PLATAFORMA SOLAR DE ALMERÍA

ANNUAL TECHNICAL REPORT
1997

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Annual Technical Report 1997

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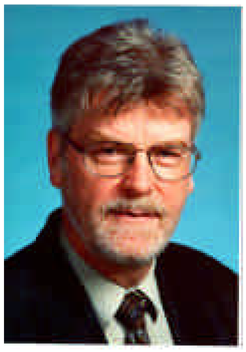
July, 1998

PREFACE



Gerd Eisenbeiß

This is the 12th annual report of the Plataforma Solar de Almería since the initiation of bilateral Spanish-German co-operation under the Convenio Hispano-Alemán (CHA) in 1987. In all these years our joint labor has been most successful and the bilateral partnership has proven fruitful and harmonious. This excellent example of combined effort and its many synergetic effects in Europe was at all times based on the common conviction that solar thermal power and some other solar thermal applications are necessary for the sustainable development of mankind.

Almost all the projects carried out at the PSA since 1987 have focussed on better cost-effectiveness and the search for new applications of solar thermal technology. This is again reflected in this yearbook, in running projects as well as in projects now in their starting phase.

But the participants in this challenging endeavor – CIEMAT and DLR jointly operating this unique test center as well as the industrial and scientific partners from so many countries all over the world – know that a completely successful dynamic marketplace for these technologies has not yet been achieved.

Cost reduction alone will not be enough to get the market going again after the first triumph of the erection of 354 MW power capacity in California 10 years ago. Therefore, the Spanish and German managers and engineers at the PSA are heavily engaged in the world-wide process of establishing a new alliance for the erection of further, more advanced solar power plants.

The conditions for success are not too bad: the technology is technically mature. Economically speaking, solar thermal power needs grants and other favorable financing conditions that seem to be available. We still lack the perfect combination of powerful manufacturing consortia with such operating and investor groups; and, of course, solar thermal power also needs good emplacement in interested helpful countries in the solar belt. Last, but not least, European governments, including the Commission of the EU, must help catalyze the assembly of the necessary players. The PSA is one of the centers of competence and commitment that works hard to bring the loose ends that exist together.

Unfortunately, this annual report is the second to the last one for which Spanish and German teams will be jointly responsible. Due to budget reductions in the German ministry of research, DLR as the German partner is no longer in a position to maintain its full presence and contribution to the PSA as it has done for so many years.

But DLR will not give up the ground gained or the joint vision of successful solar electricity production. There are several projects under way that include DLR engineers on the PSA until 2000, and we will do our best to continue jointly this challenging and promising work even beyond that date.

Gerd Eisenbeiß
Chairman of the SC of the PSA.

ACKNOWLEDGMENTS

On behalf of the PSA, the editors would like to thank:

Dr. F. Ynduraín, General Director of *CIEMAT*, and Dr. W. Kröll, Chairman of the Board of *DLR*, for their support of the German-Spanish Cooperation Agreement,

the Steering Committee members for their consistent support and involvement in the solution of financial, technical and organizational difficulties,

the PSA staff who have made the PSA what it is today,

and all the institutions and private enterprises which have funded and collaborated in our 1997 Program of Work, especially the

German *Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF)*, funding the PSA as its "Plataforma Solar de Almería" project under contract number 0328823C,

Spanish *Ministerio de Industria y Energía (MINER),* which funds the PSA within the Spanish national budget,

CEC-DGXII for funding under the following programs:

Training and Mobility of Researchers (TMR), providing research and training grants to PSA user groups from all over Europe (Contract No. ERBFMGECT950023)

Joule, which supports the DISS (Contract No JOR3-CT95-0058) and HYHPIRE (Contract No. COR3-CT95-0085) projects and

Brite Euram, which supports the SOLARDETOX project (Contract No.BRPR-CT97-0424)

CEC-DGXVII for funding under the *THERMIE* program for the MEDUCA (Contract No. BU/1006/96) and THESEUS (Contract No. TE-235-96-DE-HE) projects

to Deborah Fuldauer and Gabriela Hofmann for the composition and language editing and to Angel Soler who took most of the photographs included in this report..

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1 PSA Solar Thermal Technology 1997 Milestones and International Cooperation in Solar Power Development

1.1 PSA - Europe's Solar Thermal Showcase since 1981

Michael Geyer

Manuel Blanco

At the "Plataforma Solar de Almería" (PSA) the sun's energy is concentrated with heliostats, parabolic troughs and parabolic dishes to power conventional turbines or heat engines to generate electricity. This clean, secure, environmentally friendly power not only diversifies Europe's domestic electricity production options but, as a sustainable power system, is a potential European export asset. Modern hybrid designs and energy storage make solar thermal energy a highly value renewable power which may be provided on-demand, not only when the sun is shining, and can thus provide a major share of the renewable energy needed in the future. This is because

- Solar radiation is the largest energy resource on Earth. Only the solar radiation available in 1% of the world's deserts converted by solar thermal power systems would be sufficient to generate the entire world electricity demand for the year 2000.
- This resource is more evenly distributed in sunbelt regions than wind or biomass.
- Solar power generation costs in the range of 10-15 US cents per kWh make it one of the most cost-effective renewable power technologies.
- As measured at the Kramer Junction SEGS plants, it is an advanced, highly efficient technology providing daily sun-to-electricity efficiencies of over 18%.
- It is well-proven and demonstrated by over 7 billion kWh of solar-based electricity fed into the Californian grid.
- It is ready for more wide-spread commercial application.

The PSA has been Europe's show case of solar thermal technology development since 1981 when the two 500 kW_e IEA Small Solar Power Systems (SSPS) and the Spanish 1.3 MW_e solar power plant CESA-I went into operation (See *Fig 1.1*). Since 1987 the PSA has been run jointly 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). Spanish-German co-operation at the PSA is based on the *"Co-Operation Agreement on the Co-operation in the Field of Solarthermal Research, covering in particular the long-term Utilization of the Plataforma Solar de Almeria" (CHA)* signed by CIEMAT and DLR on October 15th in 1986.

Since solar thermal electricity was produced at the PSA for the first time in September, 1981, solar thermal power generation has been the main field of activity in its wide ranging spectrum of solar research, development and demonstration (RD&D). Developments in solar thermal electrical technologies were accelerated by high oil prices in 1973-85 that attracted the interest of several major industrial project developers and international utility companies to the various concentrating solar technologies initiated at the PSA.

Fig. 1.1 Aerial view of the Plataforma Solar de Almería

Thus, while real oil prices fell by 70% between 1981 and 1995, solar thermal electricity production costs were also reduced by 70% from the 0.50 US$/kWh$_e$ of the first solar thermal demonstrations in 1981 to less than 0.15 US$/kWh$_e$ of today's state-of-the-art solar thermal technology. Nevertheless, low oil and gas prices still make it hard for solar thermal power to compete with fossil fuels, requiring further research, development and demonstration efforts at the PSA and its partner institutions to advance performance and reduce costs of this CO_2-emission-free technology option for power generation. In this respect, the European, Spanish and German contributions to the PSA constitute an investment in clean energy alternatives and strengthen the European ability to react to possible energy price swings or the need to reduce fossil-fuel consumption for environmental or other reasons.

1.2 German withdrawal from Annex I of the Spanish-German Agreement at the end of 1998

Although the long-term belief in the solar thermal power option and the continuous support of PSA activities over the years by its partners in Europe, Spain and Germany, have been internationally justified by the recent World Bank Global Environmental Facility (GEF) Solar Initiative and the solar thermal initiative of the European Commission within the JOULE and THERMIE programs, the present German government has decided to withdraw from the PSA operation 50:50 cost-sharing agreement at the end of 1998. CIEMAT will then take over the full burden of financing and operating the PSA and securing this solar thermal show case in Europe.

Meanwhile the United States government has adopted a new Five-Year Program Plan 1998-2003 for technology research, development and field validation required for solar thermal technologies to make a major contribution to clean global energy resources in the years to come. This plan outlines four paths to the achievement of commercial competitiveness of solar thermal systems:

- The first path, *Develop and Demonstrate High-Reliability Distributed Power Systems*, focuses on the reliability of dish/engine systems as a power source for emerging distributed-energy markets. American efforts are scheduled to achieve costs in the range of 9 to 11 US cents per kWh by 2003.
- The second path, *Reduce Costs of Dispatchable Solar Power***,** identifies the highest priorities for activities required to place the power tower and commercially proven trough technologies on the dispatchable-power market. Accompanied by early demonstrations supported by both green power markets and multilateral organizations such as the Global Environmental Facility, American development should lead to next-generation plant designs capable of producing dispatchable power for 6 to 8 US cents per kWh.
- The third path, *Develop Advanced Components and Systems*, addresses further significant advances to make solar thermal technology prices in large-scale and dispatchable markets 4 to 6 US cents per kWh making it possible for US industry to install 20GW of solar thermal power by 2020.
- In the fourth path, *Expand Strategic Alliances and Market Awareness***,** the American technology effort is focused on the most critical needs of U.S. industry.

If clean power is also acknowledged in Europe to be a key to sustainable economic and energy growth, implementation measures have to be taken to build up the necessary European network and manufacturing infrastructure to respond to future challenges. The Fifth Framework Program is Europe's opportunity to respond to the United States solar thermal Five-Year Program Plan with its own strategic sustainable solar thermal development and demonstration plan for realizing the common European objectives of emission reduction and climate protection. Spain will keep the European solar thermal showcase at the PSA open, but this will need the solidarity of the European Union and bilateral support from interested partners and electric utilities.

1.3 The PSA Team and its Organization

Throughout its seventeen years of operation, the PSA has continuously added to and improved the education and training of its staff, its human capital, who have become world-wide experts in the solar field.

The PSA program and project groups, the operating and maintenance crew and the engineering team, represent a core of solar power competence. This dedicated team of scientists and engineers, experienced solar power technicians and highly skilled craftsmen, many of whom have been dedicating their skills and expertise to solar thermal activities since the late 1970s, guarantee the continuity of the solar facility. On the other hand, a certain amount of healthy fluctuation among personnel provides an exchange with industry, whereby technology and applications are transferred to industry and new ideas and modern methodologies are brought to the desert in Southern Europe where the PSA is located.

Special mention is to be given here to the contributions and achievements of the colleagues that left the PSA core team in 1997/98:

- Martin Stegmann, who was responsible for the PSA Test and Demonstration Center (TDC) and the PSA Dish Stirling Area in 1996 and 1997 and has now started his own solar engineering firm for domestic solar hot water and heating system installation in the Almería area.

A warm welcome is also extended to our new colleagues who joined the PSA core team in 1997:

- Barbara Milow, who is participating in the EU TMR scientific exchange program as a guest scientist in the PSA Solar Chemistry Group, has a Ph.D. from the University of Cologne and is currently on leave from DLR Cologne, where she has conducted numerous research projects in solar chemistry. The subject of her TMR Marie Curie research grant project at the PSA is "Application of Solar Waste Water Detoxification and Disinfection Systems in the Mediterranean and Developing Countries"
- Jesús Ballestrín, who joined the PSA core team in 1997, has a Ph.D. in Nuclear Physics from the Complutense University of Madrid. Before being transferred to the PSA from the Nuclear Security Department in CIEMAT (Madrid) where he had been since January, 1990, he was working on the noise analysis project on such subjects as stability in boiling water reactors and predictive maintenance of sensors (pressure,

temperature, etc) as well as several projects related to Nuclear Power Plants (Vandellos, Ascó, Cofrentes, Almaraz) and Spanish utilities (Endesa, Iberdrola, ANA, Fecsa, etc.).

- Eckhard Lüpfert took over responsibility for the implementation and execution of the REFOS project at the PSA. He has a Ph.D. in engineering from the Technical University of Aachen in high-temperature waste detoxification with concentrated solar radiation and had had five years of professional solar system experience at DLR Cologne prior to his new assignment at PSA.
- Wolfgang Reinalter, who took over responsibility for the DISTAL Dish/stirling systems, graduated from the Technical University of Berlin as an engineer specialized in energy and process engineering and did his final project at the PSA on flux measurement of parabolic dishes.
- Frank Schillig, who is responsible for PSA work packages in the EU Theseus project including modelling and system analysis, has an engineering degree from the Technical University of Berlin specializing in energy and process engineering and did his final project at the PSA on receivers for parabolic trough collectors. He joined DLR Cologne in 1996, where he developed dynamic simulation models for solar and fossil power plants.
- Martin Eickhoff joined the DISS Project Team in April 1997 to work on his Thesis entitled “Modelling a Simulation of Different Processes for Direct Steam Generation in Parabolic Trough Solar Collectors with Integration of Effective Control Systems”. He received a TMR Marie Curie grant for two years after finishing his studies as mechanical engineer at the University of Hannover.

Five grants have been awarded for Ph.D. research projects at the PSA under a Ciemat, DLR and University of Almeria (UAL) cooperation agreement to the following doctoral students selected by a joint PSA-UAL commission:

- Diego Alarcón Padilla studied Physics at the University of Granada and started his Ph.D. thesis entitled “Development, analysis and evaluation of tools for simulation of solar thermal concentrating systems” in April, 1997.
- Pilar Fernandez Ibañez received a degree in Physics from the University of Granada. She started to work on her Ph.D. thesis entitled “Influence of surface properties in the sedimentation and separation of the catalyst in waste water detoxification processes” in April 1997.

- Anselm Kröger-Vodde studied Electrotechniques at the University of Dortmund. The subject of his Ph.D., begun in May, 1997, is "Construction, testing and evaluation of an automated control mechanism for heliostats using a CCD camera system and implementation of the results into a simulation code to be developed for an improved power tower system".
- Rainer Kistner studied Industrial Engineering at the Technical University of Berlin. He started work on his Ph.D. thesis "Thermodynamic modelling, economic analysis and environmental evaluation of Parabolic trough solar thermal power plants" in October 1997.
- Miguel Angel Rubio Escudero studied Physics at the University of Granada. He started in April, 1997, on his Ph.D. thesis entitled "Characterization and modeling of direct irradiation".

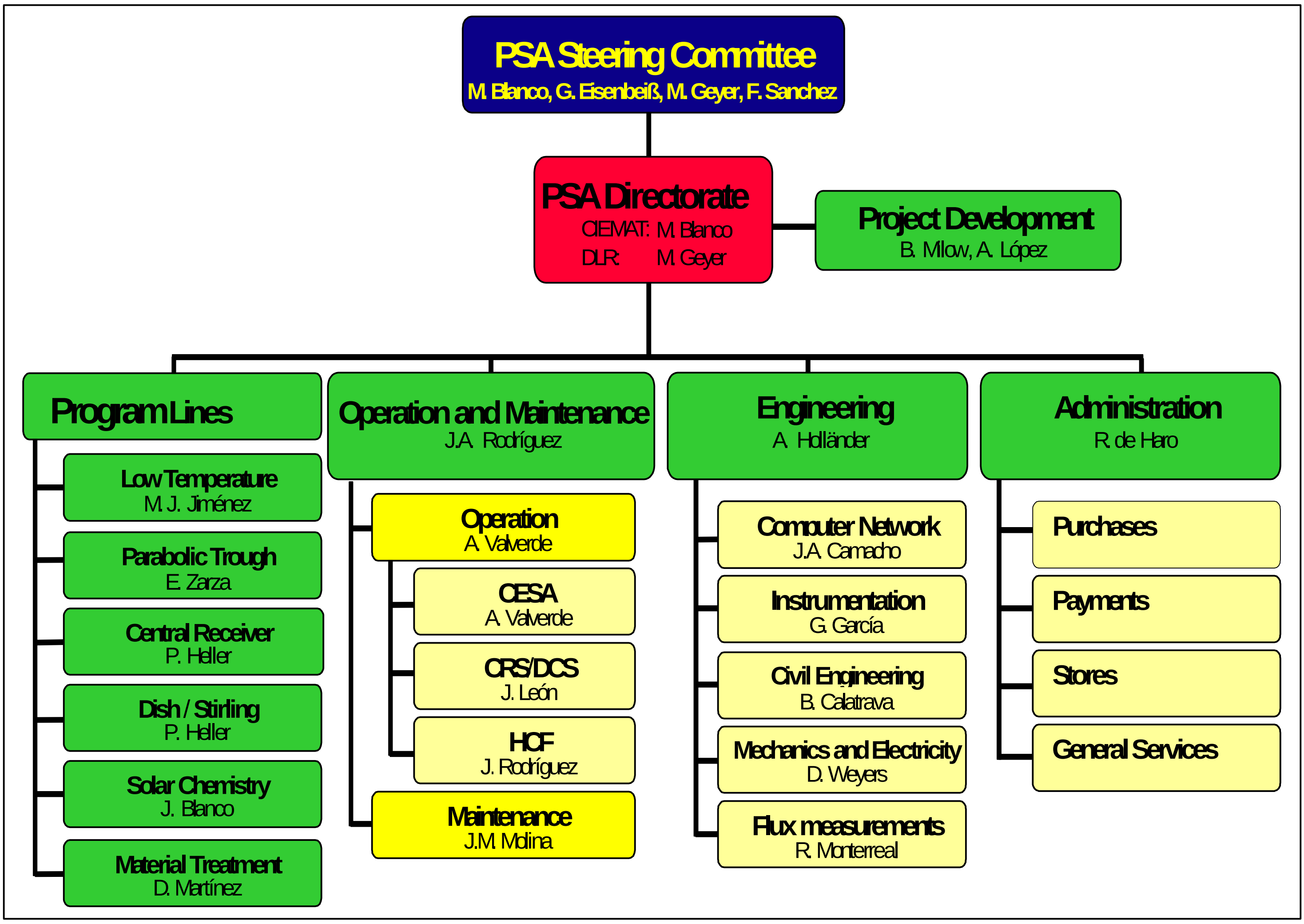

Fig. 1.3 PSA Matrix Management Organization as of 31.12.97

Thanks and appreciation must also be given to the numerous temporary collaborators, who have greatly enriched the PSA during their stay with multi-disciplinary and multi-cultural input.

Cordial thanks go to the former PSA Steering Committee members Manuel Macías Miranda of CIEMAT Madrid and Karl-Otto Pfeiffer from DLR Cologne for their long years of dedication to PSA issues. Effective January, 1998, Manuel Blanco of CIEMAT and Michael Geyer of DLR have been nominated as successors in the PSA Steering Committee.

The PSA core team is organized within a matrix management structure in three central service departments,

- Engineering
- Operating&Maintenance and
- Administration

the Directorate Project Development and Control team

and project teams in six program areas:

- Low Temperature Applications,
- Parabolic Through Collectors,
- Central Receivers,
- Dish Technology,
- Solar Chemistry and
- Materials Testing

Department and Area Heads report directly to the Spanish-German PSA Directorate, as illustrated in Figure 1.3.

1.4 The 1997 PSA Budget

The total PSA 1997 Annex I budget amounted to 622 Million Pesetas. The two Spanish-German Agreement partners each contributed 214 million pesetas. 194.4 million Pesetas were received in contributions to projects from the European Union and from industrial clients. 516.5 million Pesetas of this budget were directly allocated to the projects and 10.1 million Pesetas were invested in improvement of infrastructure. Historic development of the PSA Annual Budget since 1987 is shown in Figure 1.4.

