIT-REC (VOLUMETRIC AIR RECEIVER)

Test Engineer: J. León (on site)

Participants: CIEMAT, DLR

Duration: Sucessively ongoing campaigns

Funding: German Ministry project

Source: DLR,CIEMAT

Objectives:

To seek conclusive information on the feasibility, scale-up capacity at high thermal efficiencies, validation of fluid models and lifetime information on the various concepts and materials.

System Description:

The system is prepared for testing volumetric absorbers in the range of 200 kW_{th} to 250 kW_{th}. It consists of

- A heliostat field able to produce up to 2.7 MW
- An absorber test bed (made by Sulzer) which has an internal water/air heat exchanger and forced-air circulation, on top of the CRS tower
- Flux measurement system with Lambertian target (Hermes-II)
- Data Acquisition System

Absorber Description:

Volumetric receiver formed by 37 independent hexagonal segments attached to a support structure. Each segment consists of two parts, the hexagonal absorber structure made of SiC and the SiSiC cup it is inserted in. The support structure is a refrigerated double-walled membrane.

Status:

The 200 kW_{th} Volumetric Test Program was part of the IEA/Solar PACES Task III and now is complete.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998	0.3	1	0.1		0.3
1999	---	---	---	---	---

HYHPIRE
(Advanced Hybrid Heatpipe Receiver)

Project Leader: P. Heller
Test Engineer: W. Reinalter

Participants:

DLR, Stuttgart
IKE, Sweden
Intersol, Sweden
Schlaich, Bergermann u. Partner, Germany

Duration: **From**: Jan. 1996
To: June 1999

Funding: 295 Mio. Ptas (total project)
27 Mio Ptas (PSA)

Source: PSA Basic Budget
CEC-DGXII

Objectives:

The objective of this project is to develop an advanced hybrid heat-pipe receiver for dish/Stirling systems, including a low-emission propane-gas burner, and to demonstrate the maturity of the dish/Stirling technology. Additional tasks are the development of a cost-effective manufacturing method for porous structures and a market study of hybrid Dish/Stirling system potential in Morocco.

Description:

The hybrid receiver contains three important heat transfer zones connected by a heat pipe: first, the surface which is heated by the concentrated sunlight, second, the surface which is heated by the burner flame, and third, the surface which is cooled by the working gas in the Stirling engine. The heat is transferred from 1) or/and 2) to 3) by sodium vapor as the heat-exchange vehicle (heat pipe principle). The receiver can be operated in solar-only, fossil-only or hybrid (parallel) mode.

Status:

The site preparation at PSA including the gas supply system, the control cabinet with the control and DAS system and the necessary wiring are finished. The north DISTAL II dish facility were prepared and the package was installed after first gas-only mode ground tests. The project was extended on a cost-neutral base until June, 30, 1999.

Plans for 1999

Tests in gas-only, solar-only and hybrid modes and all the typical system operating modes will be performed, especially startup, shutdown and transient behavior. Routine operation is planned thereafter.

Man Power/Year:

Year	Main.	Oper.	Project Relat.
1998	0.1	0.5	0.5
1999	0.1	0.5	0.5

LAGAR PROJECT
(Water recovery from olive mill wastewaters after photocatalytic detoxification and disinfection)

Test Engineer Sixto Malato

Participants:

CIEMAT-PSA
INETI (Biomass Dept.), Portugal.
Technische Univ. of Wien. Institut für Physikalische Chemie, Austria
Naias Scientific Analytical Laboratoires, Greece.
A. Pereira da Silva Lda. Portugal.

Duration: **From**: 1998 **To**: 2001

Funding: 0.94 million Euro (total budget)

Source: EC DGXII

Objectives:

The objective is to develop the best (e.g., cheapest) way to use the solar photochemical detoxification technology for wastewater treatment at pilot plant scale to mineralize the recalcitrant phenolic contaminants typically found in the soluble organic fraction of olive mill waste water (OMW). The basic idea is that Advanced Oxidation Processes can be used as pretreatment methods for olive mill waste water (OMW) since the toxic aromatic compounds are mineralized by the AOPs.

Description:

Chemical treatment of wastewater by UV-irradiation, oxidants and/or catalysts (Advanced Oxidation Processes,) can achieve complete mineralization of pollutants to CO_2. Combinations of a preliminary advanced oxidation process and an inexpensive biological process are very promising for treatment of OMW, which has a high concentration of organics, most of which are biodegradable, making complete mineralization unnecessary. Therefore, the aim of this project is the destruction of the toxic compounds (mostly phenols) without mineralization of the total organic content.

In this project, the technology and economics of four different photochemical reactors that use solar irradiation captured by simple, inexpensive and efficient non-concentrating solar collector technology, for the treatment of olive mill wastewater (OMW) by oxidative photocatalysis are compared. The one selected will be employed in a small pilot plant under real working conditions in two mills, one in Portugal and another in Greece. At the end of the project, the economic assessment of the treatment systems will be reexamined. The discussion will consider the relationship between process costs and detoxification achieved, for the particular application in question.

Status:

The project has formally begun in September 1998 and the first tests have been performed for determining the best photocatalytic condition to treat the OMW in the actual photocatalysis pilot plants of the PSA.

Plans for 1999:

Design, construction and testing of two new OMW photoreactors and assembly at two olive oil mills in Protugal and Greece.

LECE
(Laboratorio de Ensayos Energeticos para Componentes de la Edificacion)

Test Engineer: M. J. Jiménez

Participants:

CIEMAT
DLR
EU DGXII
Universidad Politécnica de Madrid
Universidad Politécnica de Cataluña

Duration: CIEMAT continuous action since 1987

Funding:

Source:

CIEMAT
DLR
EU
Industry
University

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998	2		0.2	6	2
1999	2		0.2	6	2

Objectives:

- Development of methodology and improvement of testing of conventional and innovative building components using real-scale outdoor test cells to asses the reliability of these elements for saving energy in buildings.
- Establishment of standard testing and quality procedures for the integration of the LECE Laboratory into the ENAC network.
- Study of the thermal transfer process in passive solar energy applications as well as climatic resources for use in natural air conditioning techniques.
- Experimental testing of natural cooling techniques: vegetation, evaporative roofs and ventilation.
- Participation in studies on thermal characterization and the integration of solar active energy systems (photovoltaic tiles, solar collectors, etc.) into buildings.

Description:

The laboratory consists of four fully equipped quasi-adiabatic test cells, a tracking bench, and control room with two data acquisition systems. Strong thermal insulation enables indoor cell environment response to be assigned exclusively to the test component. The test sequence and data treatment follow a carefully designed procedure to increase accuracy and obtain the maximum information.

The LECE participated in the EU PASSYS II Program in 1992 and 1993. It has further participated and is participating in CIEMAT initiatives for third parties, such as the Junta de Andalucía, Universidad Politécnica de Madrid, Universidad Politécnica de Cataluña and the Building Material Manufactures Association.

Status:

After some modifications and improvements, the LECE Laboratory is fully equipped to perform any outdoor energy testing of construction components. As a complement to these facilities, the LECE is developing the area of the translucid component energy studies (Transmitance, reflectance, TSET) in order to provide complete outdoor energy assessment of any building component.

Plans for 1999:

In 1999, experiments will be performed in the LECE for the ARCHINT project (**ARCH**itectural **INT**egration of Solar System in Buildings). This is a CRAFT-JOULE project coordinated by the CIEMAT Solar Energy in Buildings Team. The other partners in the project are small and medium German, Portuguese and Spanish companies. The aim is to study the economic and technical feasibility of improving existing commercial opaque PV modules and low-temperature solar collectors, focusing on passive features for building integration.

LECE is also going to perform thermal and daylighting tests for the JOULE PV-MOBI (PV Modules Optimized for Building Integration) project coordinated by the CIEMAT Photovoltaic Team. The other partners are small and medium European companies. The aim of this project is the electrical and thermal improvement of PV semitransparent modules.

Quality control activities will be very relevant in 1999.

The LECE will continue to be constantly renovated, adapting itself to new market demands. One of the fields in which this will be most evident will be translucid component energy studies.