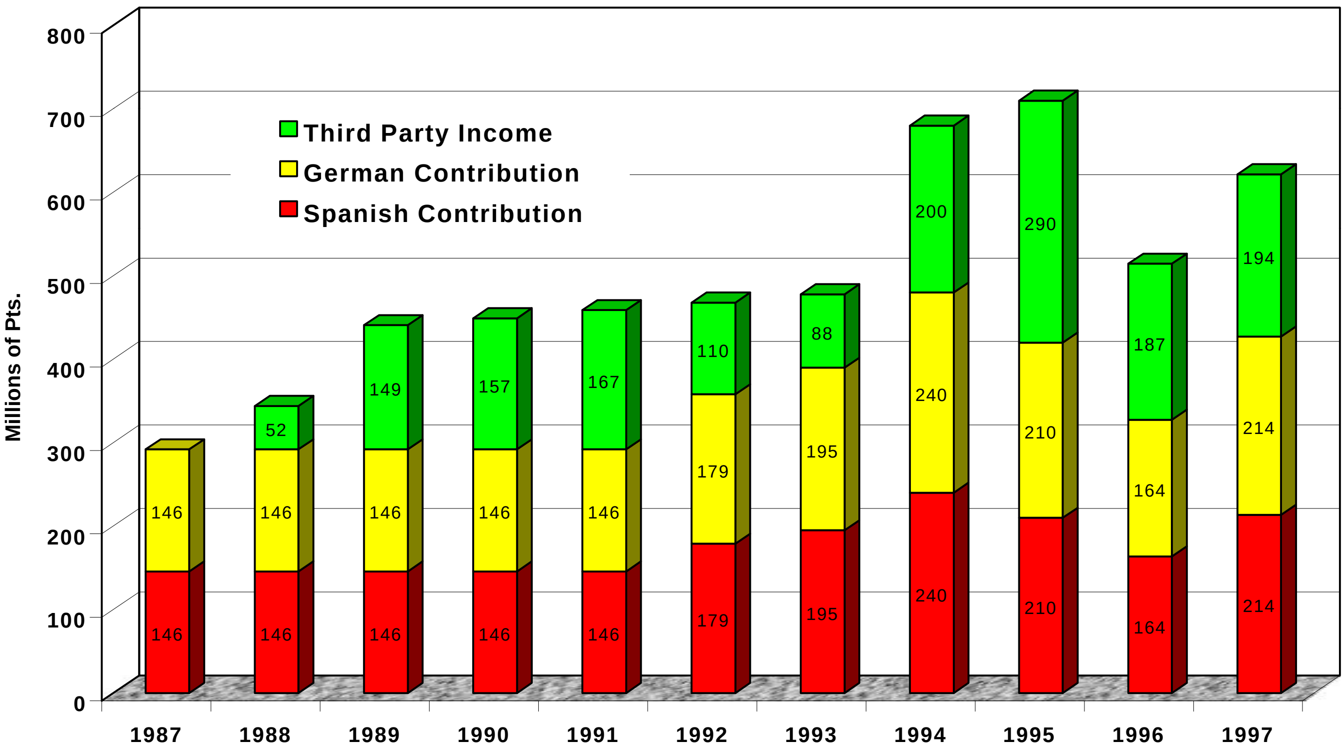

Fig. 1.4 Development of the CHA Annex I Annual Budget 1987 – 1997

1.5 The PSA Test Facilities

PSA activities have clearly diversified beyond solar thermal power plant R&D, as seen in the functions of its new and improved facilities, until it has now become one of the three centers of its kind in the world and the most versatile in Europe. Today, the major test installations available at the PSA are:

- 2.7 MW_t SSPS-CRS Central Receiver Test Facility
- 7 MW_t CESA-I Central Receiver Test Facility
- High-Flux Solar Furnace
- 1.3 MW_t SSPS-DCS Parabolic Trough Test Facility
- 174kW_t LS-3 Loop Parabolic Trough Test Facility
- 1.8MW_t DISS Loop Parabolic Trough Test Facility
- 3 x 40 kW_t DISTAL I Parabolic Dish Test Facility
- 3 x 50 kW_t DISTAL II Parabolic Dish Test Facility

The following sections describe these major facilities in more detail. Their location is illustrated in Figure 1.5.

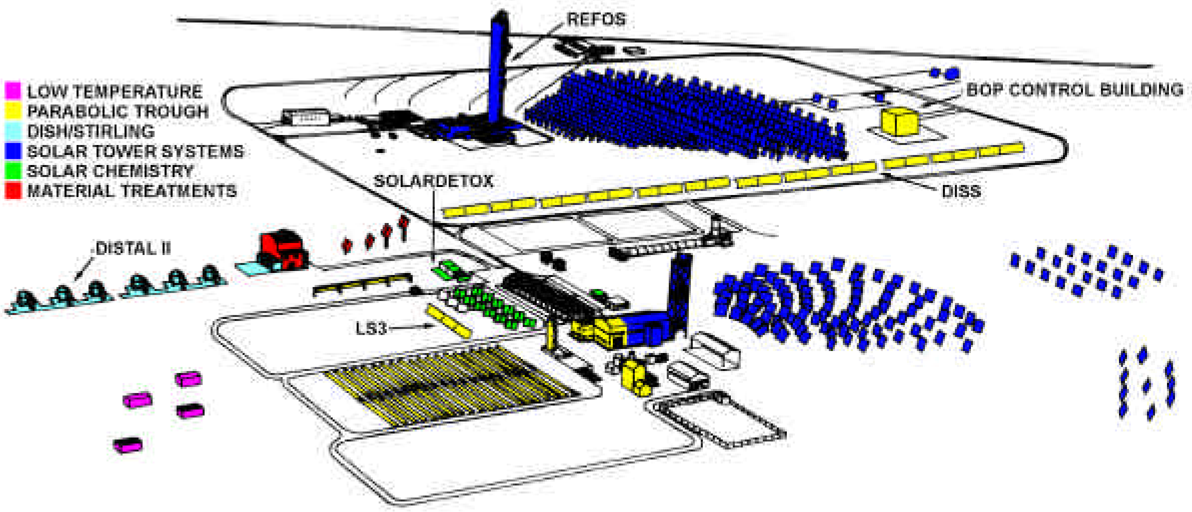

Fig. 1.5 1997 New Solar Technology Facilities at the PSA

1.5.1 7-MW_t CESA-I Central Receiver Test Facility

The CESA-I central-receiver test facility heliostat field has 300 individual-tracking 39.6-m^2 heliostat units with an average reflectivity of (clean) 92%, tracking error per axis of 1.2 mrad and beam quality characterized by 1.5 mrad error width. Maximum field power is 7 MW_t. At design 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 4m-diameter circle and 90% within 2.8 m.

The central concrete tower has a capacity of approx. 100 t at the top. Major test locations are:

- a 10 m-diameter platform on the roof 80 m above ground
- a front area just below the top
- a 4.5 m x 4.5 m bay at 60 m above ground level
- a 0.5m x 0.5m test area at 45 m above ground level
- white reflecting targets at 65 and 36 m

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

1.5.2 2.7-MW_t SSPS-CRS Central Receiver Test Facility

The heliostat field is comprised of 93 first-generation individual-tracking 39.3 m^2 heliostat units, with 20 second-generation 52 m^2 and 65 m^2 heliostats also available. Their average (clean) reflectivity is 87%, tracking accuracy 1.2 mrad error per axis and beam quality characterized by 1.5-mrad error width. At design insolation of 950 W/m^2 total field power is 2.7 MW_t. 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% of the power is concentrated within a 1.8-m circle.

The 20-ton-capacity structural-steel tower provides three test platforms, one at the top of the tower at 43 m above ground and two more at 30.5 m and 24 m. 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 first-generation parabolic-trough collector field consists of 40 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 mirror (clean) reflectivity of 92% and tracking error of less than 0.25°. The black-chrome-coated steel collector absorber tubes use 3M Santhotherm 55 synthetic thermal oil as the operating fluid. The operating range is between 180°C and 290°C. At maximum oil operating temperature of 290°, peak efficiency of 50% is achieved at noon. At 950-W/m^2 design insolation a peak thermal output of 1.3-MW_t can be reached at noon. The 114 m^3 thermocline tank stores thermal energy of approximately 5 MWht between 225°C cold and 295°C hot oil temperatures. The daily thermal energy delivered by the collector field is about 6.5 MWh_t.

A 14-cell Multi-Effect Distillation (MED) plant for sea-water desalination is connected to the parabolic trough field, which consumes 190 kW_t and has a nominal output of 3 m^3/h of desalinated water with a 9 kg distillate per 2300 kJ heat input performance ratio. The output salinity is 50 ppm total dissolved solids.

1.5.4 174 kW_t LS-3 Parabolic-Trough Facility

The LS-3 test loop was installed at the PSA during phase 1 of the DISS Project to study the behavior of the DSG process in a commercial-scale loop.

The test loop consists of a 50-m section of an LS-3-type parabolic-trough collector, which was the latest one installed at the SEGS plants in the USA. The oil circuit operates with 1000 liters of Syltherm 800 heat transfer fluid with a maximum temperature of about 400 °C and operating pressure of 20 bar. The maximum power output is on the order of 175 kW_t.

1.5.5 1.8 MW_t DISS Parabolic Trough Loop

The complete solar field of the DISS facility will be composed of 11 parabolic trough collectors with an aperture of 5.76 m and a total length of 550 m. The rows are installed on an 0.8º north-to-south sloping plot. The 550-meter-long solar field is north-south oriented instead of east-west so that the collectors installed in the evaporating section can be reassembled with a 0°, 2°, 4º, 6° or 8° angle to investigate various process options. With the proposed design, the DISS solar field will be able to work under the three DSG processes or any of several combinations of them, providing the flexibility required to investigate all the technical DSG process questions still unanswered. The system has been designed for maximum field outlet steam conditions of 400°C and 120bar. In the once-through configuration, the mass flow rate is 1 kg/s, while in recirculation a rate of 4 kg/s can be achieved. In the injection configuration the maximum pressure for water injectors is 140bar.

1.5.6 3x 40 kW_t DISTAL I Dish/Stirling Systems

The DISTAL I facility provides three individual-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 were measured in the focal plane. 90% of the power is concentrated within a 12 cm diameter. At a focal length of 4.5 m a SOLO V160 Stirling engine with a directly illuminated solar tube receiver is attached.

1.5.7 3x50 kW_t DISTAL II Dish/Stirling Systems

The DISTAL II facility demonstrates the actual design for Dish/Stirling systems. 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 is a reworked SOLO 161 Stirling engine in the focal point.

1.5.8 60-KW_t High-Flux Solar Furnace

Sunlight is reflected by four 53.61-m^2 heliostats with 90% average (clean) mirror reflectivity onto the primary concentrator, each of which illuminates a quarter of it, thus producing 60-kW total system power. The MDAC parabolic-dish concentrator, made up of 89 0.91-m-x-1.21-m sandwich facets, is 11.01 m x 10.41 m. The different facet curvature radii are set to a partial segmented cylinder surface with individual segments displaced perpendicularly to the cylinder axis. The total reflective surface area is 98.51m^2 with an average reflectivity of 92%, focal length of 7.45 m and focal height of 6.09 m. At the 120-mm focal spot, black-body temperature is 2500 K. Sunlight concentration is controlled by a 11.44m x 11.20m louvered shutter with 30 5.60 m x 0.93 m slats. The shutter can be set to 15,800 positions between 0° (open) and 55° (closed), yielding angles accurate to 0.00346° and flux regulation accuracy of $8.01 \cdot 10^{-5}$ and $4.94 \cdot 10^{-5}$ respectively. Fastest closing time is 5 seconds. The experiments can be mounted on a 0.7-m-x-0.6-m test table moveable on three axes at a maximum speed of 200mm/s along displacement paths x = 0.92m, y = 0.66m (along the optical axis) and z = 0.50m. The concentrator, test table and shutter are located inside the solar furnace building.

1.6 PSA Milestone Achievements 1997

- DISS: Purchase of all equipment and materials, delivery of main components to PSA, detailed engineering of the Balance of Plant, design of control and instrumentation, preparation of infrastructure
- LS-3 Loop Completion and first tests
- Test preparation and start-up for the pressurized volumetric air receiver (Refos)
- Comparison Campaign for large area heliostats completed
- Grid connection of the open volumetric receiver demonstration (TSA)
- Advanced salt receiver test campaign terminated (RAS)
- Colón Solar 70 m^2 heliostat prototype erected
- Start of Theseus Project
- Erection of Distal II and regular sunrise to sunset operation
- SOLARDETOX project for development of a commercial waste-water detoxification system started (June 1997)
- 3rd TMR User meeting held in February, Selection panel of independent experts to grant access in 1998 held in October 1997, first TMR user workshop held in November.
- DLR-SunLab Scientist Exchange Program started with the visit of Scott Jones from Sandia
- Local Heliostat Control System completed, CCD camera system for flux measurement installed (Engineering)
- Electrical supply, UPS and optical-fiber network as well as water supply extended to several remote buildings; more than 15000 operation hours performed
- Proposals for the Eurotrough, Eurodish and Iresmed Projects successfully submitted, EU-Joule Project FIRE completed and co-development of the DLR Synthesis concept for market introduction of solar thermal power plants (Project Development)

1.7 New Projects after 1998

In response to the 1997 EC JOULE call for proposals, the PSA is a partner in the following approved solar thermal project proposals:

- DISS II
- EuroDish
- EuroTrough

The objectives of these projects are briefly described in the following.

1.7.1 DISS II

The DISS II project continues DSG field activities at the PSA. Based on the real-scale PSA DISS test-bed collector, the three DSG processes, Once-trough, Recirculation and Injection, will be studied in experiments that determine its operating limits, temperature gradients and process control under real solar working conditions. Once the results have been collected and evaluated, improved components developed by the several partners will be tested.

Finally, more promising DSG commercial power plant concepts, including integration into Combined Cycle, will be defined and compared to find an economically optimum solution.

CIEMAT and DLR will share an important role in this project. CIEMAT will co-ordinate the project in close cooperation with DLR, especially the PSA project team, which will continue to be located at the PSA after the termination of the CHA Annex I.

1.7.2 EuroDish

In the EuroDish project, the industrial partners Schlaich Bergermann & Partner (SBP), INABENSA, Klein & Stekl, Mero and SOLO will develop new innovative components, manufacturing/erection procedures and associated tools which could reduce Dish/stirling system cost to less than 5.000 ECU/kWe. Their 80% share in the EuroDish project is a prime example of continual industrial engagement in dish/Stirling technology. Two 10-kWe EuroDish prototypes will be erected at PSA and qualified by CIEMAT and DLR. The project is scheduled to start in August,1998 and be completed by spring of 2001.

1.7.3 EuroTrough

The European firms, INABENSA, Schlaich Bergermann & Partner (SBP), Pilkington Solar International (PILKSOL) and Fichtner, have joined forces in the EuroTrough project to develop an advanced low-cost European parabolic trough collector for electricity generation and process heat applications incorporating the newest features in lightweight construction, drive, control and concentrator technologies in a collector weighting less than 30 kg/m² and at target costs of under \$200/m². A prototype section of the EuroTrough collector will be erected at the PSA and qualified by CIEMAT and DLR. Project startup is scheduled for August, 1998, and completion in January, 2001.

1.8 PSA Education, Training and Scientific Cooperation

Since 1990, the PSA, together with 10 other large European installations, has been selected by the European Commission DGXII to participate in a research subsidy program called "Access to Large-Scale Scientific Installations" (LIP), which provides financial assistance for the operating and other costs originating in the use of the PSA facilities by groups of European Community scientists who would otherwise not have access to them. Within the 1997 Access to Large-Scale Facilities TMR (Training and Mobility of Researchers) Program, more than 50 scientists from 28 research groups from universities and industry were thus able to carry out their research projects in the PSA's nine facilities. The results of this research work have been published in numerous scientific journals and congresses. At the first annual Users Workshop on November 18th and 19th, all the groups were able to present their results in two parallel sessions, Control of Solar Thermal Applications and Solar Chemistry. The proceedings of this meeting have been published in the CIEMAT conference series (See Appendix 3, List of Publications).

PSA application to the TMR program (Accompanying Measures) for a Summer School on Solar Thermal Concentrating Technologies has been approved and will be held in 1998.

Cooperation with the University of Almería continued to be fruitful, extending to joint organization of doctoral courses in renewable energies and including five grants for doctoral theses. After publication of the grants in the Official Bulletin of the Province of Almería, candidates were selected by a committee composed of members of the University and PSA. In addition to the five doctoral grants, 9 grants for practical training were also awarded. Furthermore, participation in the PSA student program has been considerably increased by participation in the EU Leonardo program. 36 students were trained at the PSA in 1997, contributing over 200 man/months to PSA research.

For 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. 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.

Within the SolarPACES framework and with DLR funding, a fruitful scientific exchange was begun between PSA and the American SunLAB, a cooperative agency of Sandia National Laboratories in Albuquerque (New Mexico) and the New and Renewable Energy Laboratory (NREL) in Golden (Colorado), with the visit of Scott Jones of Sandia, who participated in the PSA flux central receiver and dish/Stirling measurement campaigns in Spring of 1997.

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.

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Next Chapter: 2 Technical description and project achievements

2 Technical description and project achievements

2.1 Low Temperature Applications

Knowledge of the energy behaviour 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 centres working in this field the opportunity to test both already existing components and new innovative designs.

María José Jiménez
Area Head

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 construction materials. It consists of four test cells with complete instrumentation for testing of the thermal performance of building materials and passive solar components under real outdoor conditions (See Fig. 2.1) The LECE carries out its experiments as part of a continuous action of the CIEMAT solar energy buildings R&D section.

Juan de Dios Guzmán
LECE Facility Manager

The purpose of the LECE facility is to contribute to energy quality knowledge of construction components by experimenting to determine a given thermal property of a component, such as the overall thermal loss coefficient (UA), solar gain factor (gA), or system time response (τ). These properties can be used afterwards to optimize

Fig. 2.1.1 View of a PASSYS test cell and control room.

building design for energy saving without loss of comfort. Considering that 40% of the energy used in European countries is for heating, cooling, lighting, etc., this is a very important aspect of energy conservation.

The LECE activities can be classified as:

- Experimental support of specifications for legislation.
- CIEMAT Solar Energy Building project experiments.
- Collaboration with manufacturers of construction products.

And its main tasks are the following:

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

2.1.2 Infrastructure

The Laboratory has four test cells of approximately the same size as a standard room, which are well insulated by 40-cm-thick polystyrene walls. Both the wall opposite the service room and the roof are interchangeable with test specimens. Once the test components have been installed, the test sequences, appropriate procedures, and power and temperature conditions in the interior of the test cell, are started.

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

The new Solar Transmittance Sensor (STS) contributes to the laboratory's capacity for calculation of 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 enables calculation of spectral transmissivity.

2.1.3 Ongoing Projects

In 1997, the laboratory participated in the following projects to be continued into 1998:

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

PV-HYBRID-PAS:

The PSA participates in this Joule project along with the other European Laboratories that belong to the PASLINK network. The general objectives are the development and testing of thermal characterization procedures for photovoltaic components and their application to the characterization of commercial components for their comparative study.

The PSA tasks consist of the testing and thermal characterization of a *commercial opaque amorphous photovoltaic component*.

The necessary equipment was acquired in 1997. The assembly of the photovoltaic test component support structure was completed. Additional sensors were acquired and installed. The data acquisition system was modified for storage of the required set of data.

The tasks planned for 1998 are the acquisition and installation of additional sensors, modification of the data acquisition system for storage of the required data and the corresponding test and data analyses.

Fig 2.1.2 Photovoltaic modules being tested in the PASSYS II test cell.

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

CIEMAT's team for Solar Energy in Buildings is a participant in this project which has the overall objective of quantifying the thermal and shading effects of vegetation-based techniques in housing and urban planning.

This project uses the LECE facility for testing and characterization of different types of plants on the vertical wall of the CESPA I test cell during the summer.

1997 activities were the acquisition and assembly of the infrastructure that enables the selected plant to grow on the test cell and around it. Sensors have been installed and the data acquisition system was modified to collect the specified data. A first test was performed and plant behavior under the experiment conditions was studied in order to improve later tests.

The planned activities for 1998 are infrastructure improvements enabling the selected plant to grow on the test cell and its surroundings. A second test is also to be carried out during the summer, applying the knowledge acquired the previous year in this type of experiment.

Figure 2.1.3: Assembly of the experiment for APISCO project in a CESPA test cell.

ROOFSOL (Roof solutions for natural cooling):

This CIEMAT Solar Energy in Building Section was accepted by the EU Joule Program in 1995. The overall objectives of the project are:

- Create design information, in which energy performance indices will accompany to 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 of performance and energy-saving potential in a diversity of climates across the Mediterranean area.

Within the framework of this project, the LECE is being used as a facility to perform a relevant part of the experimental task consisting of the installation and thermal testing of *different configurations of an evaporative roof* to be used for cooling by semi-passive techniques. The component that is being tested is a roof pond with water sprinkling system.

The tasks carried out at PSA in 1997 have been the following: Selection, acquisition and installation of equipment such as sensors, insulation, internal support, and sprinkles, installation of the roof pond prototype, tests performance and data pre-processing.

The tasks planned to be carried out at PSA in 1998 are the installation of additional equipment such as sensors, insulation and sprinkles, tests performance and data pre-processing, for different roof configurations.

Figure 2.1.4: Evaporative roof tested in the PASSYS I test cell.

2.1.3.2 Activities under Collaboration Agreements

Agreement between Polytechnic University of Cataluña and CIEMAT

Under this agreement, the L.E.C.E. is performing the tests and characterization of *four types of bricks, fabricated with waste from different industries (textile, cardboard, etc.)* in the test cells. The results of the tests are confidential.

In 1997, one of the four special kinds of bricks made of industrial textile waste was thermally characterized. In order to achieve this characterization, a wall was built with these bricks, the necessary sensors were installed and data acquisition system modifications were implemented.

The activities planned for 1998 are: data analysis and the corresponding report on the first test carried out in the PASSYS II test cell in 1997 and testing of the remaining three kinds of bricks in the PASSYS II and CESPA IV test cells following the same procedures as for the first test.

Agreement between Polytechnic University of Madrid and CIEMAT:

The LECE is being used as the basis for *specific (UNE) regulation* of this type of test sites. The AENOR (Spanish agency for normalization) technical committee number 7 (Material Testing) must write these regulations.

Agreement between Complutense University of Madrid and CIEMAT:

LECE is collaborating in the *performance of ventilation tests* in one CESPA test cell.

In 1997, the LECE provided this team with infrastructure and technical support for its ventilation experiments.

2.1.3.3 Other European Programs

TMR Program:

LECE Laboratory is part of the facilities of the PSA included in the TMR program (Training and Mobility of Researchers). This program provides access to PSA, free of charge for user groups or individuals throughout the Member States of the European Union and Associated States (currently Norway, Lichtenstein, Iceland and Israel). The European commission covers travel and subsistence expenses of the users, as well as facility operating costs. Users are provided with infrastructure, logistical, technical and scientific support.

1997 Activities:

University of Athens group: A CESPA cell was used to design a control strategy for a shading device and a heating and cooling system. A reference wall with a double-glazed window and exterior motorized venetian blind was installed. The objective was to obtain the minimum necessary variables to implement control algorithm focused in to reach comfort saving energy.

University of Patras: This group performed a thermal stress test on a partially shadowed double-glazed window. This window was installed in a CESPA cell using a reference wall as support. The cell was able to reach an indoor temperature lower than the outdoor temperature, installing a cooling system in this cell.

Figure 2.1.5: Assembly of the experiment on window stress, carried out for TMR user University of Patras.

UMSICHT (Germany): This group evaluated an autonomous household refrigerator which uses a solar collector as the energy source. The equipment was installed in the LECE facility and used the LECE data acquisition and process control infrastructure.

Activities planned for 1998:

University of Athens: The test cells will be used to perform experiments with an evaporative material and to validate results of experiments that have been carried out in the same type of cells under other weather conditions in Greece.

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

2.1.3.4 *Other activities*

In 1997, the LECE continued implementing the quality procedures necessary to meet all the ENAC (the Spanish accrediting institution) accreditation requirements. These accreditation activities are planned to continue in 1998.

Several maintenance tasks, such as the repair of one of the cells damaged by severe weather conditions, were carried out in 1997, and personnel training, were also routine activities.

A summary of the activities programmed for 1998 is shown below:

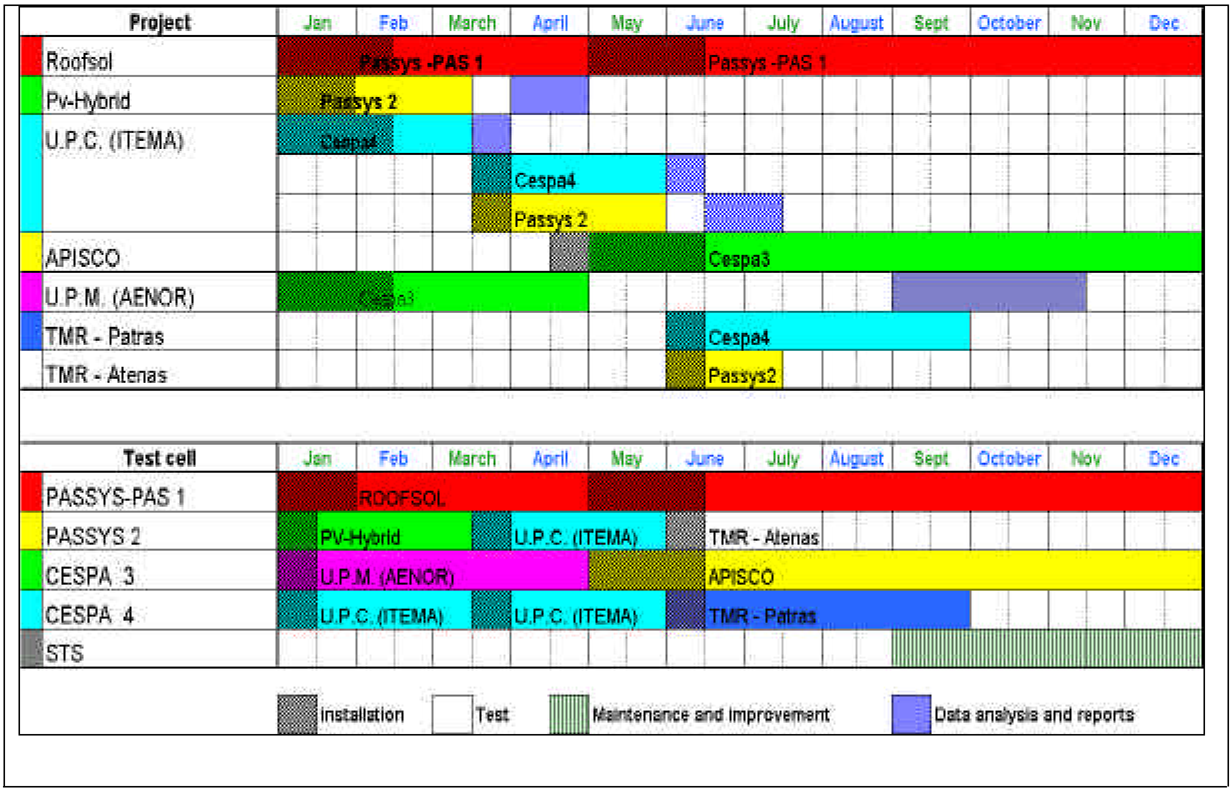

Table 1: LECE 1998 planned activities

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Next Section: 2.2 Parabolic Trough Technology

2.2 Parabolic Trough Technology

Eduardo Zarza

Pedro Balsa

The activities of the Parabolic Trough Technologies Area during 1997, were divided among five projects:

- Direct Solar Steam (DISS)
- ARDISS
- PAREX
- T.M.R. Control
- TMR-Desalination

2.2.1 Direct Solar Steam (DISS)

The DISS (DIrect Solar Steam) project is a complete RD&D program aimed at developing a new generation of Solar Thermal Power Plants with parabolic trough collectors. This R&D program is based on three points:

1. Development and implementation of improved components for parabolic trough collectors (e.g., absorber pipes with better optical and thermal properties; better mirrors; more accurate tracking systems; etc...).
2. Development of the Direct Steam Generation (DSG) process eliminating the oil now used at existing plants as a heat carrier medium between the solar field and the power block. This process would increase overall system efficiency while reducing investment cost.
3. Optimization of overall plant design and improvement of O&M procedures to achieve better coupling of the solar field and power block, with shorter startup and shutdown times.

The expected benefit of this project is a 30% reduction in the cost of electricity generated with parabolic troughs. State-of-the-art for parabolic-trough solar thermal power plants is marked by the nine SEGS plants currently in operation in California. 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.

The DISS project is planned in several consecutive phases. The first phase of the project, which was started in January, 1996, and is currently underway with European Commission financial support (Contract JOR3-CT95-0058), will last 30 months, while DISS-phase II is now planned to take 33 months. Final planning for the third and last phase of DISS will be prepared at the end of the second phase because it strongly depends on results of the experiments to be performed at the PSA DISS test facility during the second phase.

The partners in DISS-phase I are:

- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Spanish public research institution belonging to the Spanish Ministry of Industry.
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), German public research institution
- Empresa Nacional de Electricidad S.A. (ENDESA), Spanish electric utility
- IBERDROLA (ID), Spanish electric utility
- Instalaciones Abengoa S.A. (INABENSA), Spanish industry
- Pilkington Solar International GmbH, German industry
- SIEMENS-KWU, German industry
- Unión Eléctrica Fenosa (UEF), Spanish electric utility
- Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), German research center

SOLEL Solar Systems (Israel), INITEC (Spanish Engineering Company), UFISA (Spanish Engineering Company) and the Electrical Engineering and Electronics Group of the University of Manchester (UMIST) are also participating as subcontractors.

Figure 2.2.1 shows project organization on three levels:

1. The Project Committee: composed of representatives from all the sectors involved in the project (i.e. industries, research centers and electric utilities). This Committee defines the project guidelines and takes executive decisions.

2. Project Coordinator: who manages the overall project in accordance with the guidelines defined by the Project Committee

3. Task Leaders: the work packages to be performed in the project are grouped into six Tasks, with a Task Leader being responsible for the coordination of all the activities within each Task.

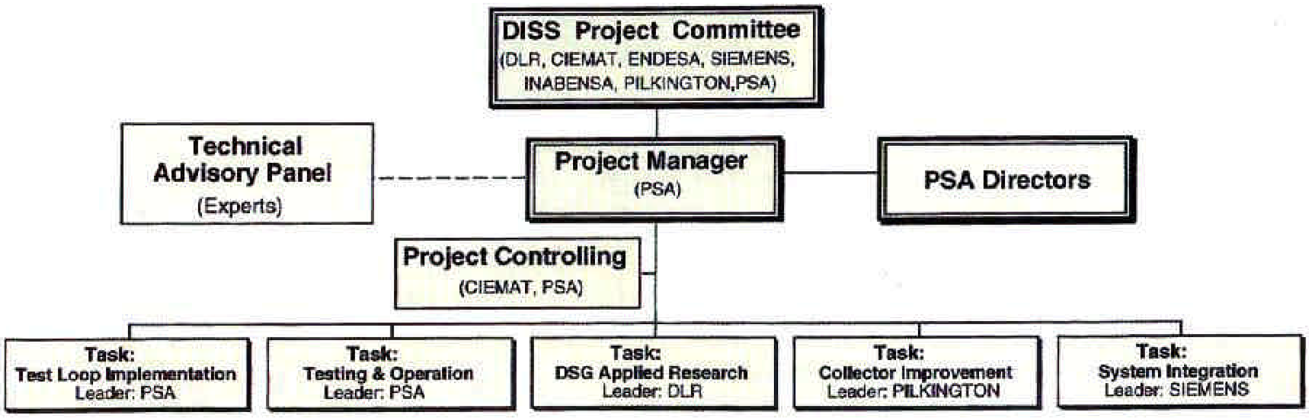


Fig. 2.2.1 DISS Project Organization

The following tasks are included in the DISS project plan:

Coordination and Management: This task includes project planning, coordination, quality and project control.

Design & Implementation of the PSA DISS test facility: This task includes the design, procurement and erection of the PSA DISS test facility, which is to be erected in two stages, a single-row system during the first phase of the project and a parallel row to be added at a later stage after enough information and experience has been gathered with the single row. Simulations have pointed out that severe transients could occur in a large DSG solar field when there are cloud transients and, therefore, implementation of the second row of collectors is considered essential. This facility will be a key tool for life-size investigation of the three DSG processes (i.e., once-through, recirculation and injection).

Testing and Operation: this task includes the operation and maintenance of the PSA DISS test facility. Tests will attempt to find out the answers to some open questions about the DSG process that cannot be found at smaller test facilities.

DSG Applied Research: Thermohydraulic aspects of DSG technology complementing the experimental results gathered at the PSA will also be investigated. Process control schemes and heat transfer enhancement mechanisms in the absorbers with two-phase flow will be developed and evaluated.

Collector Improvements: Possible collector improvements (e.g., front-surface mirrors, lighter structures, new selective coatings, anti-reflective coatings, etc.) will be studied and evaluated in this task. An oil test loop is currently being erected at the PSA for used as a test bed to evaluate improved components under real solar conditions.

System Integration: Operation, maintenance and cost issues for a commercial DSG power plant will be analyzed taking into account the experimental results gathered at the PSA DSG test facility. The lay-out and configuration of a demonstration commercial plant using the DSG technology will be prepared.

Summary of activities in 1997

1997 activities were performed under the *Design & Implementation of the PSA DISS Test Facility, DSG Applied Research* and *Collector Improvement* tasks, as well as overall project coordination and management, as summarized in the following paragraphs.

Regarding design and implementation of the PSA DSG test facility, most of the detailed single-row system design was finished and erection was begun in June, 1997. Technical specifications for purchase of the equipment were prepared by the partners involved in the detailed facility design. Most of the BOP equipment was purchased by CIEMAT. Though technical problems concerning the solar field foundation design delayed the starting date of the collector assembly, these problems were solved in the last quarter of 1997 and foundations could be laid at the end of November. The collector assembly jigs were installed on site by INABENSA the first week in December. Construction of the BOP building was begun in October and the steel structure was erected in November. The long absorber pipe delivery period and the problems with foundations have delayed construction of the test facility by another 2 months in the second half of 1997. After a difficult search, a supplier for the recirculation pump was found and the purchasing contract will be signed in January, 1998. Samples of high pressure ball joints to connect the collectors have been tested by the PSA with the collaboration of ENDESA, solving this technical constraint. The PSA DISS test facility system configuration is shown in Fig. 2.2.2, while Fig. 2.2.3 shows some parabolic-trough modules during assembly.

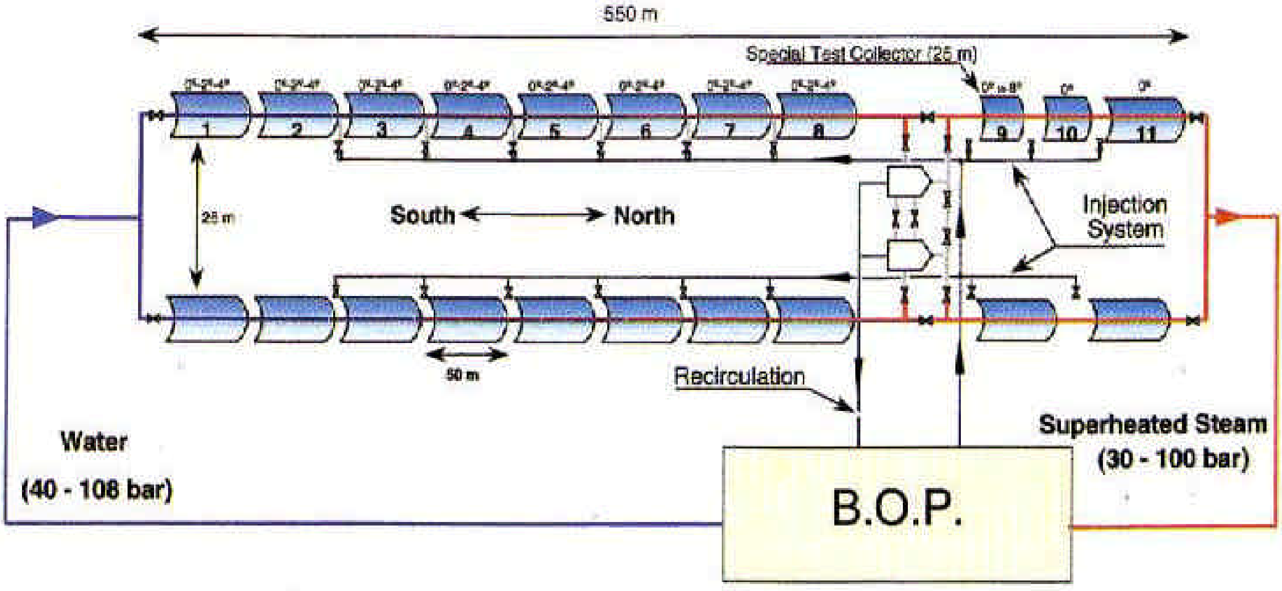


Fig. 2.2.2 Updated diagram of the PSA DISS test facility

g. 2.2.3 Some parabolic trough modules for the DISS solar field

Under the "DSG Applied Research" task, DLR has continued to develop special test equipment for DSG experiments at the PSA. A draft of the test plan to be performed at the PSA DISS facility has been prepared and will continue to be discussed in 1998. Possible absorber pipe heat transfer enhancement mechanisms have been analyzed and the study of porous coatings was started.

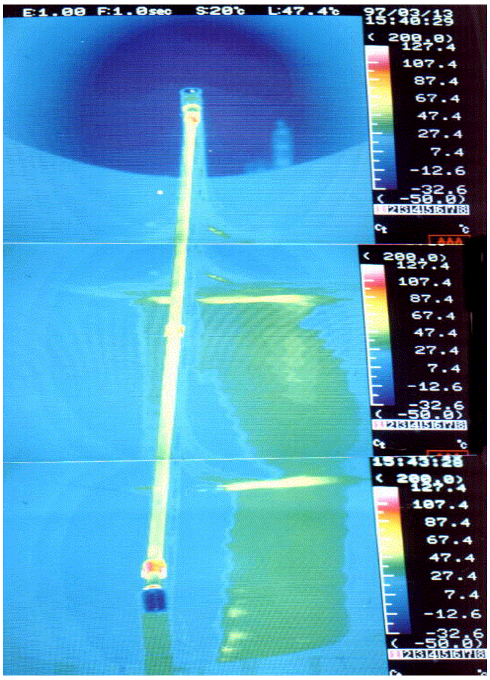
Within the "Collector Improvement" Task, the PSA HTF test loop was finished and this facility is now available to external users for parabolic-trough collector component testing under real solar conditions. This test stand, built from half an LS-3 collector, and provided with oil pump, cooler and heater, as well as an oil expansion tank, can work at up to 400 C. (Shown in Fig. 2.2.4.) The local control developed for parabolic trough collectors by the PSA in 1996 was successfully tested in 1997. CIEMAT has continued the development of new selective coatings and Sol-Gel front-surface mirrors.