MEDUCA
Model Educational Buildings for Integrated Energy Efficient Design

Project Manager: Andreas Holländer

Participants:
- Cenergia Energy Consultants
- CIEMAT
- CNR-IEREN
- CRES
- DLR
- SINTEF
- Swedish Ntnl. Testing & Res. Inst.
- SWN Stadtwerke Neum. GmbH
- The Municipality of Ballerup
- Univ. of Almeria

Duration: **From**: 1996 **To**: 2000

Funding: 1.608 MECU

Source: EU DGXII

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998	0	0	0.1	0.1	0

Objectives:

The overall aim of the MEDUCA-project is to demonstrate that energy efficient educational buildings, in which the requirements for an attractive and healthy indoor environment are fulfilled, can be designed and built. This is to be achieved in new construction and refurbishment combining conventional and innovative technologies. The aim is to create educational buildings, which will stand out as exemplary models of optimized integrated energy efficient design for new schools to be build or refurbished in the city/region where they are located, and which can also serve as the basis for the development of improved standards for this type of buildings in Europe. Specifically it is the aim that the penetration of an integrated quality technological approach to energy efficient design of educational buildings as standard practice at local level and in the countries of the proposers will be the result of this cooperation.

Description:

The project will be implemented in the University of Almería. This University, located 100 meters from the seashore, has average high temperatures of 28ºC, average minimum temperature of 16ºC and relative humidity around 60% in the summer.

The project consists of refurbishing four buildings by building an atrium in the patio they surround to acclimate the patio and the buildings that conform it. The buildings in the project have no other obstacles to the sunlight that could project shade into the atrium. The patio floor is 400 m^2 and 12 m high. Entrance to the patio is by four approximately 2-x-2-m doors, that will be used for air-current access needed for refrigeration, as well as for air-recirculation and heat redistribution during the winter. There are also a number of windows that will be used to recirculate the air and thereby acclimatize the buildings to a certain degree.

The atrium will be built on a metal skeleton. To complete the needed shading and to increment the solar chimney effect (see point 3) special glazing with selective solar spectrum coatings will be used in the atrium.

In winter, PV-powered ventilators will recirculate the hot air accumulated close to the atrium toward the bottom of the patio. The cross ventilation currents, generated naturally by pressure differences created by the difference in temperatures between the patio and the buildings and the outside will also be used to this end.

Status:

During 1998 the detailed engineering of the roof was finished. The climate measurement system was purchased. Due to some problems with the budget for the cool wall, it was decided to change the cooling interface. Some discussions were held with the alternative renewable cooling systems supplier. The final decision will be made at the beginning of 1999. During the summer break at the university, the atrium roof was erected, including the ventilation system.

Plans for 1999:

- Decision on final cooling system
- Installation of climatic sensors
- Start up of monitoring

PAREX

PSA Test Engineer: J. León, P. Balsa

Participants: CIEMAT
DLR

Duration: **From**: 1995 **To**: 1999

Funding Source: BMWi
DLR
CIEMAT

Objectives:

Development and testing of advanced parabolic trough receivers to:

- Reduce losses at higher temperatures
- Reduce thermomechanical loads due to cyclic and uneven heating ("bowing)

To increase the potential of parabolic trough collectors with thermal oil (HTF systems) or direct steam generation (DSG systems).

Description:

A number of new parabolic trough receiver concepts were evaluated by analytical and numerical methods to select promising configurations to be built and tested under real solar conditions at the PSA. These concepts are:

- Secondary concentrators
- Linear cavities
- Heat pipe
- Multiple pipes

and combinations there of. The experiments will be used to validate design assumptions and as a basis for further development and optimization.

Status:

First tests were performed at the PSA's ARDISS test facility in 1996, evaluating three PAREX prototypes: PAREX 00b, PAREX 001 and PAREX 002.

A second series of tests was performed at the PSA LS-3 test facility in 1997 and 1998. End-reflectors were tested at the PSA in 1998.

Plans for 1999:

Further tests will be performed at the PSA LS-3 test facility to evaluate and compare the performance of several configurations of parabolic-trough receivers.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998		1	0.5		1
1999		0.4	0.2		0.2

PROHERMES
(Advanced Flux Mapping on Concentrating Solar Power Systems)

Project Leader: R. Monterreal
Project Engineer PSA: A. Kröger-Vodde

Objectives:

In order to evaluate the performance of solar concentrating system components like receivers or heliostats, the PSA has prepared the PROHERMES flux mapping system.

Description:

Basing on a 14-bit CCD slow-scan camera, the customizable OPTIMAS image-processing software, and former experience with the HERMES system, a flexible flux-mapping system has been established. It measures in a receiver entrance plane or on special test targets. In both cases the camera is directed towards the target. A white diffusely-reflecting target is needed. This indirect method by analyzing re-radiation from the target permits easy evaluation of flux distribution maps. The gray-level conversion to physical power density units is made with calibrated radiation sensors.

Plans for 1999:

Application and extension of the PROHERMES system to the REFOS and TSA projects and heliostat testing and evaluation.

Man Power/Year:

Year	Main.	Oper.	Project Related	Techn.
1998			1	
1999			1	

REFOS
(Pressurized Volumetric Receiver for Solar-Hybrid Gas Turbine and Combined Cycle Systems)

Project Leader: R. Buck, DLR, Stuttgart

Project Engineer PSA: E. Lüpfert, P. Heller

Participants: DLR, CIEMAT

Duration: **From**: 1996 **To**: 6/1999

Funding: BMBF, Germany,
DLR, Germany

Objectives:

The aim of the REFOS project is to demonstrate the feasibility of the modular pressurized volumetric receiver concept. This receiver concept enables highly efficient use of solar energy in combined cycle plants and power can be scaled up as required.

Description:

Solar energy from a pressurized air receiver can be supplied with significant shares into gas-turbine-based power systems making the best possible use of the high exergy content of concentrated solar radiation. The 28% solar energy to electricity conversion efficiency with this solar air-preheating concept is a promising milestone on the way to lowering solar energy costs. A closed volumetric receiver with a secondary concentrator cone and a quartz window in a 350-kW modular unit supplies hot pressurized air through a combustion chamber or directly to a gas turbine.

Status:

One receiver module was tested in two test phases in 1998. Secondary concentrator efficiencies have been reported. Testing of the entire module is underway.

The project has been cut down to a single module. Testing of a cluster has been cancelled.

Plans for 1999:

Test of the installed module will be continued. Applications to EC program and German Ministry may enable project continuation towards integration of a gas turbine at the PSA.

Man Power/Year:

Year	Main.	Oper.	Project Related	Techn.
1998	1	1	2	0
1999	0.25	0.25	0.5	

SolWIN

Test Engineers:F. Schillig, R. Kistner, W. Ortmanns,

Participants:

DLR
National Renewable Energy Lab. (NREL)
Sandia National Laboratories

Duration: **From**: Jan. 1998
To: Dec. 1998

Funding: none

Objective:

SolWIN is a software analysis tool to visualise the technical, economical and financial viability of solar thermal power projects, including assessment of hybrid solar-fossil electricity generation concepts and resource consumption of solar thermal power systems and find least-cost solar power solutions .

1998 Achievements:

Within the SolWin site module, DLR implemented several models for estimating meteorological data. In the scope of a scientific exchange program between DLR and SunLab, a parabolic-trough model was developed and programmed by H. Price and T. Wendelin of NREL. During his stay at the PSA, R. Diver of Sandia, together with the DLR Distal Team, compiled a model for Dish/Stirling systems. Moreover, the implementation in SolWin of a stand-alone tower was begun. The existing project financing and cash-flow model was improved and extended. The credit plan module was made more flexible, in order to give the user more choices to reproduce realistic project financing structures. Insurance and tax features were also implemented in the SolWin core.

Plans for 1999:

The technical SolWin core will be complemented by a financial/economic Independent Power Plant analysis module (RENIPPLAN), for which financial support from the European ALTENER program has been approved. Partners within this project are DLR, the project coordinator, and CIEMAT and SimTech, an Austrian simulation software developer.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Stu-dents
1998	0	0	0	0	2
1999	0	0	0	1	2

THESEUS
(50 MW_e THErmal Solar European Power Station at Frangokastello, Crete)

Test Engineers: Frank Schillig
Rainer Kistner

Participants:

DLR, Cologne
PILKINGTON Solar International, Cologne
FICHTNER (consulting engineers), Stuttgart
EUCOMSA, Sevilla
CRES, Athens
OADYK, Chania (Crete)
PREUSSEN ELEKTRA, Hannover (Germany)
ENEL , Rome
PPC (Greek Public Power), Athens

Duration: **From**: January, 1997
To: December, 1998

Funding: 2.7 MECU

Source: CEC-DGXVII, Partners

Objectives:

The objective of this project is the implementation of the first large-scale European parabolic-trough power plant, of 50-MW_{el} nominal capacity, on the Greek island of Crete. The proposed project site is located in the Frangocastelló area on the southern coast of western Crete in the county of Sfakia. The power block will be a conventional Rankine cycle reheat steam turbine. The solar field energy source will be supplemented with an LPG-fired heater to supply limited auxiliary process steam for start-up and solar field freeze protection. A consortium of European industry, utilities and research institutions from Greece, Germany, Spain and Italy sponsored by the EC's THERMIE program was established in 1996.