Fig. 2.2.4 The PSA HTF test loop

2.2.2 ARDISS Project

The ARDISS (Advanced Receiver for Direct Solar Steam) project was financed 50% by the CEC Joule II program and 50% by the partners (CIEMAT, ZSW, CONPHOEBUS and INETI). The project started in December, 1994 and finished in March 1997. The goal of the ARDISS project is to analyze the technical options of the DISS process, identified as the most promising development for speeding up commercialization of solar-powered electricity production, and to develop an advanced receiver fulfilling its requirements. For this, the most promising component developments in recent years, in particular a Second Stage Concentrator (SSC) receiver, to increase concentration without penalizing collector efficiency and improve control of the DISS process, were integrated. The main tasks performed were:

- Design, construction and testing of the Second Stage Concentrator Receiver.
- Theoretical and experimental studies in Direct Steam Generation.
- Simulations for assessment of DISS solar-driven electricity production systems.
- Final report



2.2.5 Thermal Image of the ARDISS in tracking mode

Among the main results were:

- Although on-sun experiments showed poor behavior, performance during optical and thermal measurement in the new SSC lab was good, demonstrating that, once the problems encountered have been corrected, SSC receivers will be an excellent alternative for parabolic-trough collectors.

- The new front-surface mirror (Silver protected by a Sol-Gel-coated SiO_2 layer), has great potential from the point of view of efficiency and mirror cost, not only for high-temperature secondary receiver mirrors, but also for primary parabolic-trough, heliostat and dish mirrors, although further improvement of durability is needed.
- The HIPRESS experimental facilities have demonstrated that an SSC receiver simplifies DSG system configuration, broadens the range of permissible flow rates and that the range of operating conditions under which the DSG process can be controlled is wider than expected.
- SSC receivers used for the DSG process improve annual electricity production by over 20% when compared to parabolic trough systems with round receivers and oil as the heat transfer medium.

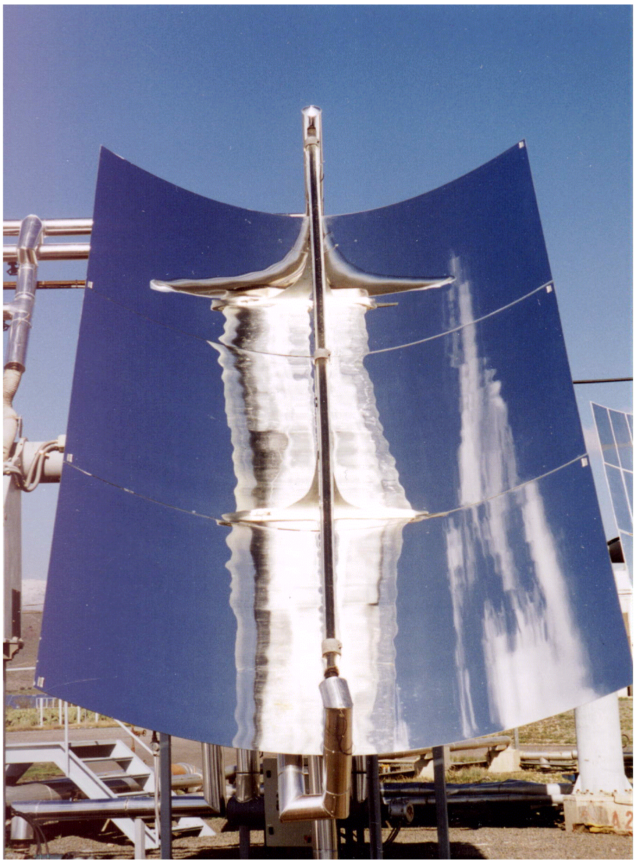


Fig. 2.2.6. Detail of ARDISS Receiver.

Summary of activities in 1997

Due to some problems with mirror durability, fabrication of the ARDISS SSR (Secondary Stage Receiver) was somewhat delayed, However, it was completed at the end of 1996, so the SSR absorber was installed at the PSA test bed in February and evaluated in the first quarter of 1997.

Helioman test stand modifications made to install the ARDISS SSC were completed on January 14, 1997 and the prototype was installed on February 27, 1997, after which time the receiver testing and evaluation were carried out. The main tests were:

- Thermal loss
- Efficiency
- Thermal Image processing

Tracking accuracy was also investigated in depth. For this purpose a device to measure angle was designed and installed by the engineering department.

2.2.3 PAREX Project

This German project managed by the DLR is aimed at developing and testing advanced parabolic-trough receivers to:

1. reduce losses at increased working temperatures
2. reduce thermomechanical loads due to cyclic or uneven heating

These advanced receivers are intended for parabolic-trough collectors with either thermal oil or direct steam generation. The main role of the PSA in the PAREX project is the installation of the PAREX absorber prototypes and their testing under real solar conditions using the ARDISS and HTF test facilities. A number of new receiver concepts were analytically and numerically evaluated to select promising configurations to be built and tested:

1. secondary concentrators
2. linear cavities
3. heat pipe
4. multiple pipes

After the durability and efficiency of the PAREX 02 prototype was demonstrated on a smaller scale in 1996 and 1997 in the ARDISS test bed, DLR will manufacture a larger prototype to be tested at the real-scale LS-3 loop which uses the same collectors as the SEGS Plants in California currently producing electricity.

The main PAREX project activities at the PSA in 1997 were:

- Modification of the PAREX 02 prototype by the PSA Maintenance Department.
- Routine operation of the PAREX 02 prototype for durability, May-July 1997.
- Thermal evaluation of the bare absorber, September-December, 1997.

2.2.4 Training and Mobility of Researchers Control

In the earliest stages of solar energy R&D in the Small Solar Power Systems project, standard industrial PID feedback controllers were already found to be incapable of coping with solar radiation transients, causing unnecessary shutdown of the solar field and clearly demonstrating the need for advanced controllers for solar plants. The main objective of this project is the development and testing of advanced control algorithms for use in solar power plants. The ACUREX parabolic though solar collector field served as a test bed. Apart from solar energy, there are other manifold motivations for this line of research. The techniques that have been applied to the ACUREX field may also be applied to many industrial processes and the work carried out has in turn served as an impulse for new theoretical development.

The project has been running at the PSA since 1990. In 1997, it was financed by the CEC DG XII Training and Mobility of Researchers program.

The main achievements in 1997 within the framework of this project are briefly listed below:

1. A separate session devoted to the work at the Plataforma Solar de Almería with six papers presented at the 1997 European Control Conference (the most important control event worldwide in 1997)
2. 100% fulfillment of the weeks committed in the Training and Mobility of Researchers contract for the second year.
3. Approval of the Horus project by the Portuguese national R&D Planning Board.

Besides the main goal mentioned above, this project has been highly productive academically. Three Ph.D. theses are currently underway. There was an exchange of postgraduate students among institutions involved in the project, Univ. Firenze, INESC and Univ. Bochum. At several European universities, the project has also had a strong impact on undergraduates through the PSA student 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.

A TMR Users Meeting took place in February 1997. At this event, the results obtained in the first year of the project were presented and some useful information was distributed (papers, programs, etc).

The controllers tested under real operating conditions at the ACUREX Field in 1997 were:

Univ. of Oulu (Finland):

Linguistic Equation Controller

The Linguistic Equation approach provides a flexible environment for combining expertise in development of intelligent systems. The knowledge base of the expert system is represented by linguistic relationships which can be converted into matrix equations. This year the basic scheme tested in 1998 was modified by the incorporation of braking action and unsymmetry effect.

Univ. Firenze (Italy) and INESC (Portugal):

Switching controller.

The switching control strategy has been used to cope with changes in plant dynamic behavior induced by different operating conditions. This year the control scheme incorporated a feed-forward series proposed by the Plataforma Solar de Almería.

Univ. of Bochum.

This university collaborated with INESC in the testing of two controllers, a bank of LQG controllers tuned to work at different operating points and a non-linear predictive controller.

Other control-related activities

In order to simplify the work of the ACUREX field users, the PSA has developed a control module linked to the Data Acquisition System. This program provides an example of how to deal with the plant monitoring software, reducing the mixing time.

A simple, quickly implemented feed-forward based on the energy balance in equilibrium was also developed and tested in 1997. This scheme, designed by the PSA, was also used by some of the institutions involved in the control project.

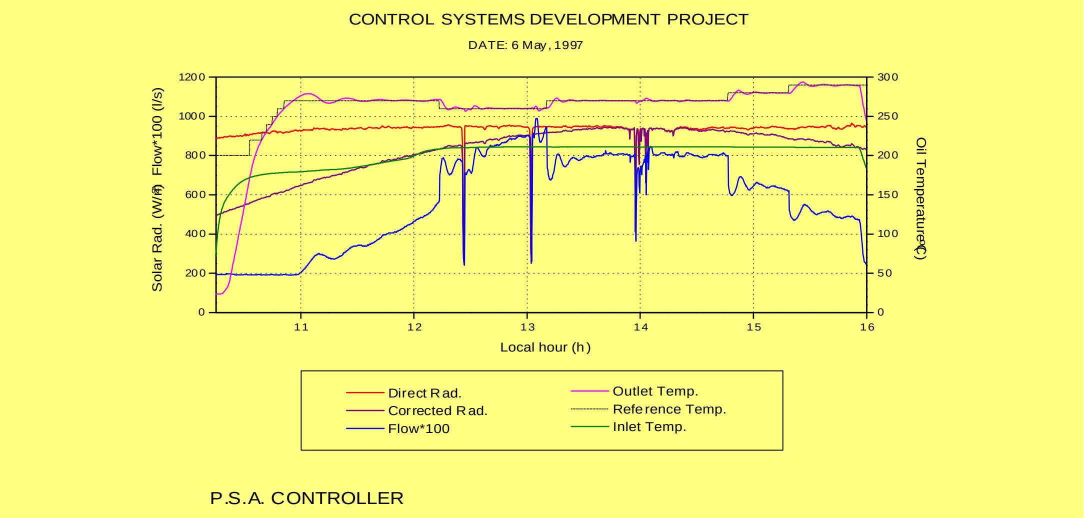


Fig. 2.2.7. Controller response during a set-point tracking test.

2.2.5 TMR Desalination Project

This project deals with the work carried out from 1987 to 1993 within the PSA *Solar Thermal Desalination* project. In 1997, two groups were selected as users for the desalination plant Univ. of Ulster and Heliostat Ltd.

The Univ. of Ulster analyzed the full desalination plant energy chain. This study showed the very low level of emissions produced, not only during operation, but throughout its life cycle from component fabrication to demolition.

The HELIOSTAT company reviewed the PSA desalination plant as a test bed for an innovative collector it has developed. In 1998 this collector will be thermally evaluated here.

The solar desalination system used for this project, inaugurated in 1988, is composed of:

- 14-effect MED plant
- parabolic trough solar collector field
- thermocline thermal energy storage tank.

The 14-effect MED plant is shown in Fig. 2.2.8. 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 the thermal oil tank. Hot oil from the storage system provides the MED plant with the thermal energy it requires. The MED plant is composed of 14 cells or effects. The sea water is preheated from Cell to Cell in the 13 pre-heaters. From Cell (1), the feedwater goes from one Cell to another by gravity before being extracted from Cell (14) by the brine pump. Part of the sea water used to cool the condenser is rejected and the rest is used for the feed water required to spray the Cell-1 tube bundle.

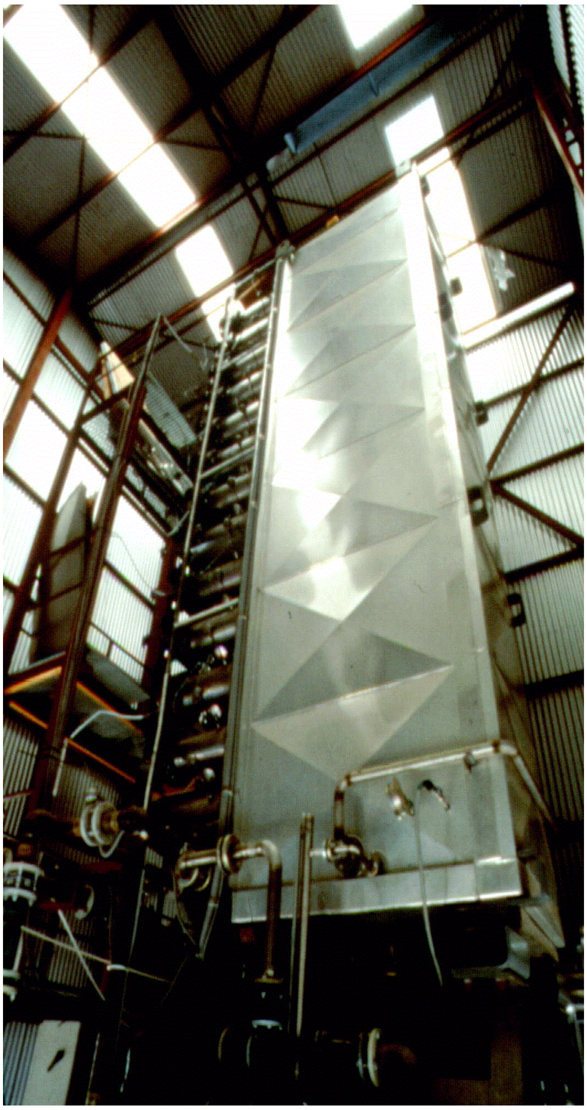


Fig. 2.2.8. View of the Desalination Plant.

2.3 *Dish/Stirling Systems*

Among the solar thermal systems for generating electricity, the parabolic concentrator with Stirling engine is distinguished by its high efficiency and the ease with which it can be adapted to specific consumption structures. Overall solar to electrical conversion efficiencies of up to 30% could be demonstrated. Due to the small system sizes from 3 to 50 kW_{el} power generation plants containing several units can be clustered and easily extended to meet the local demand.

Martin Stegmann (until 31.10.97)

Peter Heller (since 1.11.97)

Wolfgang Reinalter

Francisco Martín

Since 1991, when Schlaich, Bergermann and Partner (SBP) erected their first 9 kW_{el} Dish/Stirling units (DISTAL I) for long-term testing, the PSA has been working successfully in this field of investigation. Continuous operation since 1992 has resulted in about 29,000 hours of operation and more than 3,500 hours in 1997. The other main event at the Dish/Stirling test site was the startup and testing of three new 10 kW_{el} SBP systems (DISTAL II), erected in late 1996. Including the new systems, the PSA can now refer to more than 30,000 hours of experience in the operation of Dish/Stirling systems.

2.3.1 DISTAL I

The DISTAL I test facility consists of three 7.5-m-diameter single-faceted stretched-membrane concentra-

Table 2.3.1 SBP 9kWel DISTAL I Dish Stirling System specifications

CONCENTRATOR		**RECEIVER**		**STIRLING PCU**	
Manufacturer	SBP	**Manufacturer**	Solo	**Manufacturer**	Solo
Type	Single-Facet, Stretched Membrane	**Type**	Directly illuminated Tubes	**Type**	Alpha-Type, V 90°
Aperture Dia.	7.5m	**Aperture Dia.**	~12 cm	**Displaced Vol.**	160ccm
Reflecting Area	42 m^2			**Totally Swapped Vol.**	226ccm
Focal Length	Ca. 4.5 m			**Working Gas**	Helium
Concentration Factor	> 2000	**Peak Flux on Surface**	17 kW/cm^2	**Max. Pressure**	15 Mpa
Focal Ratio	0.6	**Peak Temp. on Surface**	850°C	**Max. Gas Temp.**	~650°C
Output	34 kW_{th}	**Output**	29 kW_{th}	**Output**	9 kW_{el}
Efficiency	81%	**Efficiency**	85%	**Efficiency**	29%

Fig. 2.3.1 Distal I test facility

tors totaling 44 m^2 aperture area. The concentrators are mounted on a 'polar' axis, following the sun at a constant speed of rotation throughout the day. The Power Conversion Unit (PCU) at the focus uses a directly illuminated tube receiver connected to a SOLO V160 Stirling engine to produce an electrical output power of 9 kW_{el}. in grid-connected mode. In 1997 the facility was operated continuously and also served as an EU-DGXII Training and Mobility of Researchers (TMR)'. test facility. The DISTAL I systems have now accumulated 29,000 hours of operation.

In 1998, operation will continue as long as manpower is available and no major problems occur. The facility will also be accessible again for users of the TMR Program. Three scientists have submitted proposals for a stay at the DISTAL test site. Besides training at the facility, PCU process parameter measurements will be integrated in a simulation model for the design of a free-piston engine.

2.3.2 DISTAL II

The erection of three new SBP 10-kW_{el} Dish/Stirling systems was completed in 1997. Like DISTAL I, the systems consist of a single-faceted stretched-membrane concentrator with a Solo Stirling engine at its focus. The concentrators were manufactured using a new laser welding method. Tracking is done by azimuth/elevation drive system which is computer controlled and allows full automatic operation. Due to the stiff structure there are no corrections needed during the day. For optimization of the yearly energy output the concentrator was enlarged to a diameter of 8.5 m which allows to reach full power at about 850 W/m^2.

Fig. 2.3.2 Distal II test facility (foreground)

The V160 Stirling engine was completely reworked by Solo and optimized in respect to the manufacturing process and the output power (now called 'Solo V161'). The highly stressed direct illuminated tube receiver is based on the prototype with crossed tubes developed and tested in the DISTAL I facility. On the surface of the receiver temperatures up to 820°C are reached which lead to a working gas temperature of about 650°C. As working fluid the system uses helium with a maximum pressure of 15 MPa. At insolation over 850 W/m^2, when the working gas has reached its maximum pressure and temperature, the receiver has to be cooled by a ventilation system to release the excess energy collected by the enlarged concentrator.

During startup, many system settings could be defined and performance tests made and evaluated. As observable from the data plotted below, the system already shows very good response, but system parameters still have to be optimized to reach design performance. For this, further qualification testing of major components was necessary and additional measurement campaigns were started that are to be continued in 1998.

Table 2.3.2 Data of SBP10 kW_{el} Systems

CONCENTRATOR		RECEIVER		STIRLING PCU	
Manufacturer	SBP	**Manufacturer**	Solo	**Manufacturer**	Solo
Type	Single-Facet, Stretched Membrane	**Type**	Directly illuminated Tubes	**Type**	Alpha-Type, V 90°, crosshead
Aperture Dia.	8.5 m	**Aperture Dia.**	~18 cm	**Displaced Vol.**	160 ccm
Aperture Area	55 m^2			**Complete Gas Volume**	250 ccm
Focal Length	ca. 4.7 m			**Working Gas**	Helium
Concentration Factor	>2000	**Peak Flux on Surface**	17 kW/cm^2	**Max. Pressure**	15 Mpa
Focal Ratio	0.55	**Peak Surface Temperature**	850°C	**Max. Gas Temperature**	~650°C
Output	45.8 kW_{th}	**Output**	≤33 kW_{th}	**Output**	10 kW_{el}
Efficiency	81%	**Efficiency**	≤85%	**Efficiency**	30%

With the help of SANDIA´s video-scanning system, VSHOT, membrane quality was measured for two of the three units. It showed slight deviations of the membrane at the rim due to the manufacturing process and helped to identify possibilities of improvement. A flux measurement campaign was started and will be continued in 1998.