Description:

The THESEUS project consists of a nominal 50-MWe-net solar power plant with an advanced parabolic trough collector field as the primary heat source. The project site is expected to be in the Frangokastelló area on the southern coast of western Crete. The THESEUS solar thermal power plant is comprised of a moderate-pressure (100 bar), low-temperature (371°C) Rankine reheat-steam cycle electric generating system with a nominal power of 50 MWel, using solar thermal energy as its primary heat source. The solar field energy source is supplemented by an LNG-fired boiler to supply steam during conditions of low solar insolation

Status:

During 1998 final decisions were made on the ownership structure, project site and plant configuration. In the initial project proposal to the European Commission, two ownership possibilities were foreseen: a utility owned alternative and a private ownership (IPP). Both options have been carefully investigated and the IPP structure selected.

During the development phase, a complete technical design report was prepared. The final goal of the EC project was the completion of the application document for the "Permit for Installation" from the Greek Ministry of Development according to the Greek law 2244/94. This law allows private entities to produce and sell electricity from renewable energy sources. In parallel, THESEUS S.A., a Greek Private Share-

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998				0.9	1
1999					

holding Company, was founded. A German Venture Capital Fund took over the majority of THESEUS S.A., committed to raise the equity capital for the project; a major German State bank offered to provide the entire loan financing.

Plans for 1999:

Though the original project ended in December 1998, during the first quarter of 1999 the THESEUS S.A. submitted the application for the 1st phase for the Permit for Installation. Recently, the THESEUS S.A together with Pilkington, Fichtner, ENEL, O.A.DY.K., METKA and DLR completed a new proposal to the EU within the 5th framework. Provided that the EU will support the project and the Greek Ministry will confer the required permissions, the erection of the solar field and the power block is scheduled for the year 2001 and 2002

TMR
(Training & Mobility of Researchers Program)

Test Engineer: Diego Martínez Plaza

Participants: European Commission DG XII

Duration: **From**: January, 1996
To: December, 1998

Funding: 264 Million Pts.

Source: EC-DGXII

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998				0.8	
1999	Project ended in December 1998				

Objectives:

TMR is an initiative of the CEC-DGXII, which has four activities:

1. Research Networks
2. Access to Large-Scale Facilities
3. Training through Research
4. Accompanying Measures

The PSA has been running a contract for activity number 2, 'Access to Large-Scale Facilities'.

The aim of the program is to promote, through the stimulation of training and the mobility of researchers, a quantitative and qualitative increase in human resources within the European Community.

The essential objective of the LSF activity is to provide research teams with access to large facilities important for high-quality research. This activity is intended to be of particular significance to researchers working in regions of the Community where such facilities do not exist.

The objectives of the program coincide with those of the PSA by contributing to the dissemination of the use of a wide range of industrial solar thermal technology applications, from electricity generation to passive architecture, throughout Europe.

Description:

Under the above mentioned contract, the PSA has offered access to the following facilities free of charge:

- Detox Loop, Solar Furnace, Acurex Field and Solfin : 28 Weeks within the three years
- Desalination Plant and LECE: 12 Weeks
- Dish/Stirling: 11 Weeks
- Solar Dryer: 2 Weeks
- CESA-1: 8 Weeks

Access included all infrastructure, logistic, technical and scientific support that is normally provided to external users of the facility.

A minimum of 50 different groups has benefited by the end of this contract, with a minimum of 28 groups given access per year.

One of the contract requirements was that the PSA widely publicize the access so offered.

Users have been selected annually, after publishing a 'Call for Proposals' followed by an application period. A Selection Panel consisting of 10 experts, at least 6 of who are not from CIEMAT, meets in October to select the users for the following year.

Two types of access were offered:

Access-to-Research: The research group was expected to bring its own research proposal to be performed at one of the facilities above, with the support of the corresponding PSA project leader typically for a periodfrom two weeks to two months.

Access-for-Training: This option was addressed to individual users who received a comprehensive overview of all the industrial applications of solar energy currently under development at the PSA and had the oppor-tunity to take part in ongoing projects. Typical duration is between three and six months.

Status:

The program has covered its third year at PSA and by the end of 1998, 50 different groups have participated.

Plans for 1999:

The project ended in December 1998.

TMR Control Project

Test Engineer: Pedro Balsa Escalante

Participants:

Norwegian University of Science and Technology, Norway
INFOTECH - University of Oulu (Finland)
FCT/UNL (Facultade de Ciencias e Tecnologia/Universidade Nova de Lisboa), Portugal
CEL (Control Engineering Laboratory), University of Bochum, Germany
DEI (Departamento de Engenharia Informática), Universidade de Coimbra (Portugal)
Industrial Control Centre, Strathclyde University, United Kingdom

Duration: **From**: 1996 **To**: 1998

Source: CEC-DGXII

Objectives:

The main objective of this project is the development and testing of advanced control algorithms for use in solar power plants, providing European research groups with the experimental facilities needed to:

- Perform an in-depth study of the difficulties involved in improving control design schemes for parabolic-trough solar collector fields.
- Test and validate their theoretical approaches concerning new advanced control algorithms improving control system performance, response speed, robustness and rejection of disturbance.

Description:

Solar power plants deliver thermal energy in the form of sensible heat in a fluid (liquid or gas) which is heated to a desirable temperature. Since the primary energy (solar radiation) varies, without proper control, the temperature of the output fluid also changes.

Parabolic-trough collectors have proven to be an efficient way to meet the requirements of these industrial processes. Good control performance using PI and PID controllers could be achieved by accepting a slow speed of response and, consequently, long settling times, restricting their range of application as an energy source. It became evident that improved control schemes for parabolic-trough solar collector fields is a requirement to open a wider field of application for these systems.

The PSA ACUREX facility and the flexible and reliable control software provide a very valuable versatile test bed for this purpose.

Status:

During 1998 the main control schemes tested have been controllers based in fuzzy logic, gain-scheduling controllers, adaptive predictive controllers and advanced schemes that combine classical control theory and the new advanced control techniques.

Plans for 1999

Since the EC contract for TMR program has finished in 1998, a new proposal will be submitted in 1999.

TMR Desalination Project

Test Engineer: Pedro Balsa Escalante

Participants:

PROBE (Centre for Performance Research On the Built Environment)
University of Ulster, Northern Ireland

Duration: **From**: 1996 **To**: 1998

Source: EC-DGXII

Objectives:

The shortage of drinking water affects many countries in the third world, which also lack conventional energy resources. During recent decades the desalination plant market has greatly increased.

For these reasons the Solar Desalination plant was included in the TMR proposal in order to promote solar desalination among European Countries.

Description:

The Solar Desalination system used for this project is composed of:

- 14-cell MED (Multi-Effect Distillation) plant
- parabolic-trough solar collector field
- thermal storage system

The system operates with Santotherm 55 synthetic thermal oil as the heat-transfer fluid, which is heated as it circulates through the solar collectors. The solar energy thus converted into thermal energy in the form of the sensible heat of the oil, is stored in a thermal oil tank. Hot oil from the storage system provides the MED plant with the thermal energy it requires.

The plant evaporator body includes 14 cells at successively decreasing temperatures and pressures from cell (1) tube bundle and condenses as it is sprayed by feedwater. The condensation/evaporation process is repeated in cells (2) to (14). The vapor produced in cell (14) at 33ºC/0.05 bar is condensed in a final condenser cooled by seawater. The water condensed in each cell goes through a U-shaped tube to the next cell and finally to the condenser. The product water is then extracted from the condenser by means of a distilled water pump. The feedwater required to spray the cell (1) tube bundle is part of the water coming out of the condenser.

Status:

During 1998 a new advanced collector, tracking concentrating inverted absorber CPC, for low temperatures designed by the University of Ulster was tested at the plant.

Plans for 1999

Since the EC contract for TMR program has finished in 1998, a new proposal wil be submitted in 1999.

TMR DETOXIFICATION PROJECT
(Large Field Water Detoxification at Plataforma Solar de Almería)

Test Engineer: Sixto Malato Rodríguez

Participants:

- UMR CNRS C 6503, Université de Poitiers (France)
- Laboratoire CNRS "Photocatalyse, Catalyse et Environnement", Ecole Centrale de Lyon (CNRS, France).
- Laboratoire de Chimie Industrielle, Université de Metz (France)
- Dipartimento di Ing. Chimica dei Processi e dei Materiali, Università di Palermo (Italy)
- Inst. of Environmental Engineering, Laboratory of Biological Engineering, Swiss Federal Institute of Technology (EPFL, Swiss).
- Institut für Physikalische-und Umwelt-Chemie an der Universitat Bremen (Germany).

Duration: **From**: 1996 **To**: 1998

Funding: 1.5 million Ptas. (in 1998)

Source: UE DGXII / PSA

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998	0.1	0.2	0.1	1	0.2
1999	-	-	-	-	-

Objectives:

Provide European research groups access to the PSA pilot plants for demonstrating pre-industrial-scale feasibility of photocatalytic processes previously tested in the laboratory.

Description:

The latest advances in water purification have concerned the oxidation of persistent organic compounds generally refractory to common detoxification processes dissolved in water. These methods, based on catalysis and photochemistry, are denominated Advanced Oxidation Processes (AOP). Among them, those which produce strongly degrading hydroxyl radicals ($^\bullet OH$) have been successfully developed. Because of their strong oxidative nature (E°=2.8 V), which is much greater than other traditional oxidants (e.g. ozone: 2.07 V, hydrogen peroxide: 1.78 V, chloride dioxide: 1.57, chlorine: 1.36 V, etc.), $^\bullet OH$ radicals are able to completely mineralize organic carbon into CO_2. Methods based on H_2O_2/UV, O_3/UV and H_2O_2/O_3/UV combinations employ photolysis of H_2O_2 and ozone to produce such hydroxyl radicals. However, these radicals can also be generated (i) by a UV-irradiated semiconductor, when in contact with water, or (ii) by the Photo-Fenton process, in which Fe^{2+} ions are oxidized by H_2O_2, thus producing one $^\bullet OH$ and one Fe^{3+} ion, which then act as light-absorbing species producing another $^\bullet OH$ radical and regenerating the initial Fe^{2+} reactant. Both processes are of special interest because the use of sunlight is possible.

The PSA has been working in the application of solar chemistry to water detoxification and in particular the photocatalytic decontamination of used water, since 1990, in both national and international projects. This experience acquired in solar detoxification systems engineering has led to the development and erection at the PSA of the largest Solar Detoxification Pilot-Plant Facility in Europe, which has been successfully used by many European Research Institutions.

Status:

1998 activities centered on solar degradation of organic compounds with TiO_2, Photo-Fenton reagent and photoelectrochemical reactors. Six different EC research groups were at the PSA for one month each.

Plans for 1999:

R&D activities are to be published in a special issue of the international journal *Catalysis Today* and a proposal to the EC for continuation the project will be prepared.

TMR Materials Treatment

Project Manager: Diego Martínez

Participants:

ENSMP (Ecole National Superieur de Mines de Paris) France
IST (Instituto Superior Tecnico) Portugal
NTU (National Tecnichal University) Greece
HUT (Helsinki University of Technology) Finland

Duration: **From**: January, 1996
To: December, 1998

Funding: 8,4 Million Pts.

Source: CEC-DGXII "Training & Mobility of Researchers Programme. Access to Large-Scale Facilities Activity".

Man Power/Year:

Year	Main.	Oper.	Eng.	Proj. Relat.
1998	0.2	0.8	-	1.0
1999	No Activity			

Objectives:

The high-concentration thermal flux delivered by solar furnaces is very suitable for materials research and development, with the advantage of using a clean and renewable energy which prevent conventional energy expenses and toxic wastes production.

The materials obtained after solar treatment present generally very good physical properties and homogeneous surfaces.

Some of the possibilities solar furnaces offer in materials treatment involve:

- Physical-chemical and thermo-chemical study of high-temperature materials
- Study of the thermo-physical properties of materials under solar-concentrated radiation
- Thermal shock testing of high performance materials
- Aerodynamic heating simulation
- Thermal effect simulation of nuclear explosion on materials and components

A brief description of the ongoing activities on this topic includes:

- Thermo-mechanical loads on some industrial refractory materials submitted to thermal shock
- Surface modification of metal alloys by coating with predeposited metal powders
- Preparation of refractory carbides and carbonitrides from compacted metal and carbon powder mixtures
- Thermal fatigue testing of tool steel

Description of the facility

The High Concentration Facility (HCF) Solar Furnace basically consists of a 98.51-m^2 parabolic mirror which concentrates the incoming sunlight at the focus of the parabola. The light is directed on the parabolic concentrator by four flat, non-concentrating heliostats with a total reflecting area of 214.44 m^2 that continuously track the sun.

The PSA Solar Furnace delivers a power of about 60 KW in a 20-cm-diameter circle with a peak thermal flux of 3 MW/m^2.

The computer-controlled slats of a louvered shutter regulate the amount of energy.

Other equipment available includes:

- Test table movable on three axis
- Data Acquisition System
- Vacuum Chamber
- Infra-red Camera for Temperature Measurement
- Tilted Mirror
- Rotating Device

TSA
(Phoebus Technology Program Solar Air Receiver)
TMR Solfin Project
(Solar Fine Chemical Synthesis)

Test Engineer: C. Richter

Participants:

Department of Chemistry, University of Reading, UK
Institut f. Organische Katalyseforschung an der Universität Rostock, Germany
School of Chemical Sciences, Dublin City University, Ireland
Dip. di Chimica e Centro di Studio su Fotore-attività e Catalisi del C.N.R., Università degli Studi di Ferrara, Italy
Dipartimento di Chimica del Politecnico, Milano, Italy

Duration: **From**: 1996 **To**: 1998

Funding: 0.7 MPTs (in 1998)

Source: UE DGXII / PSA

Objectives:

- Give EC research groups access for training and research in solar photochemical synthesis.
- Identify photochemical synthesis with potential for further up-scaling
- Determine best chemical conditions for solar photochemical synthesis of fine chemicals

Description:

A good many photochemical reactions of interest for synthesis fall within the UV-range, 300 - 400 nm, where the solar spectrum offers only low density photon flux. One possible approach to improving UV-range performance is non-concentrating collector systems, e.g., CPCs, capable of collecting more UV-photons per aperture area during a year than concentrating systems. These considerations led to the installation in September, 1996, of a CPC collector with 2m2 aperture area as photoreactor, together with the equipment to make up a closed chemical loop. An additional small test loop was added to the Solfin facility to allow preliminary tests with a low total volume of reaction mixtures. The photoreactor is a 1-m-long by 0.2-m-wide CPC mirror with an optical concentration of 2. A 32-mm-OD Liebig-type glass cooler is mounted in its line of focus. The reaction mixture is circulated by a small centrifugal pump magnetically coupled through the outer compartment of the cooler and thus irradiated. All components are interconnected by flexible corrugated PTFE tubes.

Status:

Until 1998 8 groups in 13 research stays performed numerous tests of a great variety of different reactions. The efficiency of a relatively simple nonconcentrating, CPC based collector system for performing preparative synthetic reactions on a small and medium scale using solar radiation was clearly demonstrated.

Plans for 1999:

Further evaluation and publication of results, improvements in infrastructure, preparation of new project proposals based on experiences gained during 1996 – 1998.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1998	0.1	0.1	0.1	0.5	0.1
1999	-	-	-	-	-

Test Engineers: A. Valverde

Participants:

Duration: **From**: Jan. 1998
To: Dec. 1998

Funding: 600,000 Ptas (1998)

Source: PSA Basic Budget

Objectives:

- Operation of the TSA system to gain experience and operation hours
- Demonstrate the performance and reliability of the TSA to customers and visitors
- Demonstrate operation in grid connected mode

Description:

22 new absorber elements installed in the TSA receiver in 1996 had been tested for 430 h in 1997 and showed not only improved temperature behavior, but also further potential for improvement in the manufacturing process. In 1998, system ability to produce electricity with the CESA-1 steam turbine was again demonstrated and the PSA personnel gathered even more experience in operating the system in grid-connected mode. As parallel operation of REFOS and TSA was not possible, TSA was only operated in the few periods available when the tower was not in use for the REFOS project.

Status:

The TSA system is operational even though there it was not possible to accumulate many hours of operation in 1998 (60 hours total). There is no further TSA-related R&D planned for the near future.