Several components, like the control and tracking system, were able to be improved during startup. Their already very good performance will be optimized during future operation. Up to now, the new dishes have been operated on-sun for about 1000 h.

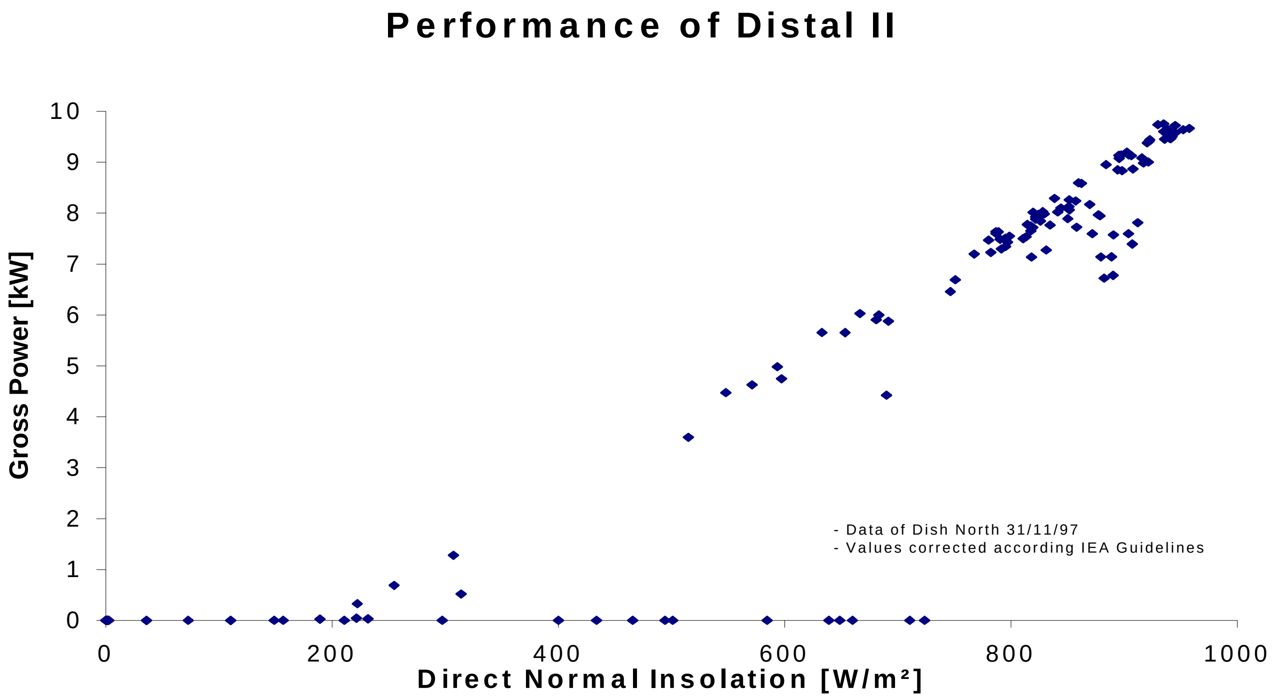


Fig. 2.3.3 Performance data of DISTAL II

2.3.3 HYHPIRE

As the Dish/Stirling technology is intended for remote applications not requiring grid connection, the development of receivers that can use both solar and fossil energy is more than reasonable. With such a hybrid receiver investment in a fossil backup system can be avoided.

Conventional receiver technology with directly illuminated tubes is not very suitable for hybrid-mode operation. The efficiency of the Stirling process strongly depends on the 'dead volume' caused mainly by the receiver heat transfer tubes. To reduce that volume, the same tubes would have to be used for absorption of solar radiation and heat exchange between combustion gas and working gas. These two processes are quite different and their special needs can't be met in the same optimized design.

To solve this problem, a 'heatpipe receiver' using a heat exchange fluid (e.g., sodium) to conduct the heat (at a nearly constant temperature) from separated transfer areas to the working gas tubes of the Stirling engine is applied. In these separate areas, the heat exchange surfaces as well as the absorption surface can be optimized to meet the special needs of the different transfer processes.

Within the EU-funded HYHPIRE project ('Development of Advanced Hybrid Heat-Pipe Receivers in Dish/Stirling Systems for Decentralized Power Production'), a second generation hybrid heatpipe receiver has been developed, in-

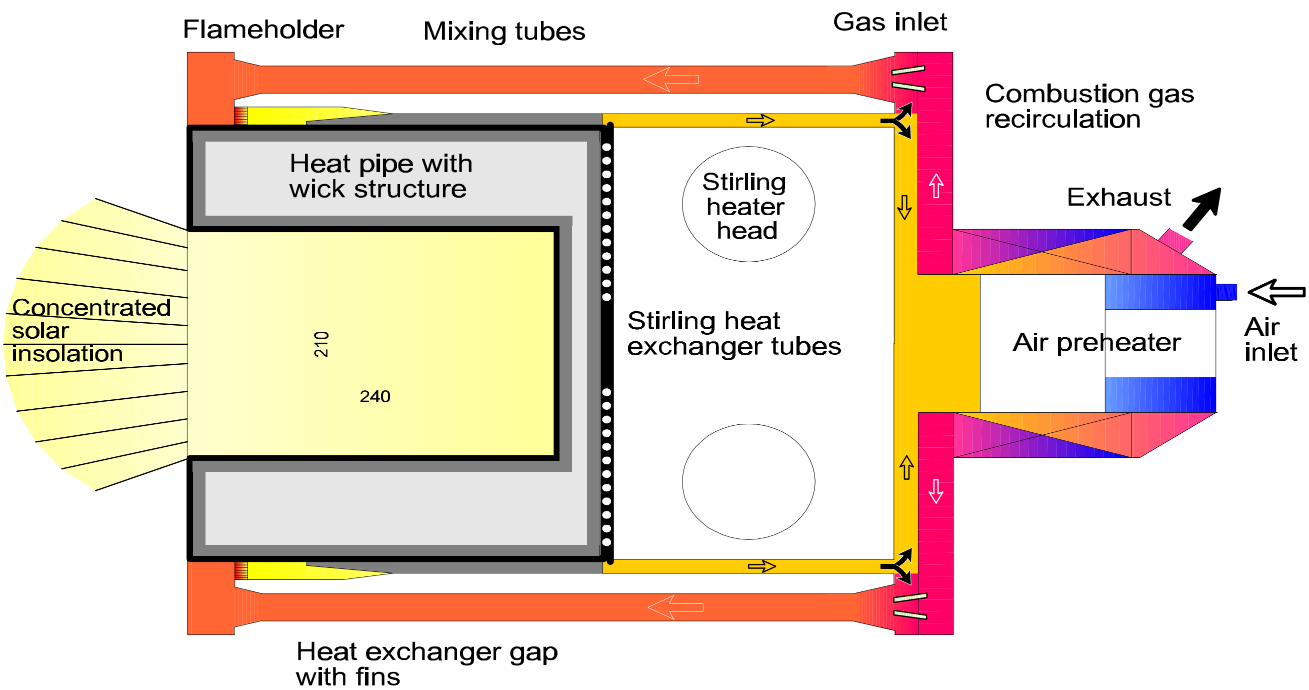


Fig. 2.3.4 Advanced Heat Pipe Receiver

cluding a well-adapted low-emission combustion system. A new cost-effective simplified manufacturing method replaces the welded wick (See diagram Fig. 2.3.4) with a plasma-sprayed porous structure that decreases system investment.

Technical maturity of the system will be demonstrated in on-sun testing at the PSA in early 1998. The site and tests were planned in 1997, although the main PSA work packages are for 1998 and 1999.

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2.4 Central Receivers

The activities in central receivers technology include the development and test of components like heliostats, receivers etc. but also the simulation, investigation and assessment of power tower plant concepts. The experience gained during operation of complete systems is also an important task in this area. In 1997 the following projects had been conducted:

1. TSA – Technology Demonstration Program Solar Air Receiver, the volumetric receiver for the PHOEBUS tower power plant on top of the CESA-tower, recently connected to the Spanish grid
2. REFOS – Volumetric pressurized receiver for solar assisted fossil-fired gas turbine and combined cycle power plants, a receiver development and testing project on the CESA-tower
3. RAS – Receptor Avanzado de Sales (advanced salt receiver), the internal molten salt film test receiver on the SSPS-tower, now terminated
4. Volumetric Receivers – High temperature open volumetric ceramic receiver developments on the SSPS tower
5. Heliostats – Test and comparison of two large area advanced heliostats and a new heliostat for the Colón Solar project, situated behind the CESA-field
6. Colón Solar - Integration of solar thermal energy in a conventional electricity plant in south-west Spain
7. THESEUS - System Analysis of a 50 MW_{el} Thermal Solar European power Station for Crete
8. SolWin – Software tool and data base for performance, emissions and financing aspects of solar power projects

These projects shall provide essential steps towards efficiency improvements and cost reduction to overcome market barriers.

Peter Heller (Area Head)

Eckhard Lüpfert (Refos)

Frank Schillig (Theseus)

Jesús Ballestrín (Colón Solar)

Javier León (Volumetric/RAS)

Antonio Valverde (Operation)

Diego Alarcón (Doct/Simulation)

Rainer Kistner (Doct/Economics)

2.4.1 TSA

In the years following the successful PHOEBUS Technology Program Solar Air Receiver (TSA) test campaign in 1993 and 1994, the main goal was the optimization of receiver and steam generator control. In 1995 and 1996 work on the automatic aiming-point strategy programs was completed and several tests were performed. In late 1996, 22 new TSA receiver absorber elements were installed. Their new design allows them to be manufactured in fewer steps and with less material at a lower cost. Both performance and reliability of the new type of absorber element were to be demonstrated first in a 100-h test at moderate temperature and thereafter, in long-term operation at nominal temperature.

In the 100-h test, the absorbers were operated at 700°C. The material was observed for deviations in color indicating variations in material density. Fig. 2.4.1 shows typical absorber element material colors. It may be deduced that the wick structure manufacturing process should be improved to avoid locally higher material densities and resulting higher temperatures at those points, especially at the center of the elements and sometimes in the direction of roll.

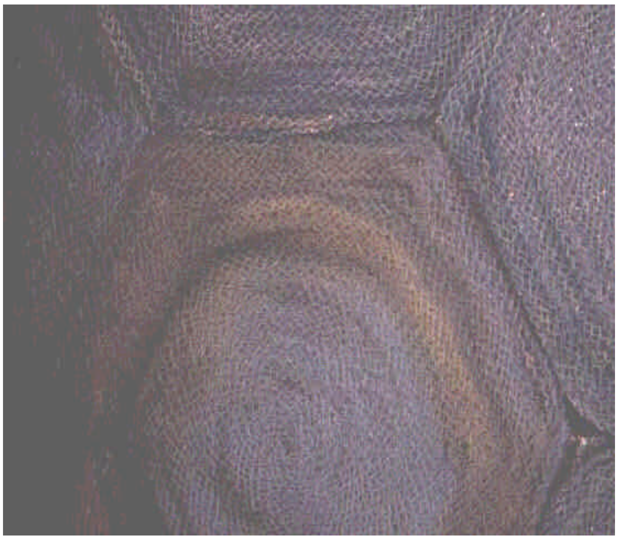


Fig. 2.4.1: Absorber after 100-h test

Another critical design issue, closing of the gaps between the elements by dilatation at design temperature, was to be investigated in the next step. Therefore, 5 thermocouples were mounted on the back of several absorber elements to compare the absorber outlet temperatures with air temperatures in the gap. The picture in Fig. 2.4.2 shows that the temperature of the gap element almost reaches design point, which verifies that the gap does close and that there is almost no loss of efficiency from this effect.

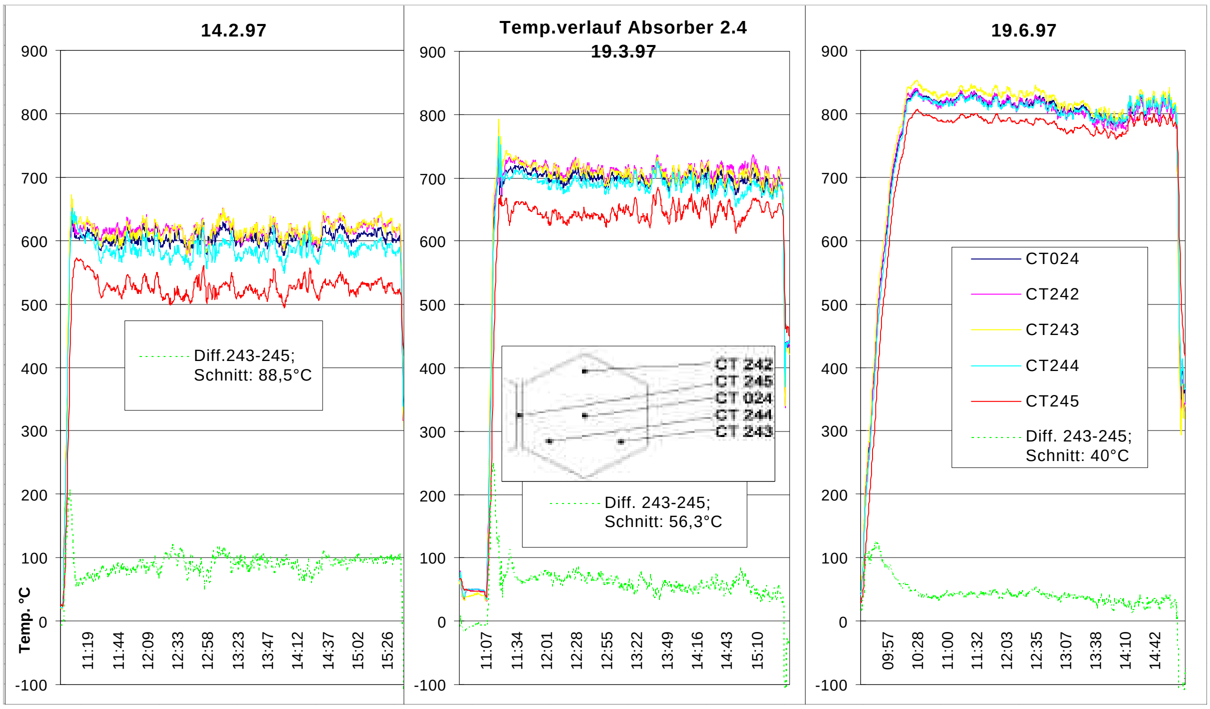


Fig. 2.4.2: TSA: Gap temperature at different temperatures (`600°, 700° and 800°C)

During 1997, the TSA was connected to the existing CESA-1 steam turbine system. Operators were trained in starting up receiver, steam-generator and turbine systems from May to June. The operating personnel requirement has been reduced to 50% due to the advantageous behavior of the automatic aiming-point strategy. Since June, power produced by the TSA has been fed into the Spanish grid, although it should be mentioned that the sizes of the two systems are not very compatible, resulting in a power output of only about 200 kW.

2.4.2 REFOS

The REFOS project includes development and testing of a volumetric receiver for solar-hybrid gas turbine and combined-cycle systems.

The REFOS air-receiver, designed for an operating pressure of 15 bar, is being developed at DLR Stuttgart, Institute for Technical Thermodynamics, and under testing at the PSA. The REFOS receiver is a modular volumetric pressurized receiver for air preheating in combined-cycle power plants (See Fig. 2.4.3), a highly efficient and cost-effective technology. Up to 50% savings in fuel is achievable in a combined cycle by solar preheating the air from 400 to 800°C at 15 bar. Even though this receiver technology is more demanding, the solar air-preheating concept is considered to be the most cost-effective way to generate electricity in a solar thermal plant.

The aim of the REFOS project is to demonstrate the feasibility of the modular concept for a pressurized volumetric receiver with a nominal power rating of 350 kW per module, (See schematic in Figs. 2.4.4 and 5.)

The tests in this research project will be performed over a period of two years at the PSA. In 1997 most of the preparation and erection up to the installation of the first secondary module have been completed. The following steps have been taken:

- preparation of the 60-m level of the CESA-1 plant, gantry and rails for the drive of secondary concentrator and receiver
- the design, construction and erection of a test-bed radiation shield at a 35° angle of the optical axis to the tower
- design and erection of an additional cooling circuit with heat-exchanger between the irradiated parts and existing components
- measurement of solar flux density on each heliostat for comparative calculation of the radiation distribu tion during testing (Fig. 2.4.6)
- mounting of secondary concentrator (Fig. 2.4.7), radiation protection and calorimeter
- preparation and set-up of the optical measurement systems: temperature measurement with infrared camera on top of a mast and solar flux measurements with a new moving target

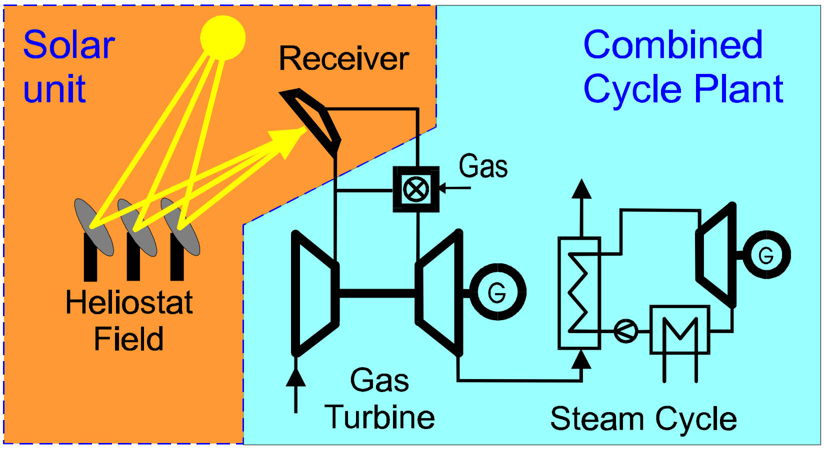


Fig. 2.4.3 Scheme of the solar air preheating concept for a combined cycle plant

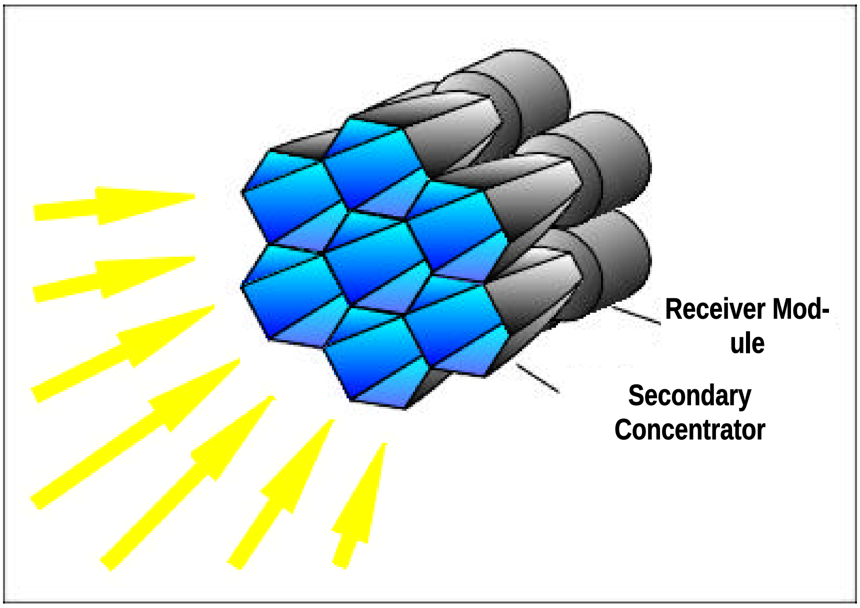


Figure 2.4.4: The modular receiver concept

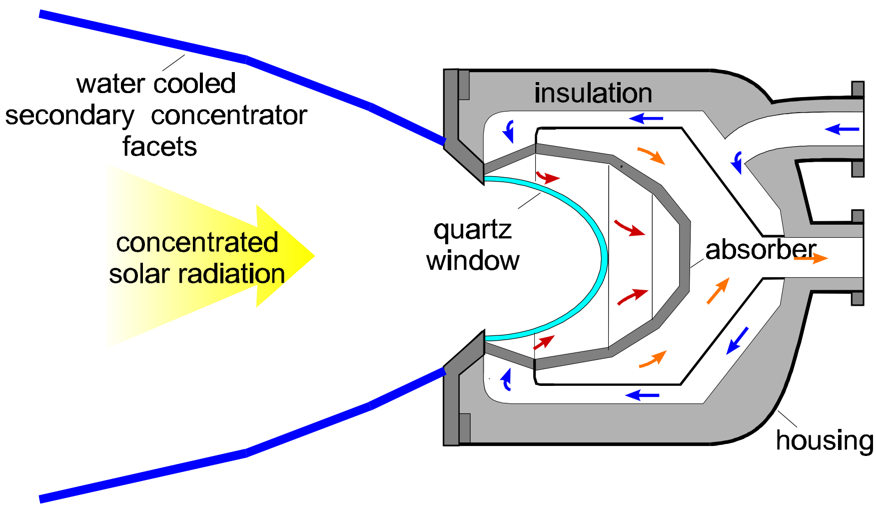


Figure 2.4.5: Section of the secondary/receiver module

In the first tests, scheduled for March, 1998, the measurement devices will be qualified and the outlet power of the secondary concentrator module will be evaluated as a function of irradiation conditions and heliostat operating strategy. The closed volumetric receiver will replace the cold-water calorimeter device in the tests that follow.