Plans for 1999:

Since the publication of the Spanish Royal Decree at the end of 1998, interest of industrial partners in such proven technologies as TSA (Phoebus) has been reignited for commercial tower power plants to produce and sell electricity on the Spanish market. A new demonstration phase is therefore planned for 1999 to convince industry of the performance and reliability of the open volumetric receiver concept.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1998	0.1	0.1	0	0.2
1999	0.1	0.1	0	0.2

APPENDIX 2

LIST OF COLLABORATING INSTITUTIONS AND COMPANIES

CENTRAL RECEIVER AREA

AICIA
Prof. Valeriano Ruiz
Escuela Superior de Ingenieros
Dpto. Ingeniería Energética y Mecánica de Fluidos
Camino de los descubrimientos, s/n
41092 Sevilla (Spain)
Tel.: 34-95-4487234
Fax: 34-95-4487233
e-mail: varuher@esi.us.es

Babcock & Wilcox Española S.A.
Mr. Enrique Sánchez
Alameda de Recalde, 27
48009 Bilbao (Spain)
Tel.: (94) 495 1967

DLR Institute of Technical Thermodynamics
Mr. Reiner Buck
Pfaffenwaldring 38-40
D-70569 Stuttgart
Tel.: +49 711 6862-602
Fax:+49 711 6862-747
e-mail: reiner.buck@dlr.de

DLR Solar Energy Technology
Dr. Robert Pitz-Paal and Dr. Bernhard Hoffschmidt
Linder Höhe
D-51140 Köln
+49 2203 601 4714
Fax +49 2203 66900
email: Bernhard.Hoffschmidt@dlr.de

Electricidade de Portugal, S.A.-PROET
Mr. Antonio Ferreira da Costa
Av. Estados Unidos da America, 55
1700 Lisboa (Portugal)

Fichtner Solar GmbH
Mr. Georg Brakmann
Sarweystrasse 3
D-70191 Stuttgart
Tel.: 49-711-8995-0
Fax: 49-711-8995-459
e-mail: brakmanng@fichtner.de

GHERSA I+D
Mr. Pedro Grimaldi
Avda. del Puerto 1-6º E
11006-CADIZ (Spain)
Tel.: 34-956-289311
Fax: 34-956-282202
e-mail: igrimaldip@nexo.es

L&C Steinmuller GmbH
Mr. Manfred Schmitz-Goeb
Fabrikstrasse 1
D-51641 Gummersbach
Tel.: 49-226185-0
Fax: 49-226185-2999
e-mail: maschmit@Steinmueller.de

Sevillana de Electricidad, S.A.
Mr. David Corrochano
Avda. de la Borbolla, 5
41004 Sevilla (Spain)
Tel.: 34-95-4417311
Fax: 34-95-4412128
e-mail: corrocha@sevillana.grupoendesa.com

INABENSA
Mr. Rafael Osuna González-Aguilar
Oficina Tecnica, Div. Taller
Manuel Velasco Pando, 7
41007 Sevilla
Tel.: 34-95-493 6111
Fax: 34-95-493 6015
E-mail: rosuna@inabensa.abengoa.com

Max-Planck-Institut fuer Physik (Werner-Heisenberg-Institut)
Dr. Rainer Plaga
Foehringer Ring 6
80805 Muenchen
Germany
Tel. 49-89-32354-224
FAX 49-89-3226704
email plaga@mppmu.mpg.de

SunLab
Sandia National Laboratories, Albuquerque, NM
and
National Renewable Energy Laboratory, Golden, CO
Henry Price
1105 W. 11th Ct.
Broomfield, CO 80020
U.S.A.
+1-303-384-7437
Fax +1-303-384-7495
email: PriceH@tcplink.nrel.gov

Universidad de Almeria (Escuela Politécnica Superior)
Dpto. de Arquitectura de Computadoras y Electrónica
Mr. José Antonio Gázquez
Almería 04071
Tel: 34-950-215074
Fax: 34-950- 215486
e-mail: root@mizar.ualm.es

PARABOLIC TROUGH AREA

BADENWERK
z.Hd. Herrn Scherer
Postfach 1680
76005 Karlsruhe
Alemania

BAYERNWERK
z. Hd. Herrn Hopf
Nymphenburgerstr. 9
80335 München
Alemania

BEWAG
z. Hd. Herrn Fischer
Puschkinallee 52
12436 Berlin
Alemania

BMW
z. Hd. Dr. Julianne Wolf
Hufelandstrasse 6
Underground
U2 Am Hart
80788 München
Alemania
Fax: +49-89-38270430014

Center for Renewable Energy Systems (CRES)
19TH Km Marathonos Avenue
19009 Pikermi
Grecia

Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V.
EN-TT
z. Hd. Herrn Markus Eck
Vaihingen
Pfaffenwaldring 38-40
D-70569 Stuttgart
Alemania
Fax +49-711-6862783

ENDESA
Atn: Mr. Manuel Alonso
C/Principe de Vergara, 187
28002 Madrid
España
Fax. +34-91-5638181

Escuela Superior Ingenieros Industriales
Dpto. de Automática
Prof. Eduardo Fernandez Camacho
Avda. Reina Mercedes s/n
41012 Sevilla
España
Fax. +34 5 444-6849

EVS
Abt: K-MU-G
z. Hd. Dr. Martin Müller
Postfach 10 12 43
70011 Stuttgart
Alemania

FICHTNER GmbH & Co. KG
z. Hd. Dr. Georg Brackmann
P.O. Box 101454
Serweystr. 3
70013 Stuttgart
Alemania

HEW AG
z. Hd. Dr. V. Braunmühl
Überseering 12
22297 Hamburg
Alemania

IBERDROLA
Dirección de Producción
Atn: Mr. Jesús García
c/ Hermosilla, 3
28001 Madrid
España
Fax. +34-91-5782094

INABENSA
Atn: Mr. Rafael Osuna
c/ Manuel Velasco Pando, 7
41007 Sevilla
España
Fax. 34 95 4936015

INITEC
Gerencia Energia
Atn: Mr. Manuel Ruiz
Principe de Vergara, 120
28002 Madrid
España
Fax: +34-91-5871454

Pilkington Solar International GmbH
Atn.: Mr. Paul Nava
Mühlengasse, 7
D-50667 Köln
Alemania
+49 221 258 11 17

Schlaich Bergermann und Partner (SBP)
z. Hd. Dr. Wolfgang Schiel
Hohehzollernstr. 1
70178 Stuttgart
Alemania

SOLEL
Att.: Mr. E. Mandelberg
Har-Hotzvim
P.O.B. 45033
Jerusalem 91450
Israel
Fax +972 2 5323 162

UMIST
Department of Electrical Engineering and Electronics
Att.: Dr. F. M. Hughes
P.O.Box 88
Manchester M60 1QD
Reino Unido
Fax +44 161 200 4820

ZSW
Attn.: Dr. Jurgen Rheinländer
Hessbrühlstr. 21 c
D-70565 Stuttgart
Alemania
Fax +49 711 7870 200

SOLAR CHEMISTRY AREA

Detoxification

AEPLA
D. Luis Roy Parge
Almagro, 44 - 3º
28010 Madrid
Fax: 91-3197734

Ayuntamiento de El Ejido
Area de Agricultura
D. Antonio Escobar
C/ Cervantes, 122
04700 El Ejido (Almeria)
Fax: 485912

ECOSYSTEM
Mr. Martin Vincent
Verge de Montserrat, 76
08392 Llavaneras (Barcelona)
Tel: 93-7952853
Fax: 93-7952870
e-mail: ecosystem@mx4.redestb.es

Universidad de Almería
Dept. Física Aplicada
Dr. F. Javier de las Nieves
Cañada de San Urbano
04120 La Cañada - Almeria

Universidad de Almería
Dept. Ing. Química
Dr. Emilio Molina Grima
Cañada de San Urbano
04120 La Cañada - Almeria

Solardetox Project (BRITE-EURAM)

AOSOL
Mr. Joao Correira de Oliveira
Estrada de Caminho de Serra
Leceia
P.O. Box 1040
2745 Barcarena
Portugal
Tel: (+351) 1-421 2776
Fax: (+351) 1-421 2755
E-mail: aosol@mail.telepac.pt

CIEMAT-DER
Alfonso Vidal
Avda. Complutense 22
28040 Madrid
Tel: 91 - 346 6496
Fax: 91 - 346 6037
email: vidal@ciemat.es

CISE
Dr. Mirella Musci
Mrs. Cristina Casale
Casella Postale 12081
20134 Milano, Italy
Tel: (+39) 2-21672461
Fax: (+39) 2-21672620
e-mail: 0253musc@s1.cise.it

DLR
Dr. K.H. Funken
Dr. Christian Sattler
Hauptabteilung Energietechnik
D-51170 Köln, Germany
Tel: (+49) 2203 - 601 3220
Fax: (+49) 2203 – 66900
email: kh.funken@dlr.de

EC DGXII
Dr. Salvador Cervera
Rue Montoyer 75
B-1049 Brussels, Belgium
Tel: (+32) 2 - 295 8765
Fax: (+32) 2 - 296 0550
email: salvador.cervera@dg12.cec.be

ECOSYSTEM
Mr. Martin Vincent
Verge de Montserrat, 76
08392 Llavaneras (Barcelona)
Tel: 93-7952853
Fax: 93-7952870
e-mail: ecosystem@mx4.redestb.es

HIDROCEN
Mr. Pablo Trincado
Camino del Valle, 12
Pol. Ind. Finanzauto
28500 Arganda del Rey, Madrid
Tel.: (+34) 1-8712112
Fax: (+34) 1-8715132
email: hidrocen@batch-pc.es

INETI
Dr. Manuel Collares-Pereira
Estrada do Paço do Luminar
1699 Lisboa Codex, Portugal
Tel: (+351) 1-7127000
Fax: (+351) 1-7163797
e-mail: collares.pereira@ite.ineti.pt

SCHOTT ROHRGLAS
Dr.F. Doenitz
Dr Martin Brunotte
Erich-Schott Strasse
Postfach 1180
95660 Mitterteich, Germany
Tel: (+49) 9633-80415/(+49) 9633-80401
Fax: (+49) 9633-80450
e-mail: pathworks!srmailmt!brt@drsmt.attmail.com

UNITO
Dipartimento di Chimica Analítica
Università degli Studi di Torino
Prof. Claudio Minero
via P. Giuria 5
10125 Torino, Italy
Tel: (+39) 11-6707632
Fax: (+39) 11-6707615
e-mail: minero@silver.ch.unito.it

TMR - Solfin

Institut für Organische Katalyseforschung
an der Universität Rostock e.V.
Dr. Barbara Heller
Buchbinderstraße, 5-6
D-18055 Rostock
GERMANY
Tel.: +49-381 466 9346
Fax: +49-381 466 93 24
e-mail: bhelle@chemiel.uni-rostock.de

Department of Chemistry, The University of Reading
Prof. Andrew Gilbert
PO Box 224, Whiteknights
Reading
Berkshire RG6 6AD, UK
Tel.: +44-118 9317420
Fax: +44-118 9316331
e-mail: A.Gilbert@reading.ac.uk

School of Chemical Sciences, Dublin City University
Prof. Albert Pratt
Dublin 9, IRELAND
Tel.: +353-1-704 5310
Fax: +353-1-704 5503
e-mail: pratta@ccmail.dcu.ie

University of Ferrara
Department of Chemistry
Dr. Andrea Maldotti
Ferrara, ITALY
Tel.: +39 (0) 532 291147
Fax: +39 (0) 532 240709
e-mail: mla@dns.unife.it

Polytecnical University of Milano
Department of Chemistry
Dr. Tullio Caronna
Milano, ITALY
Tel.: +39 (0) 22 3993000
Fax: +39 (0) 22 3993080
e-mail: Caronna@dept.chem.polimi.it

TMR – Detox

CNRS/Ecole Centrale de Lyon.
Dr. Jean Marie Herrmann
Photocatalyse, Catalyse et Environement
B.P. 163
69131 Ecully Cedex
FRANCE
Tel.: +33 72 1864 93
Fax: +33 78 33 03 37

César Pulgarin
Ecole Polytechnique Federale de Lausanne
Institute of Environmental Engineering – Bioengineering
CH-B Ecublens
CH – 1015 Lausanne
Switzerland
Tel: +41 – 21 6934720
Fax: +41 – 21 6934722
E-mail: cesar.pulgarin@dgr.epfl.ch

Institut für Solarenergieforschung Hannover (ISFH)
Dr. Roland Goslich
Sokelanstraße 5
D-30165 Hannover
GERMANY
Tel.: +49-511 358 50 31
Fax: +49-511 358 50 10
e-mail: isfh.goslich@oln.comlink.apc.org

Technische Universität Wien
Institut für Physikalische Chemie
Dr. Rupert Bauer
Getreidemarkt 9/156
A-1060 Wien
AUSTRIA
Tel.: 43-1 588 01-5162
Fax: +43-1 586 8273
e-mail: rbauer@fbch.tuwien.ac.at

Universidad de Barcelona
Facultad de Química
Dept. de Ingeniería Química
Dr. Jaime Giménez
C/Martí i Franqués, 1
08028 Barcelona
Tel: 93-4021293
Fax: 93-4021291
E-mail: gimenez@angel.qui.ub.es

University of Metz
Institut Universitaire de Technologie
Dr. Didire Robert
Rue Victor Demange
57500 Saint-Avold
France
Tel: 87 939108
Fax: 87 939101

University of Palermo
Dipartimento di Ingegneria Chimica dei Processi e dei Materiali
Prof. Leonardo Palmisano
Viale delle Science
90128 Palermo, Italy
Tel: +39 – 91 6567215
Fax: +39 – 91 6567280
E-mail: palmisan@dicpm.unipa.it

LAGAR (FAIR Program)

A. Pereira da Silva Lda.
Mr. Antonio Pereira
Rua Padre Hermano de Almeida Lima, 3
Abela, 7540 Santiago do Cacem (Portugal)
Tel: +351 69 92563 / 92268
Fax: +301 69 92563

INETI
Dra. Ana Vieira
Estrada do Paço do Lumiar, 22
1699 Lisboa Codex, Portugal
Tel: (+351) 1-716 5141
Fax: (+351) 1-716 3797
e-mail: ana.vieira@ite.ineti.pt

Naias Scientific Analytical Laboratoires, S.A.
Mr. Bitros Polychronis
46B Neosikon
Pireas, 185-36 Athens (Greece)
Tel: +301 4280 495
Fax: +301 4520 307

Technische Universität Wien
Institut für Physikalische Chemie
Dr. Rupert Bauer
Getreidemarkt 9/156
A-1060 Wien
AUSTRIA
Tel: +43-1 588 01-5162
Fax: +43-1 586 8273
e-mail: rbauer@fbch.tuwien.ac.at

TMR USERS

Process Heat

Univ. of Athens.- Department of Applied Physics
Dr. A.I. Dounis
Sp. Davari, 18
19400.- Koropi
GREECE
+30 1 662 45 41
+30 1 662 45 41

Univ. of Patras
Department of Physics,
Dr. Ioanis Tripanagnostopoulos
GR 26500 Patras
GREECE
Tel.:+30 61 997446
Fax: +30 61 991980
e-mail: “yianpan@physics.upatras.gr”

TMR Control

INESC
Prof. Joao Miranda Lemos
Rua Alves Redol, 9
Apartado 13069
1000 Lisboa Codex
PORTUGAL
Tel.: +351 1 310 02 59
Fax: +351 1 314 58 43

Ruhr Universität Bochum
Fakultät für Elektrotechnik
Prof. Ing. H. Unbehauen
Universitätsstraße 150
D-44780 Bochum
GERMANY
Tel.: +49 234 700 4071
Fax: +49 234 709 4101
e-mail: office@esr.ruhr.uni-bocuhm.de

Univ. de Firenze
Prof. Edoardo Mosca
Via de Santa Marta, 3
I-50139 Firenze
ITALY
Tel.: +39 55 4796257
Fax: +39 55 4796363

Univ. de Sevilla
Escuela Superior de Ingenieros
Dpto. de Ingeniería de Sistemas y Automática
Prof. Eduardo Fernández Camacho
Avda. Reina Mercedes, s/n.-
41012 Sevilla
SPAIN
Tel.: +95 455 68 65
Fax: +95 455 68 49
e-mail: eduardo@esi.us.es
eduardo@cartuja.us.es

Univ. of Oulu
Dept. of Process Engineering
Control Engineering Laboratory
Mr. Esko Juuso
Linnanmaa
SF-90570 Oulu
FINLAND
Tel.: +358-81-5532460
Fax: +358-8-5532466

Univ. of Oulu
Dept. of Process Engineering
Control Engineering Laboratory
Dr. Kauko Leiviskä
Linnanmaa
90570 Oulu
FINLAND
Tel.: +358-8-5532460
Fax: +358-8 553 23 04/553 24 66

Universidad de Almería
Dpto. de Lenguajes y Computación
Prof. Manuel Berenguel Soria
E-04120 La Cañada (Almería)
Spain
Tel.: 34 950 215683
Fax: 34 950 215129
e-mail: beren@ualm.es

University of Ulster
Faculty of Engineering, School of the Built Environment
Prof. Brian Norton
Newtownabbey County Antrim BT37 0QB
NORTHERN IRELAND
Tel.: +44 1232 365131
Fax: +44 1232 366816
e-mail: B.Norton@ulst.ac.uk

High Flux Tech.