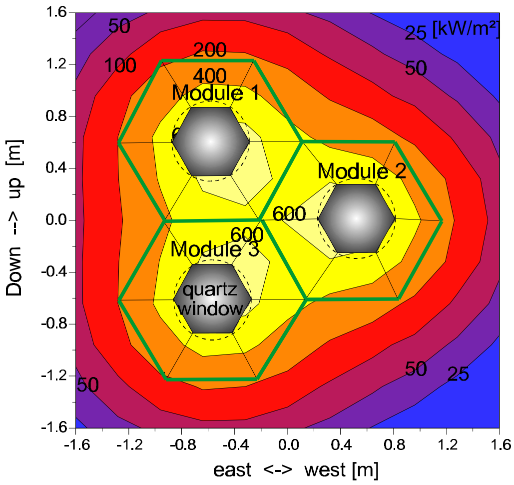


Fig. 2.4.6 Calculated incident radiation on the three hexagonal modules and the test set-up

Fig. 2.4.7 Front view of the secondary concentrator with flux-gage and calorimeter installed

2.4.3 RAS

The RAS (**R**eceptor **A**vanzado de **S**ales) project, completed in 1997, tested the Internal Film Receiver (I.F.R.) concept. Development and optimization of its operational reliability were the most important activities carried out during that time.

The IFR consists of a film of molten salt which flows down the back of a flat stainless steel plate. The black coating on the plate's outer surface absorbs the sunlight while the fluid molten salt works as a panel cooling system. The type of molten salt used as heat transfer fluid was an eutectic mixture of KNO_3 and $NaNO_3$.

Although the potential of the RAS had been pointed out many times before, there were no experimental data available based on this concept before this project. This experiment therefore addressed technical questions and uncertainties associated with the internal film receiver concept.

Fig. 2.4.8 RAS: General view in operation

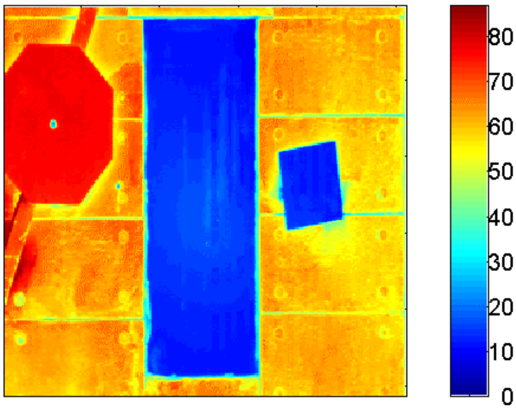


Fig. 2.4.9 Target prepared for measuring RAS panel reflectivity

The summary of the achieved objectives is listed as follows:

- Directly measured efficiencies over 60% (at nominal conditions) that could lead to 80% with reasonable improvements, such as panel coating (See Fig. 2.4.9) and rear insulation.
- Experience acquired in salt-loop management
- Reliability of the plant and its subsystems demonstrated, except automatic mode

- Heat transfer coefficient between salt film and metal panel surface measured
- Nominal power on panel without any damage to the plate: 0.576 MW
- Flow measurement with experimentally obtained curves since the confidence in the flow meter was scant.

2.4.4 VOLUMETRIC RECEIVERS

The second phase of testing of the *Cor-Rec* absorber, a volumetric receiver absorber made of cordierite ceramic, was completed in the volumetric test bed with very good results once the air flow distribution acting on the peripheral modules had been modified. For that purpose, new ducts which achieve a flatter flow distribution able to refrigerate the outer modules better than in the first phase, were opened. Thus the temperatures reached in the air were as high as expected and the distribution reached was more homogeneous. Small failures detected on the surface of some modules have to be investigated.

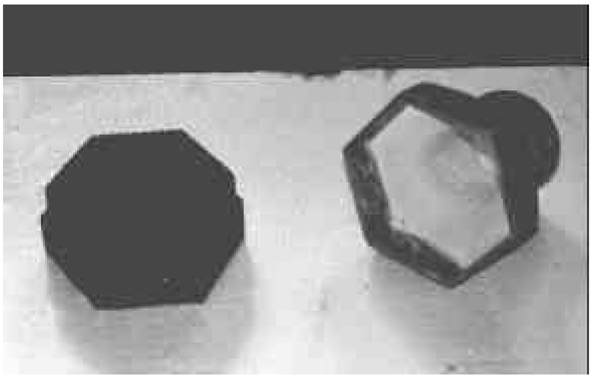


Fig. 2.4.10 Absorber and cup

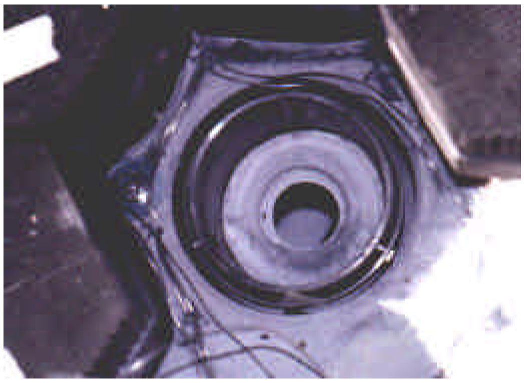


Fig 2.4.11 Membrane support

In the *Cor-Rec* test campaign, the flux measurement system was changed from the radiometer cross, which made an integration along the surface from 13 single values, to the Hermes-II system. Three lambertian plates were mounted on the previously reinforced cross support.

The next volumetric absorber mounted was the *Hit-Rec*. It is made of silicon carbide (SiC) ceramic pieces fitted into SiSiC cups, forming 37 modules which together make a total surface of 0.49 m². The module support structure is a double-walled membrane cooled by the inlet air at ambient temperature. The air leaves the membrane and passes through the modules to the front, which has been slightly preheated, and is sucked into the absorber. This new module mounting concept makes their replacement easier in case of failure.

The first set of tests conducted was very successful, reaching air temperatures over 900°C just behind the absorber.

2.4.5 Heliostat Technology Program

2.4.5.1 ASM150 - GM100 Comparison

An extensive test program carried out in 1997 compared the performance of two large-scale heliostats, the 150-m² stressed-membrane ASM150 heliostat and the 100-m² facetted GM100. The comparison included beam quality, tracking accuracy, flux distribution, power consumption and also cost estimates for a future power plant.

Fig. 2.4.12 shows both heliostats in operation. Evaluation of the beam quality was based on the new simulation code developed by the PSA staff, with which the real sunshape picture, taken by a high resolution (14 bits) CCD device, is projected onto a lambertian target using ray-cone approximation and the intrinsic properties of the heliostat reflective surface. The results are shown in Fig. 2.4.13. The ASM150 beam quality was 1.7 mrad, which is almost as good as in the first measurement campaign (1.5 mrad). The GM100 optical quality was 2.3 mrad. Both heliostats fulfill PHOEBUS requirements for beam qualities of better than 2.6 mrad.

Fig. 2.4.12 GM100 and ASM150 large-area heliostats at the PSA

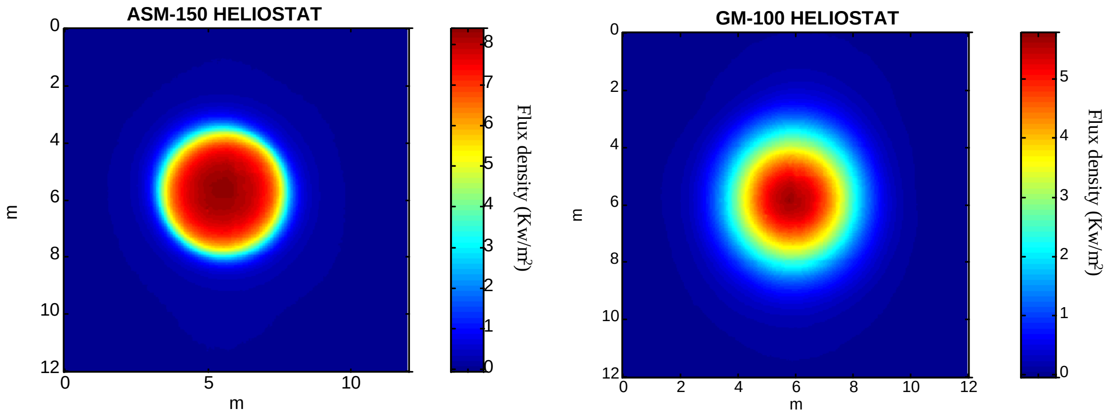
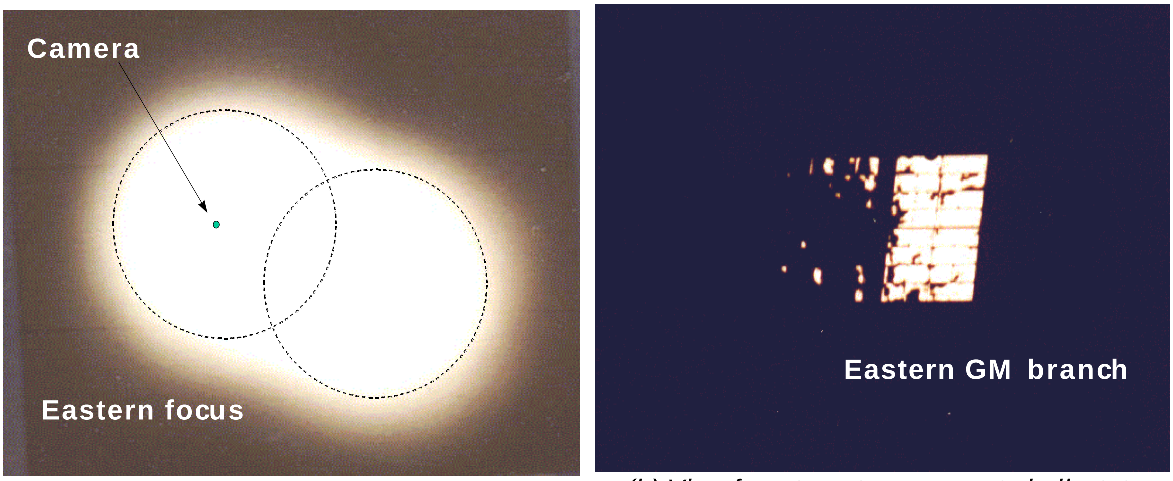


Fig. 2.4.13 Flux density distribution map

Another effect was observed in the GM100 four months after canting its facets. Fig. 2.4.14 shows the double focal spots indicating that the eastern and western branches of the heliostat each had their own focal point. This can be seen directly in the picture from the tower onto the GM100 (Fig. 2.4.14), where one branch is seen dark. The reason seems to be the distortion of the horizontal torque tube due to gravity loads as a function of the angle of elevation.



(a) *GM100 split focus on target,* (b) *View from target camera onto heliostat*

Fig. 2.4.14 GM100 split focus four months after canting

Since the cost of the heliostat field has a strong influence on the total cost of a solar power tower plant, the focus on development will be heliostat cost reduction for the near future. To compare the ASM150 and GM100 heliostat costs, it is essential to look at a realistic number of units manufactured. Therefore the following assumptions were defined for the comparison:

- Price in US$/m² for 1 unit, a 30-MWe and a 100-MWe plant (US$1=1.70 DM=142.8 Ptas)
- Costs for 1 unit at production site
- 30-MWe and 100-MWe plant site: Jordan
- Insolation: 1000 W/m²

- Reflectivity: clean surface

The costs of both heliostats are given in Table 2.4.1. Note that the GM100 manufacturer would increase the surface by 20 m² to 120m² (GM120) with nearly the same support structure.

Tab 2.4.1 ASM-150 and GM-120 Costs

HELIOSTA T	1 UNIT (US$/m²)	30-MWe Plant (US$/m²)	100-MWe Plant (US$/m²)
ASM150	2353	206-235	206-235
GM120	875	273	255

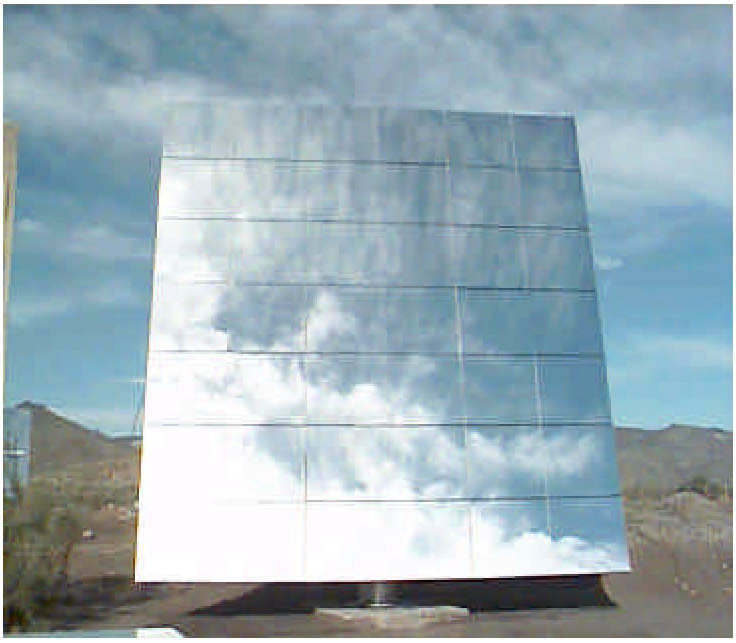
ASM150 costs for a 30-MWe plant are already calculated for a manufacture in series and stay the same up to a plant size of 150 MWe. For higher production, prices would decrease due to further rationalization.

For further details, see PSA internal report, "Large Area Heliostat Comparison at PSA", (R09/98-RM) PSA, November, 1997.

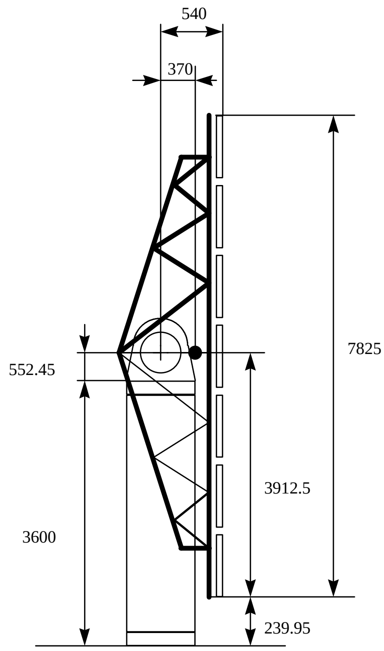
2.4.6 The Colón Solar Heliostat

Based on CIEMAT's long experience, the INABENSA company manufactured a 70-m^2 heliostat prototype for the Colón Solar project in 1997. This heliostat consists of 21 1.1-m-x-3.0-m FLAGSOL facets, with a reflectivity of 94% and an estimated annual average reflectivity of 90%. The overall electrical consumption of the heliostat is about 250 watts per day. Focal length is 380 m and beam optical quality is 2.4 mrad (X axis) by 3.1 mrad (Y axis). The heliostat field planned will consist of 489 of these units (34,200 m^2 total reflective surface).

All the concepts developed for the GM100 heliostat have been incorporated into the new Colón Solar heliostat prototype local controller. The use of speed controllers to run small AC motors makes this device the beginning of a new generation of local heliostat controllers.



Front view



Side view (mm)

Fig.2.4.15 Colon Solar heliostat

2.4.7 Colón Solar

The integration of solar thermal energy in a conventional electricity plant is the main goal to be achieved in the Colón Solar project. A new type of hybrid plant is proposed for this (Fig.2.4.16). The central receiver technology was chosen as the most promising technology for large power plants. In addition, its integration into a combined cycle enables higher thermodynamic efficiencies.

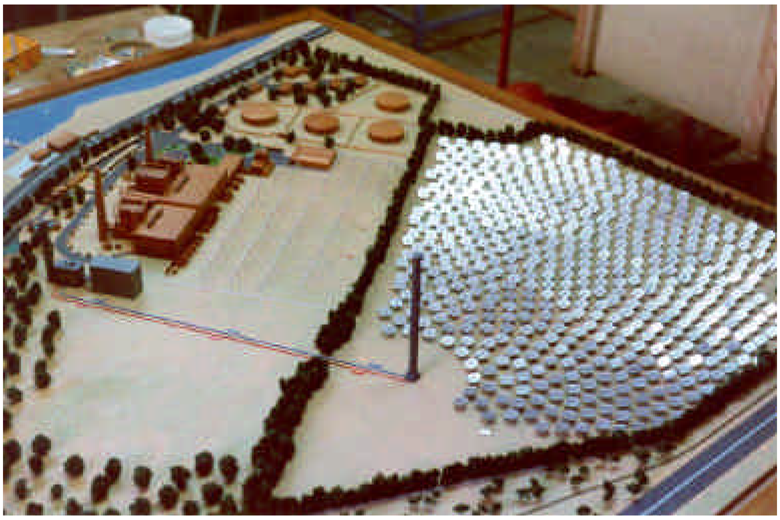


Fig. 2.4.16 Colón Solar Plant

Previous projects, such as Solgas, have shown that a hybrid plant which combines solar thermal energy and natural gas is both feasible and profitable.

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

The following companies are participating in this project:

- Electricity companies (Sevillana de Electricidad, Endesa, Electricidade de Portugal).
- Industries (ABB, Abengoa, Babcock Wilcox Española, PROET).
- Research centres (Ciemat, DLR, AICIA).