Helsinki Univ. of Technology
Processing and Heat Treatment of Materials
Mr. Tuomas Katajarinne
P.O. Box 6200
SF-02150 ESPOO
FINLAND
Tel.: +358 90 45 12 705
Fax: +358 90 45 12 660
e-mail: tkatajar@cc.hut.fi

HTC Technologie Centrum Schwerte GmbH
Mr. Frank Mast
Im Heiligen Feld 17
58239 Schwerte
GERMANY
Tel.: +49 2304 941130
Fax: +49 2304 9411321

Instituto Nacional de Engenharia e Tecnologia Industrial (INETI)
Dr. João Farinha Mendes
Azinhaga dos Lameiros a Estrada do Paço do Lumiar
1699 Lisboa Codex
PORTUGAL
Tel.: +3511 716 51 41/ 42 11
Fax: +351- 716 37 97/ 0901
e-mail: mailto:fmendesdms01.ineti.pt
farinha.mendes@ite.ineti.pt

Instituto Superior Técnico
Depto. Engenharia Materials
Dr. Luis Guerra Rosa
Avda. Rovisco Pais
1096 LISBOA CODEX
PORTUGAL
Tel.: +351 1 841 8135
Fax: +351 1 849 9242

Katholieke Universiteit Leuven Dept. MTM
Prof. J.P. Celis
de Croylaan, 2
B-3001 Leuven
BELGIUM
Tel.: +32-16 32 13 12
Fax: +32-16 32 19 91
e-mail: jean-pierre.celis@mtm.kuleuven.ac.be

VIOLAMP
Mr. Manos Paradissis
50, Kanari Street-Helioupolis
16343 Athens
GREECE
Tlf: (+30) 1 9916817
Fax: (+30) 1 99 344 46

National Technical University of Athens
Department of Mechanical Engineering
Dr. Dimitri Pantelis
9, Hiroon polytechnioy Avenue
15710 Zografou
GREECE
Tlf: (+30) 1 772 36 91
Fax: (+30) 1 772 11 97

Ecole Nationale Superieure des Mines de Paris
Centre des Materiaux
Dr. Michel Boussuge
BP 87
91003 Evry Cedex
FRANCE
Tlf: (+33) 1 60763000
Fax: (+33) 1 60763150

Universidad de Sevilla
Escuela Superior de Ingenieros
Dpto. De Ingeniería Mecánica y de los Materiales
Dr. José María Gallardo
Avda. de los Descubrimientos S/N
E-41092 Sevilla
SPAIN
Tlf. 95-4487304

Solar Chemistry

CNRS/Ecole Centrale de Lyon.
Photocatalyse, Catalyse et Environement
Dr. Jean Marie Herrmann
B.P. 163
69131 Ecully Cedex
FRANCE
Tel.: +33 72 1864 93
Fax: +33 78 33 03 37

CNRS/Institut de Chimie des Substances Naturelles
Dr. Charles Giannotti
Ave. De la Terrasse
91198 Gif sur Yvette Cedex
FRANCE
Tel.: +33 1 69 82 30 55
Fax: +33 1 69 07 72 47
e-mail: Charles.Giannotti@icsn.cnrs-gif.fr

Dipartimento di Chimica Organica
dell'Universita di Pavia
Prof. Angelo Albini
Viale Taremattì, 10
27100 Pavia
ITALY
+39 382 507 323
e-mail: fasani@ipv85.unipv.it

Institut für Solarenergieforschung GmbH Hameln / Emmerthal
Dr. Roland Goslich
Sokelanstraße 5
D-30165 Hannover
GERMANY
Tel.:v +49-511 358 50 31
Fax: +49-511 358 50 10
e-mail: isfh.goslich@oln.comlink.apc.org

Technische Universität Wien
Institut für Physikalische Chemie
Dr. Rupert Bauer
Getreidemarkt 9/156
A-1060 Wien
AUSTRIA
Tel.: +43-1 588 01-5162
Fax: +43-1 586 8273
e-mail: rbauer@fbch.tuwien.ac.at
e-mail: hfallman@fbch.tuwien.ac.at

Univ. de Barcelona
Departamento de Ingeniería Química, Facultad de Química
Dr. Jaime Giménez Farreras
c/Martí i Franquès, 1.-
08028.- Barcelona
SPAIN 93/402 12 93
93/402 12 91

Univ. Complutense de Madrid
Facultad de Ciencias Quimicas
Depto. Química Orgánica
Prof. Diego Armesto
Ciudad Universitaria
28040 Madrid
SPAIN
Tel.: +34 1 394 43 16
Fax: +34 1 394 41 03
e-mail: mailto:darmesto

Univ. de Poitiers
Faculté des Sciences, Catalyse en Chimie Organique
Dr. Octav Enea
40, avenue du Recteur Pineau,
86022 Poitiers Cedex
FRANCE
Tel.: +33 5 4945 39 20
Fax +33 5 4945 36 00

PARABOLIC DISH AREA

Institut für Solare Energieversorgungstechnik (ISET)
Königstor 59
34119 Kassel
Germany

Intersol Corporation
PL 416 Marbak
30594 Halmstad
Sweden

Klein+Stekl GmbH
Kolbe, Otto
Heusteigstr. 41,
70180 Stuttgart
Bus: (49) 711 9672-154
Bus Fax: (49) 711 9672-130
E-mail: Otto Kolbe [otto.kolbe@klst.com]

L&C Steinmüller GmbH
Fabrikstrasse 1
51641Gummersbach
Germany

Mero Systeme GmbH & Co KG
Max-Mengeringhausenstr. 5
D-97084 Würzburg
Germany

Schlaich Bergermann und Partner (SBP)
Hohenzollernstr. 1
70178 Stuttgart
Germany
Tel.: +49 711 6487 120
Fax: +49 711 6487 166

SOLO Kleinmotoren GmbH
Postfach 60 01 52
71050 Sindelfingen
Germany

LOW TEMPERATURE AREA

Belgian Building Research Institute Test Centre (BBRI)
AV. P. HoloFFE,21
B-1342 Limelette
BELGIUM
Tel.: (32-2) 653-8801
Fax: (32-2) 653-0729

CONPHOEBUS
Zona Industriale
Casella Postale
I-95030 Piano d'Arci
(Catania)
ITALY
Tel.: (39-95) 7489210
Fax.: (39-95) 7489111

Departamento de Tecnología de la Edificación de la EUAT de la UPM
Escuela Universitaria de Arquitectura Técnica
Avenida Juan de Herrera, 6
28040 Madrid
SPAIN

Joint Research Centre Ispra
Institute for System Engineering and Informatics (JRC)
Bldg. 45
I-21020 Ispra (VA)
Italy
Tel.: (39-332) 789842
Fax.: (39-332)789992

HUNTER DOUGLAS, S.A.
Avenida de la Justicia 48
28100 Alcobendas (MADRID)
Spain
Tel: 91 6617314
Fax: 91 6611566

ITEMA de la Universidad Politécnica de Cataluña
Carretera Nacional 150 Km 14.5
08220 TERRASSA (BARCELONA)
Spain

Pilkington Solar International
Mühlengasse 7
D-50667 Köln
Germany
Tel.: (49 221) 925 970 0
Fax.: (49 221) 258 11 17

TNO Building and Construction Research
Dep. Of Indoor Environment
P.O. Box 29
2600 AA Delft
The Netherlands
Tel.: (3115) 26 08 435
Fax.: (3115) 26 08 432

UMSICHT Institute for Environmental, Safety and Energy Technology
Osterfelderstrasse3
D-46047 Oberhausen
Germany
Tel 492088598-100
Fax 492088598-290

Universidad de Patras (Grecia)
Departamento de Física. Laboratorio de Energía Solar
26500 Patras
Greece
Tel/Fax 30 61 99 74 72

MEDUCA

Cenergia Energy Consultants,
Sct. Jacobs Vej 4
Ove Christen Morck
DK-2750 Ballerup, Denmark
Tel 45 44 66 00 99
Fax 45 44 66 01 36
e-mail: cenergia@compuserve.com

CIEMAT
Guillermo Schwartz Juste
Avda. Complutense, 22
E-28040 Spain
Tel 34 91 346 63 44
Fax 34 91 346 60 37
e-mail: willy@sunny.ciemat.es

CNR-IEREN
Antonino Giaccone
Via U. La Malfa 153
I-90146 Palermo, Italy
Tel 39 91 637 4666
Fax 39 91 637 4601
e-mail: giac@cuc.unipa.it

Centre for Renewable Energy Sources (CRES)
Gregory Economides
19th km Marathonos Ave.
GR-19009 Pikermi, Greece
Tel 30 1 60 39 90
Fax 30 1 60 39 905
e-mail: groiko@cresdb.cress.ariadne-t.gr

DLR
Andreas Holländer
Apartado 649
E-04080 Almeria, Spain
Tel 34 950 38 79 35
Fax 34 950 36 50 15
e-mail: andreas.hollaender@psa.es