The project schedule is:

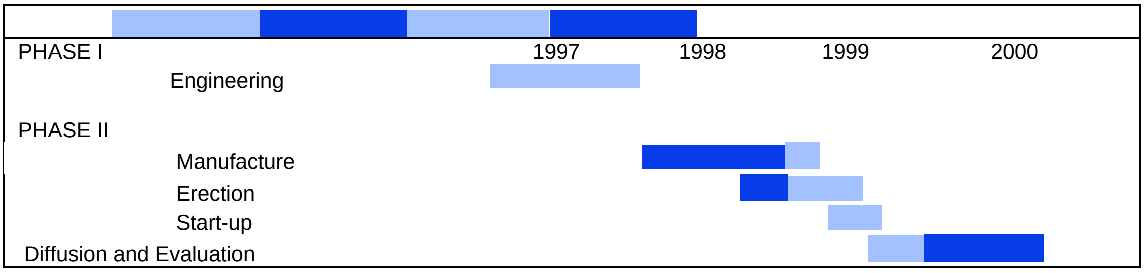


Figure 2.4.17 Colón Solar project phases

By the end of 1997, the major parts of the first phase had been completed and the engineering details had been specified. The prototype of heliostat has been installed at the PSA and a success test campaign has been partially concluded.

Table 2.4.2 Main characteristics of the total power plant

Electrical power			106.1 MWe
Efficiency:	with sun:	(70%)	58.7 %
		(100%)	49.8%
	without sun:	(56%)	51.6 %
		(100%)	44.8%
Original efficiency:			37.7 %
Solar power to fluid:			21.5 MWt
Annual energy transmitted by the solar system to the power system:			43.23 GWh
Heliostat field:			North
Average insolation:			860 W/m^2

The solar plant produces saturated steam to a Brayton-Rankine combined cycle in the conventional plant. The solar system was optimized with the ASPOC, DELSOL and HELIOS codes providing input for the heliostat field, weather conditions, economic estimates and design point.

Features of the solar receiver are:

- Cylindrical cavity, vertical boiler tubes and aperture tilted 30º
- Boiler surface: 140x9 m
- Cavity radius: 4.43 m
- Max. radiation on the receiver panels: 690 KW/m^2
- Aperture dimensions: Vertical: 6.6 m
  Horizontal: 7.1 m
- Efficiency: 92%

- Losses (radiation, convection and conductivity):
- Boiler tubes made of carbon steel SA 210 A1
- Tube design temperature:
- Saturated steam flow up to 50 t/h at 332ºC
- Boiler painted with Pyromark (absorptance 0.965)
- Tower 109 meters high with 5 meter radius

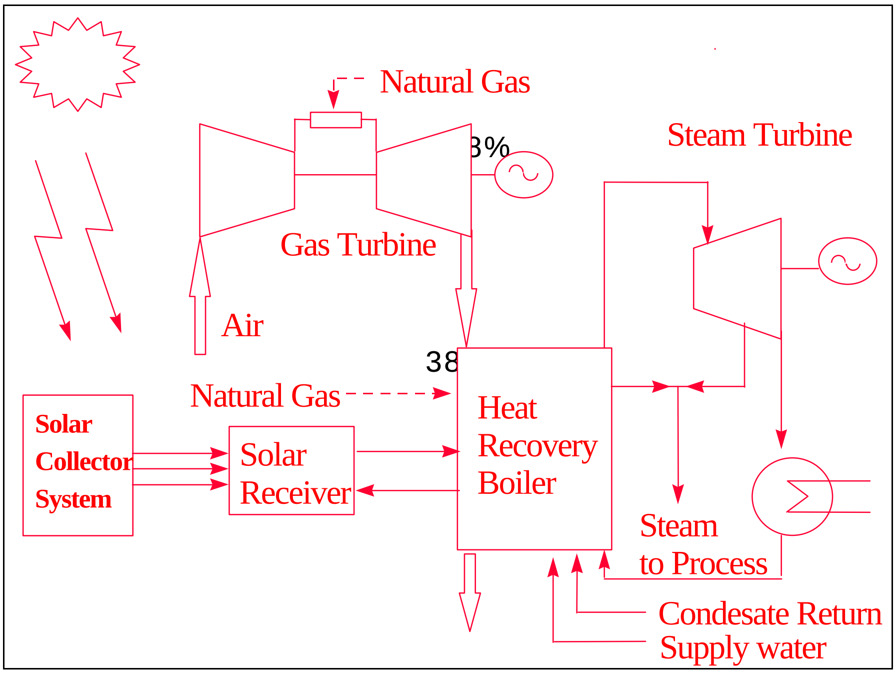


Figure 2.4.18 Block diagram of Colón Solar

The flux distribution expected on the receiver is shown in Fig. 2.4.19.

The main PSA contributions during the first phase of the project have been:

- Project co-ordination and management
- Solar system conceptual design and optimisation
- Functional specifications of components and subsystems
- Detailed engineering
- Prototype heliostat local control
- Testing and evaluation of the Colón Solar heliostat
- O&M cost estimates
- Support in the definition of control and operating strategies.

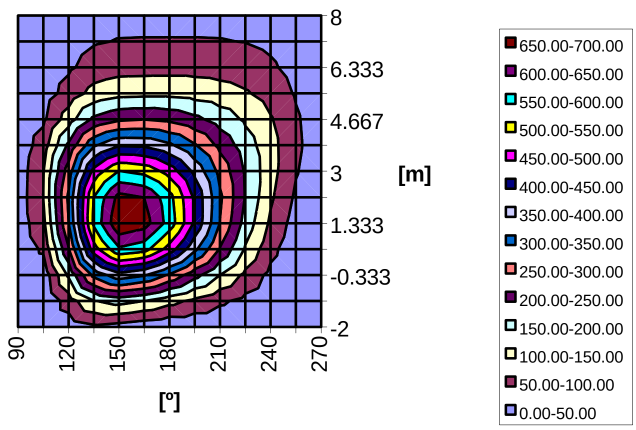


Fig.2.4.19 Flux distribution expected on the receiver (kW/m²)

2.4.8 THESEUS

The objective of the EU THESEUS project is the implementation of the first large-scale European parabolic trough power plant with 50 MWe nominal capacity, on Crete, to be designed, licensed and erected within 4 years from the beginning of 1997. Figure 2.4.20 shows an overview of the project plan. THESEUS attempts to qualify and strengthen European companies specialized in solar field component engineering and manufacturing, to revive and reorganize the industrial supply network by setting up an experienced, strong and dedicated supply consortium which is able to respond to their customers' need for a reliable technology, secure spare-part supply and adequate maintenance. Such a group of European suppliers also aims at creating a supply source for future parabolic-trough solar-thermal power plants in various developing sunbelt countries like India, Jordan and Morocco, as envisaged by the World Bank Solar Initiative. Successful erection of this first European parabolic trough power plant of significant size will place European industry and research organizations in a prime position for such similar sunbelt power plant developments. The collaboration of several utilities assures that the design of this first European solar thermal demonstration plant satisfies utility requirements and will be a showcase for subsequent project plans.

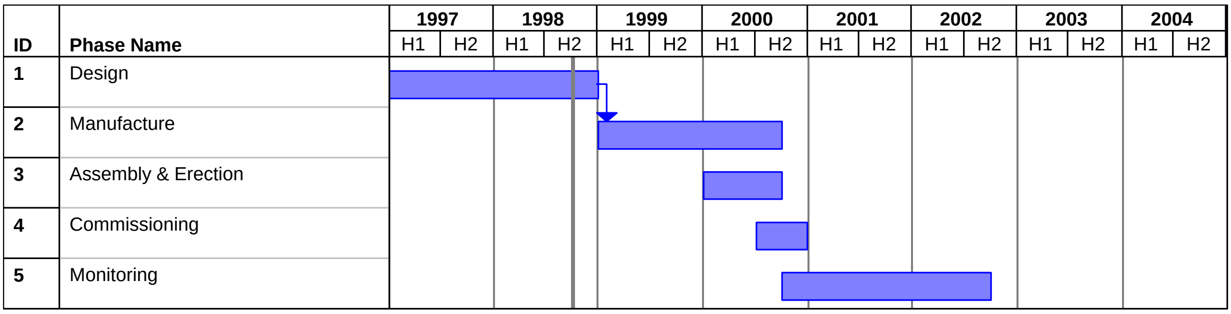


Figure 2.4.20 THESEUS project phases

The project design phase, which initially lasted from 1.1.1997 until 31.3.1998 and was prolonged by the European Commission until 31.12.1998, consists of the following key tasks:

1. Political and Regulatory: licensing, obtaining subsidies, negotiating the power purchase agreement with the Public Power Corporation of Greece (PPC), and evaluating project integration in PPC's plans for expansion.
2. Conceptual Plant Design: power block, solar field and site engineering
3. Project Cost Estimate

4. Project Economic Analysis
5. Definition of Contractual Framework: ownership, supply consortium, O&M, and fuel supply
6. Financing: definition of financing structure, loan and equity negotiations, and grant applications
7. Environmental and Social: environmental permit
8. Dissemination

PSA contributions to the THESEUS project focus mainly on the development of the conceptual plant design, the determination of plant emissions and the financial analysis of power plant implementation as an Independent Power Producer (IPP) project. Fig. 2.4.22 shows the THESEUS project cash flow over a project lifetime of 25 years, based on performance data and Greek economic data given in the EU-proposal.

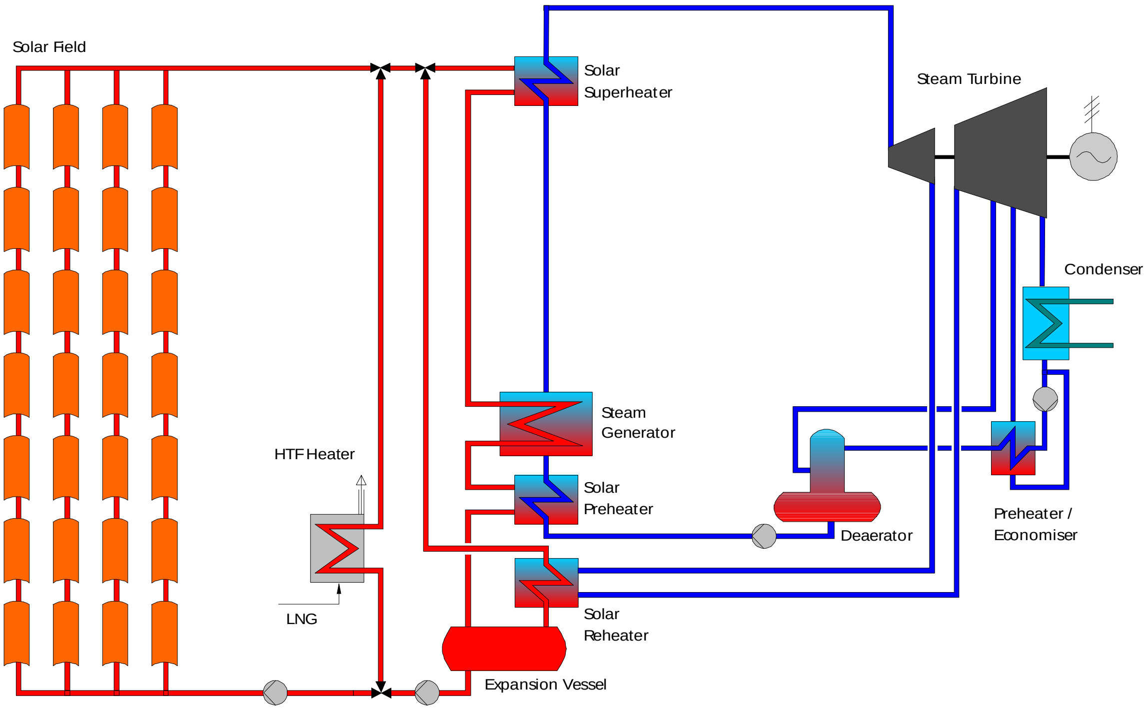


Figure 2.4.21: THESEUS power plant flow scheme

2.4.9 SolWin

With the intention of facilitating and promoting the market introduction of solar thermal electricity generating technologies, a software tool named SolWin is being developed jointly by DLR at Plataforma Solar de Almería and SunLab, USA. It addresses users with varying knowledge on renewable power generation, in particular those that are not familiar with solar thermal technologies, such as bankers and financiers, governments, IPPs and utilities. It therefore introduces the user to the technology and provides information on the various technical aspects, offering a reference database of today's renewable and conventional electricity generation technologies. The first version concentrates on solar thermal technologies and fossil "shadow" concepts that are used to compare the performance, the emissions and the financing of solar thermal power projects.

It is supposed to help analyse and evaluate hybrid solar-fossil electricity generation concepts, the solar potential of selected sites, the resource consumption of solar thermal power systems, find least-cost solar power solutions and develop financing schemes for solar thermal power plants. SolWin also contains several editable databases to provide the user with information on different solar thermal technologies, fuels, meteorological data, cost and financing data.

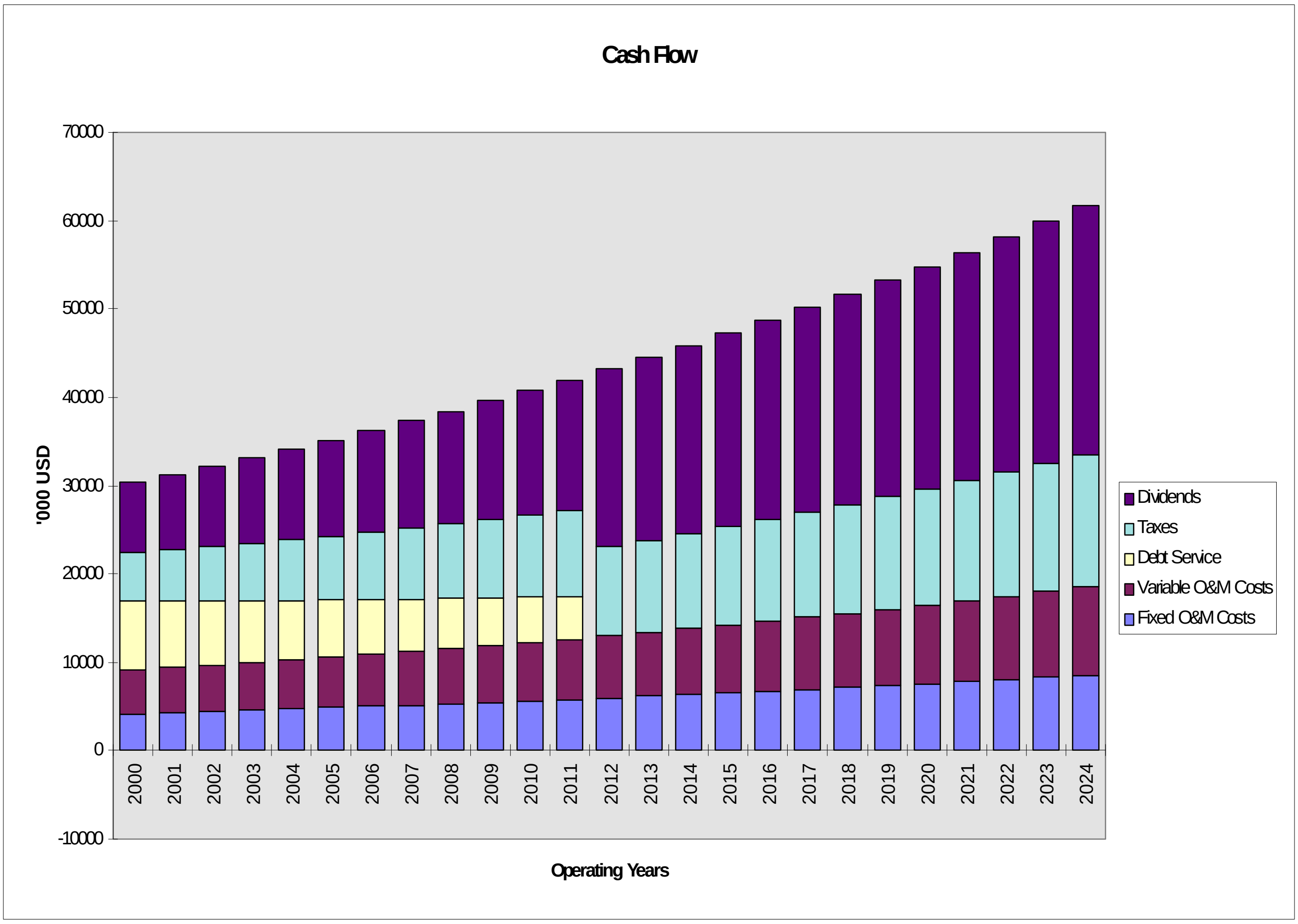


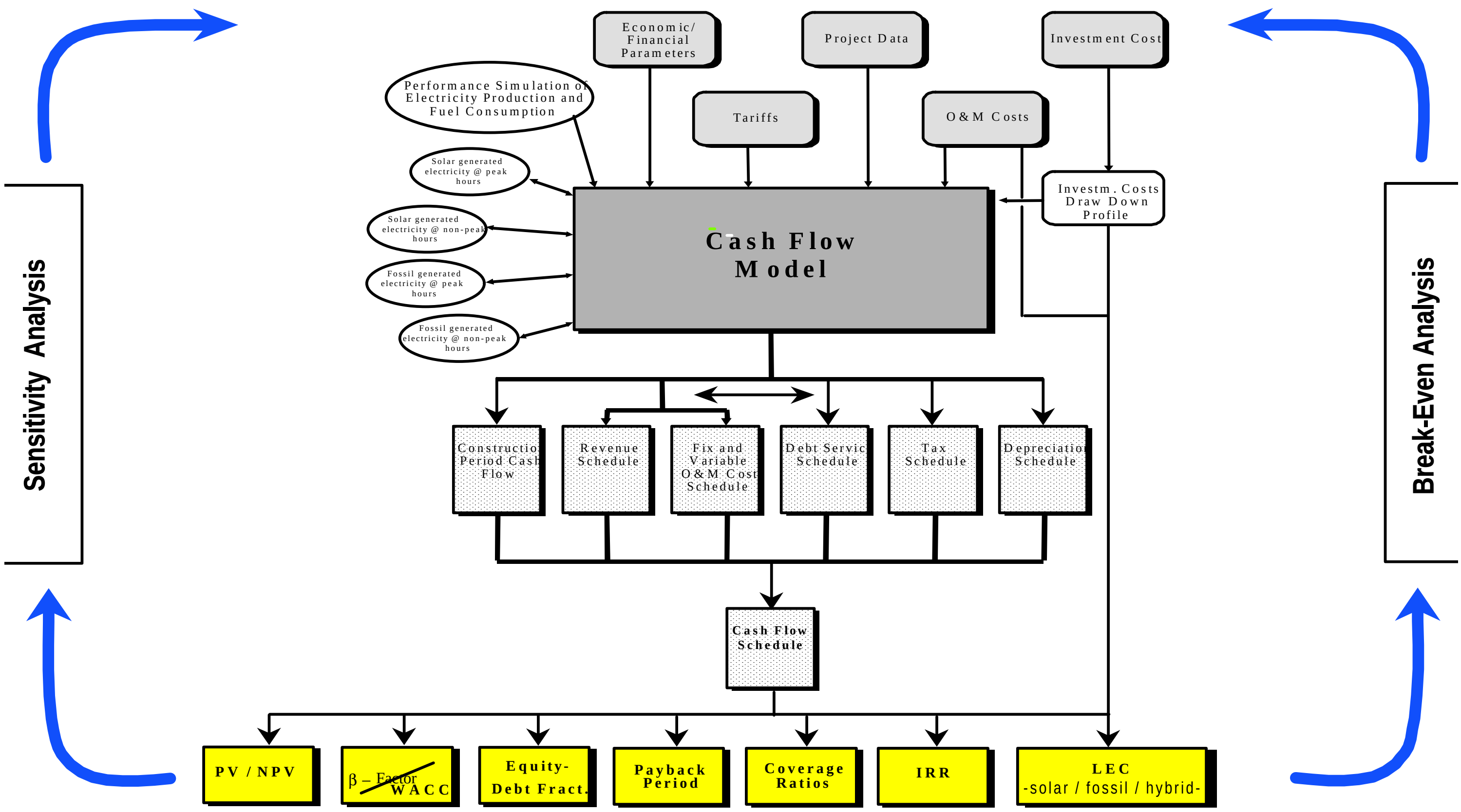
Fig. 2.4.22 Cash flow simulation results for the THESEUS project

By the end of 1997, the major parts of the first phase had been completed and the engineering details had been specified. The prototype of heliostat has been installed at the PSA (Plataforma Solar de Almería, Spain) and a success test campaign has been partially concluded.