SINTEF
Arch. & Building Techn.
Karin Buvik
Alfred Getz vei 3
N-7034 Trondheim, Norway
Tel 47 73 59 26 20
Fax 47 73 59 82 85
e-mail: karin.j.buvik@civil.sintef.no

Swedish Ntnl. Testing & Res. Inst.
Box 857
S-50115 Boras, Sweden
Tel 46 33 16 50 00
Fax 46 33 13 19 79
e-mail: ake.blomsterberg@sp.se

SWN Stadtwerke Neum. GmbH
Gerd Sigel
Bismarckstr. 51
D-24534 Neumünster, Germany
Tel 49 4321 202 310
Fax 49 4321 202 386
e-mail: sigel.swn@t-online.de

The Municipality of Ballerup
Jorgen Osterkrüger
Ballerup Town Hall
DK-2750 Ballerup
Tel 45 44 77 20 00
Fax 45 44 77 27 17
e-mail: jos@balk.dk

Univ. of Almeria
Manuel Perez Garcia
La Cañada de San Urbano, s/n
E-04120 Almeria, Spain
Tel 34 950 21 52 95
Fax 34 950 21 54 77
e-mail: mperez@ualm.es

APPENDIX 3

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JOURNALS

[1.] Agüera, A., Almansa, E., Malato, S., Maldonado, I. and Fernández-Alba, A., Evaluation of Photocatalytic Degradation of Imidacloprid in Industrial Water by GC-MS and LC-MS". *Analyses*, 26, 245, 1998.

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APPENDIX 4

CONTACTS

Plataforma Solar de Almería

Address:
Apartado 22
04200 Tabernas (Almería)

Tel.: + 34-950-387900
Fax: + 34-950-365300/34-950-365015

Directorate

Dr. Manuel Blanco Muriel	Dr. Michael Geyer
CIEMAT-PSA Director	DLR-PS
Tel.: + 34-950-387914	Tel.: + 34-950-387916
Fax: + 34-950-365300	Fax: + 34-950-362719
e-mail: manuel.blanco@psa.es	e-mail: michael.geyer@psa.es

Deborah Fuldauer	Annie Sarre
Secretary - CIEMAT PSA Directorate	DLR Directorate
Tel.: + 34-950-387914	Tel.: + 34-950-387905
Fax: + 34-950-365300	Fax: + 34-950-362719
e-mail: deborah.fuldauer@psa.es	e-mail: annie.sarre@psa.es

Low Temperature

María José Jiménez Taboada	Juan de Dios Guzmán Domínguez
Low Temperature Area Head	
Tel.: + 34-950-387922	Tel.: + 34-950-387952
Fax: + 34-950-365015	Fax: + 34-950-365015
e-mail: mjose.jimenez@psa.es	e-mail: juande.guzman@psa.es

Parabolic Trough

Eduardo Zarza Moya	Andreas Holländer
Parabolic Trough Area Head	DLR Parabolic Trough Area Head
Tel.: + 34-950-387931	Tel.: + 34-950-387935
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: eduardo.zarza@psa.es	E-mail: andreas.hollaender@psa.es

Carmen Montesinos Carretero	Loreto Valenzuela Gutiérrez
Secretary	Responsible Control-related activities
Tel.: + 34-950387932	Tel.: + 34-950-387934
Fax: + 34-950-365015	Fax: + 34-950-365015
e-mail: carmen.montesinos@psa.es	E-mail: loreto.valenzuela@psa.es

Rainer Kistner	Eckhard Lüpfert
Project Leader THESEUS	Project Leader EuroTrough
Tel.: + 34-950-387906	+ 34-950-387906
Fax: + 34-950-365313	+ 34-950-365313
E-mail: rainer.kistner@psa.es	e-mail: eckhard.luepfert@psa.es

Central Receiver

Peter Heller	Dr. Eckhard Lüpfert
Central Receiver Area Head	Project Leader REFOS
Tel.: + 34-950-387949	Tel.: + 34-950-387906
Fax: + 34-950-365313	Fax: + 34-950-365313
E-mail: peter.heller@psa.es	E-mail: eckhard.luepfert@psa.es

Frank Schillig	Jesús Ballestrín Bolea
Project Leader THESEUS	GRAAL
Tel.: + 34-950-387906	Tel.: + 34-950-387956
Fax: + 34-950-365313	Fax: + 34-950-365300
E-mail: frank.schillig@psa.es	E-mail: jesus.ballestrin@psa.es

Rafael Monterreal Espinosa	Manuel Romero Álvarez
Flux Measurement	CIEMAT Manager Central Receiver
Tel.: + 34-950-387921	Tel.: + 34-91-346 6487
Fax: + 34-950-365015	Fax: + 34-91-346 6037
E-mail: rafael.monterreal@psa.es	E-mail: manuel.romero@psa.es

Dish / Stirling

Peter Heller	Wolfgang Reinalter
Dish / Stirling Area Head	Dish Technology
Tel.: + 34-950-387949	Tel.: + 34-950-387930
Fax: + 34-950-365313	Fax: + 34-950-365013
E-mail: peter.heller@psa.es	E-mail: wolfgang.reinalter@psa.es

Solar Chemistry

Julián Blanco Gálvez	Dr. Christoph Richter
Area Head Solar Chemistry	
Tel.: + 34-950-387939	Tel.: + 34-950-387948
Fax: + 34-950-365015	Fax: + 34-950-365313
E-mail: julian.blanco@psa.es	E-mail: christoph.richter@psa.es

Dr. Sixto Malato Rodríguez	Pilar Fernández Ibáñez
Tel.: + 34-950-387940	Tel.: + 34-950-387940
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: sixto.malato@psa.es	E-mail:: pilar.fernandez@psa.es

Julia Cáceres Vázquez	Antonio Campos Rodríguez
Tel.: + 34-950-387957	Tel.: + 34-950-387960
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: sixto.malato@psa.es	E-mail: antonio.campos@psa.es

Access and Training

Diego Martínez Plaza	Cruz Mª López Bonilla
Head of Access and Training	Administrative Assistant
Tel.: + 34-950-387950	Tel.: + 34-950-387951
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: diego.martinez@psa.es	E-mail: cruzmaria.lopez@psa.es

Operation and Maintenance

José Antonio Rodríguez Povedano	Antonio Valverde Cantón
Head of Operation, Maintenance and Engineering	Head of Operation
Tel.: + 34-950-387933	Tel.: + 34-950-387945
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: joseantonio.rodriguez@psa.es	E-mail: antonio.valverde@psa.es

Javier León Alonso	José Rodríguez García
CRS/DCS Operation	HCF Operation
Tel.: + 34-950-387937	Tel.: + 34-950-387938
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: javier.leon@psa.es	E-mail: jose.rodriguez@psa.es

José Manuel Molina Villalba	Bernabé Calatrava López
Head of Maintenance	Civil Engineering and Security
Tel.: + 34-950-387942	Tel.: + 34-950-387946
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: josemanuel.molina@psa.es	E-mail: bernabe.calatrava@psa.es

Juan Antonio Camacho Martínez	Jaime Aranda López
Systems Manager	Programmer
Tel.: + 34-950-387923 - 24	Tel.: + 34-950-387923 - 24
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: juanantonio.camacho@psa.es	E-mail: jaime.aranda@psa.es

Ginés García Navajas	Dieter Weyers
Instrumentation	Mechanics and Electricity
Tel.: + 34-950-387925	Tel.: + 34-950-387947
Fax: + 34-950-365015	Fax: + 34-950-365015
E-mail: gines.garcia@psa.es	E-mail: dieter.weyers@psa.es

Administration

Rafael de Haro Carreño	Carmelo Quero Ferrer
Head of Administration	Purchaser
Tel.: + 34-950-387918	Tel.: + 34-950-387919
Fax: + 34-950-365300	Fax: + 34-950-365300
E-mail: rafael.deharo@psa.es	E-mail: carmelo.quero@psa.es

Mª Dolores Jara Carrascosa	Manuel Sánchez Clemente
Cashier	Stores
Tel.: + 34-950-387919	Tel.: + 34-950-387926
Fax: + 34-950-365300	Fax: + 34-950-365300
E-mail: mdolores.jara@psa.es	E-mail: manuel.sanchez@psa.es

Jesús Torrecillas Moreno	Esther Ramos Quillez
Human Resources	Invoicing
Tel.: + 34-950-387912	Tel.: + 34-950-387926
Fax: + 34-950-365300	Fax: + 34-950-365300
e-mail: jesus.torrecillas@psa.es	e-mail: mesther.ramos@psa.es

Eugenia Prior Rueda
Public Relations
Tel.: + 34-950-387900
Fax: + 34-950-365300
e-mail: meugenia@psa.es