The solar plant produces saturated steam to a Brayton-Rankine combined cycle in the conventional plant. The solar system was optimized with the ASPOC, DELSOL and HELIOS codes providing input for the heliostat field, weather conditions, economic estimates and design point.

The core of SolWin is a detailed cash-flow model, so that all important project parameters, such as the Internal Rate of Return (IRR), the levelized electricity costs (LEC) and the financial viability of solar thermal power projects may be examined. Further intermediate results are technical performance data, environmental benefits and resource consumption of the power project. Furthermore, it also allows the accomplishment of sensitivity analysis and the optimisation of technical and economic parameters. Fig. 2.4.23 shows the SolWin structure.

Another important aspect, and one of the main objectives of SolWin, is the creation of a standardized tool that will be used widely by engineers and scientists who are involved in solar thermal power project development. The first step in that direction has already been taken with the involvement of DLR and SunLab, two important research centers in the field of solar thermal technologies, and the inclusion of well-documented calculating procedures. An additional advantage of SolWin is its modularity, which makes it an easily expandable tool.



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2.5 Solar Chemistry

Julián Blanco

Sixto Malato

Christoph Richter

Barbara Milow

Pilar Fernandez

Recent decades have witnessed increased contamination of the Earth's drinking water reserves. To solve this problem, apart from reducing emissions, two main water treatment strategies are being followed: (i) chemical treatment of drinking water, contaminated surface and groundwater and (ii) chemical treatment of waste waters containing biocides or non-biodegradable compounds.

The decontamination of drinking water is done mainly by procedures that combine flocculation, filtration, sterilization and conservation, to which a limited number of chemicals are added. The chemical treatment of polluted surface and groundwater or wastewater, is part of a long-term strategy to improve the quality of water by eliminating toxic compounds of human origin before returning the water to its natural cycles. This type of treatment is suitable when a biological processing plant cannot be adapted to certain types of pollutants that did not exist when it was designed.

The latest advances in water purification have been in the oxidation of very persistent organic compounds dissolved in water. The methods based on catalysis and photochemistry have been denominated Advanced Oxidation Processes. Among them, those which produce hydroxyl radicals (•OH) have had growing success. Due to the strong oxidative nature of this compound, much greater than other traditional oxidants, it is able to completely transform organic carbon to CO_2. Methods based on H_2O_2/UV, O_3/UV and H_2O_2/O_3/UV combinations utilize photolysis of H_2O_2 and ozone to produce the hydroxyl radicals. But these radicals can also be generated with a semiconductor (photocatalysis) which absorbs UV radiation when this is in contact with the water. The latter process is of special interest, since it can use natural (solar) UV, if the semiconductor used has an appropriate energetic separation between its valence and conduction bands which can be surpassed by the energy content of a solar photon ($\lambda \geq 300$ nm). Titanium dioxide particles (TiO_2) have been demonstrated to be an excellent catalyst for this application.

2.5.1 Collaboration within the European Commission's TMR Program (Solar Detoxification)

As the PSA is a unique European center for experimentation in the field of applied solar energy, it has been selected by the European Commission as a Large-Scale Scientific Installation since 1990, providing European research groups with access to the PSA by financing their travel expenses, to promote the use of solar technologies. One of these technologies is Solar Detoxification and, from April to November, five Chemical Research Groups have used the PSA Detox Installations to carry out different research programs on this subject:

University of Poitiers (France)

Photoelectrochemical reactors for Medium Concentrating Solar Collectors. Two kinds of photoelectrochemical reactors have been built using long sheets of TiO_2/Ti as the working electrodes and Pt/SnO_2 conductive glass as the counter electrodes (Fig. 2.5.1). Several long-term experiments have been conducted in the Helioman modules (Fig. 2.5.2) to measure photocurrent values and degradation of a model compound (4-chlorophenol). The long-term efficiency of TiO_2 layers deposited on Ti is good and opens the possibility of using metal substrates with a large surface area.

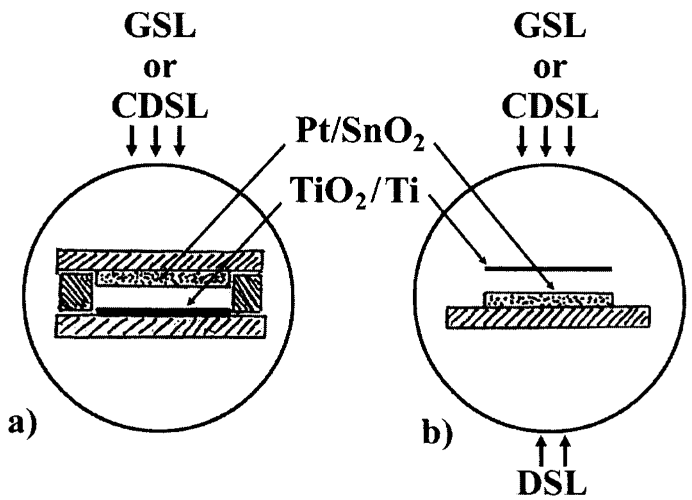


Fig. 2.5.1. Schematic cross sections of a) reactor with nanocrystalline ceramic 6mm thick; b) reactor with thin TiO_2 layer.

Institut für Solarenergieforschung GmbH Hannover (ISFH, Germany):

Comparison of Degradation of atrazine and 4-chloropheno in CPC and a Double-Skin Sheet Reactor (DSSR) using two TiO_2 photocatalysts (P-25 and Hombikat). The CPC was more efficient than the DSSR for 4-chlorophenol degradation with both photocatalysts. Atrazine is more efficiently degraded in the CPCs and better with Hombikat than P-25.

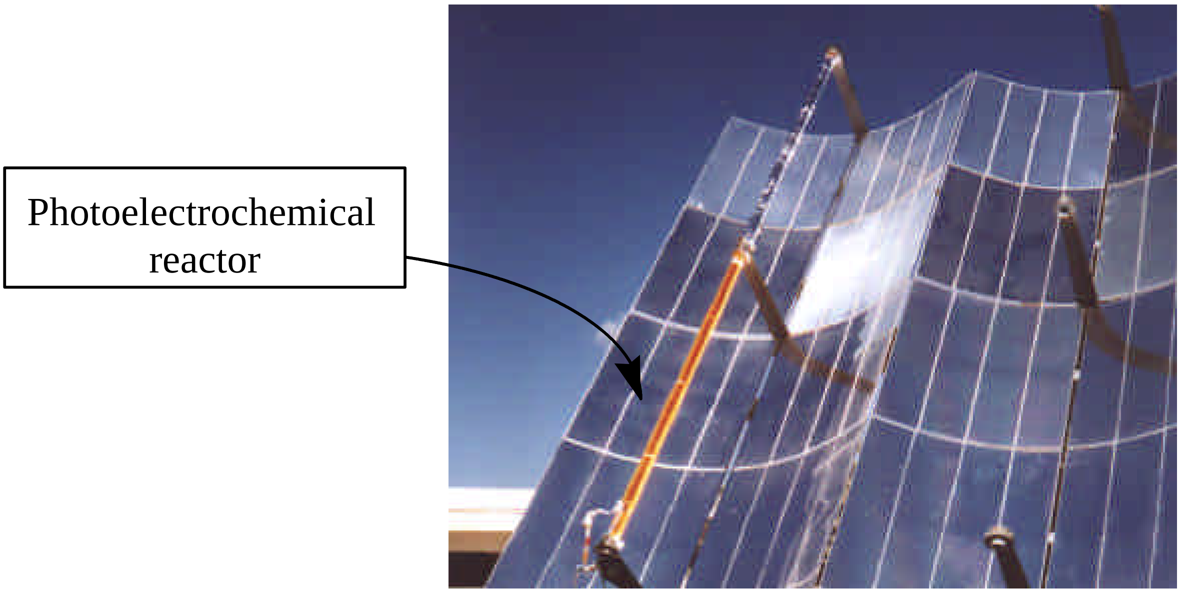


Figure 2.5.2 Helioman module in operation with a photoelectrochemical reactor mounted inside a Pyrex glass tube.

Institut für Physikalische Chemie. Technische Universität Wien. (TUW, Austria):

Degradation of pesticides and olive mill wastewater (OMW) by Photo-Fenton reagent (Fe^{2+}/H_2O_2). Total degradation (as TOC) of pesticides and mill waste water with Photo-Fenton catalyst is possible in PSA reactors. 500 mg TOC/L of pesticides are 80% destroyed in 3 hours using PSA-CPCs field (Fig. 2.5.3). Similar results were obtained with OMW.

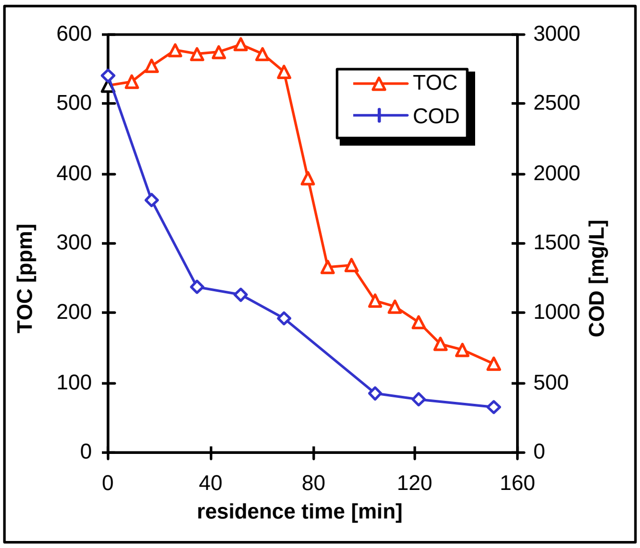


Figure 2.5.3. Degradation of a mixture of 10 commercial pesticides in the CPC. c($FeSO_4$)=2 mM, pH_0=2.1 (TOC: Total Oxygen Carbon; COD: Chemical Oxygen Demand).

University of Barcelona (Spain):

Photocatalytic degradation of 2,4-dichlorophenol using CPCs and a flat reactor. From the data obtained with this model compound, a new model has been proposed to relate the amount of radiation entering the CPCs and the radiation measured by PSA UV sensors. The flat reactor, which is a very cheap simple system) is only 50% less effective than the CPCs.

Ecole Centrale de Lyon. Photocatalyse, Catalyse et Environement (CNRS, France):

Comparison of 4 TiO_2-photocatalysts from different European manufacturers: Rhône-Poulenc, Degussa P-25, Tioxide, Hombikat. The CPC field was used to perform these experiments. The degradation of 4-Chlorophenol and Malic Acid was used to compare catalysts efficiencies. The results are:

(i): RP>P25>Hombikat≈Tioxide with 4-Chlorophenol;
(ii) P25>RP>Hombikat≈Tioxide with Malic Acid.

2.5.2 Pesticide Detoxification Project in El Ejido (Almería)

The Spanish province of Almería has undergone considerable economic growth during the last 20 years due to the installation of large numbers of greenhouses, which benefit from the extremely sunny climate. Unfortunately, this development is accompanied by an intensive use of a wide variety of pesticides with the subsequent problem created by the empty plastic bottles. According to 1996 data, 5.2 x 10^6 kg of phytosanitary products were consumed in the region, producing around 1.5 million empty bottles per year. Until now these containers have usually been burnt or buried. As the problem has been growing in recent years, a parallel rising environmental consciousness in the region is concerned about the recycling of these pesticide bottles. The recycling process includes washing of the shredded plastic containers, which leaves relatively small amounts (hundreds of cubic meters per year) of waste water. Suitable treatment is therefore required to prevent the pollution of surface waters, soil and ground waters on disposal of these contaminated waters. This study has been designed to provide a practical assessment of the potential of Solar Advanced Oxidation Processes (SAOPs) for the deg-

Commercial Product	Active Ingredient	Other Ingredients	Manufacturer
Rufast	acrinathrin 15%	organics(1)	Rhône-Poulenc
Vertimec	abamectin 1.8 %	organics(1)	Merck
Match	lufenuron 5%	cyclohexanone 21% arom. hydroc. 62%	Ciba-Geigy
Tamaron 50	methamidofos 50%	organics(1)	Bayer
Confidor	imidacloprid 20%	organics(1)	Bayer
Vydate	oxamyl 24%	organics(1)	Du Pont
Thiodan	endosulfan α-β 35%	organics(1)	AgrEvo
Dicarzol	formetanate 50%	inert(2)	AgrEvo
Scala	pyrimethanil 40%	inert(2)	AgrEvo
Previcur	propamocarb 72.2%	inert(2)	AgrEvo

(1) Detected by TOC analysis (difference between active ingredient TOC and simulated rinsates TOC). Type and concentration not available from manufacturer.

(2) Inorganic and/or water.

Table 2.5.1 Information on Commercial Pesticides Used in Photocatalytic Experiments.

radation of this kind of agricultural rinsates. In order to simplify the study, we have assumed: a) The concentration of organics remaining in the water after the washing process is determined by on-line TOC analysis. b) The design concentration of organics in the water before photocatalytic treatment has been set at TOC = 100 mg/L. The water will be reused until this level is reached.

The formulations selected (Table 2.5.1) are sufficiently representative of all those used in Almería greenhouses.

With these considerations, solar degradation experiments were performed, the results of which are presented in Fig. 2.5.4. At first sight, it is evident that the addition of the extra oxidant is substantially beneficial. An induction period of 0.1 moles of photons per liter is obtained with peroxydisulphate and around 0.2 moles of photons per liter without it, after which the total organic carbon is transformed into CO_2. This induction period is due to photodegradation of the original molecule into other organic intermediates preceding final mineralization. After this, the TOC curve slopes sharply towards 0 in the presence of 10 mM peroxydisulphate, suggesting that the additive strongly accelerates degradation of intermediates, leading to a very important reduction (at least 5 times) of the moles of photons necessary for total mineralization. 60 mg $S_2O_8Na_2$ per mg of TOC is required. This reduction would also decrease the solar collector surface necessary to degrade the organics in the process water by the same factor. The size of the photoreactor is the most important barrier to SAOP commercialization.

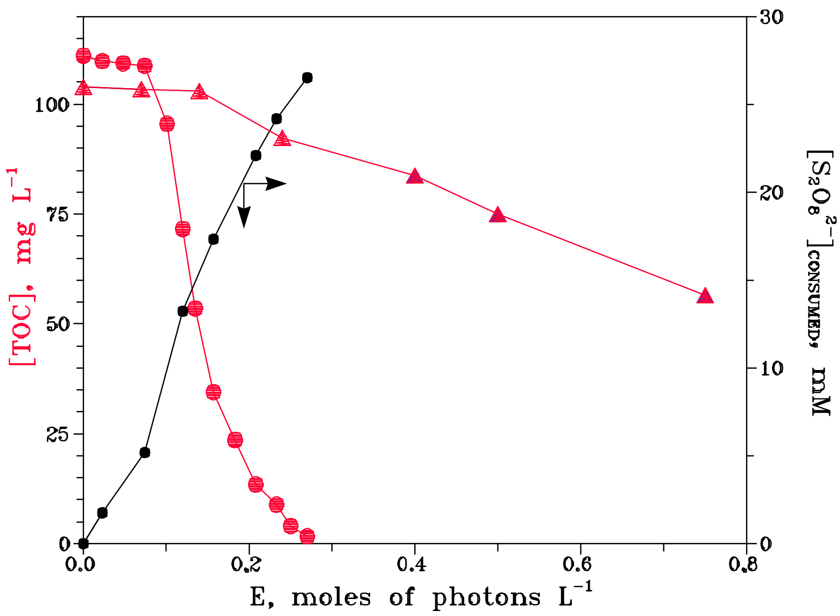


Figure 2.5.4. Degradation of mixtures of 10 commercial pesticides), 10% TOC each, with and without peroxydisulphate: (●) TOC mineralization and (●) $S_2O_8^2$ consumed with an unchanging concentration of $S_2O_8^{2-}$ (10 mM); (Δ) TOC without $S_2O_8^{2-}$.

Treatment costs are not examined here because much more experimentation is needed to optimize the pesticide wastewater treatment, but these results have clearly demonstrated that one attractive way to markedly enhance the TiO_2 photocatalytic degradation of organic pollutants in water streams is to add an efficient ($S_2O_8^{2-}$) electron acceptor to the system. When the major concern is to mineralize the organic pollutants, the use of an additional oxidant is perfectly justified.

2.5.3 Water Recovery from Olive Mill Wastewaters after Photocatalytic Detoxification and Disinfection (LAGAR)

The objective of this new CEC project (approved in 1997 to commence in 1998) is the development of the best (e.i. cheapest) possibility of utilizing solar photochemical wastewater treatment for the mineralization of recalcitrant phenolic contaminants typically found in the soluble organic fraction of olive mill wastewater (OMW) on a pilot-plant scale. So in this project, the detoxification efficiency of four different photochemical reactors, using solar irradiation captured by simple, inexpensive and efficient non-concentrating solar collector technology, will be compared technically and economically for the treatment of olive mill wastewater (OMW) by oxidative photocatalysis, and those selected will be installed in a small pilot plant under real working conditions in two factories, one in Portugal and another in Greece.

Table 2.5.2 Summary presentation of LAGAR Tasks

Tasks	Targets	Resources (man/months)
Task 1. Project management	To insure coordination, homogeneity of method, information flow, financial control, EC relations	6.5
Task 2. Chemical characterisation of OMW	Checking the composition of waste water and definition of standard analysis protocols for important parameters	3
Task 3. Photocatalytic treatment stage	Laboratory selection of the best photocatalytic process	16
Task 4. Design and construction of new reactors	Construct 3 reactors for the study of OMW mineralization.	11.5
Task 5. Test of reactors	Test performance of 4 reactors with model compounds and real effluents.	38.5
Task 6. Biotoxicity assessment of different treatment stages	Develop biotoxicity tests to evaluate the effectiveness of the photocatalytic processes.	7
Task 7. Installation of the reactor in a factory in PT and GR	Identify and solve specific problems derived from the integration of the reactors into a real production line.	5.5
Task 8. Tests in the olive mills	Demonstrate the feasibility of a photocatalytic detoxification system integrated in factory.	21
Task 9. Process assessment and dissemination of results	Economic and technical assessment of the treatment systems. Dissemination of the results.	8.5

At the end of the project, the system economics will be assessed. The discussion will consider the ratio between the process cost and detoxification achieved, with regard to the final consumer of the treated wastewaters. The project will last 2.5 years.

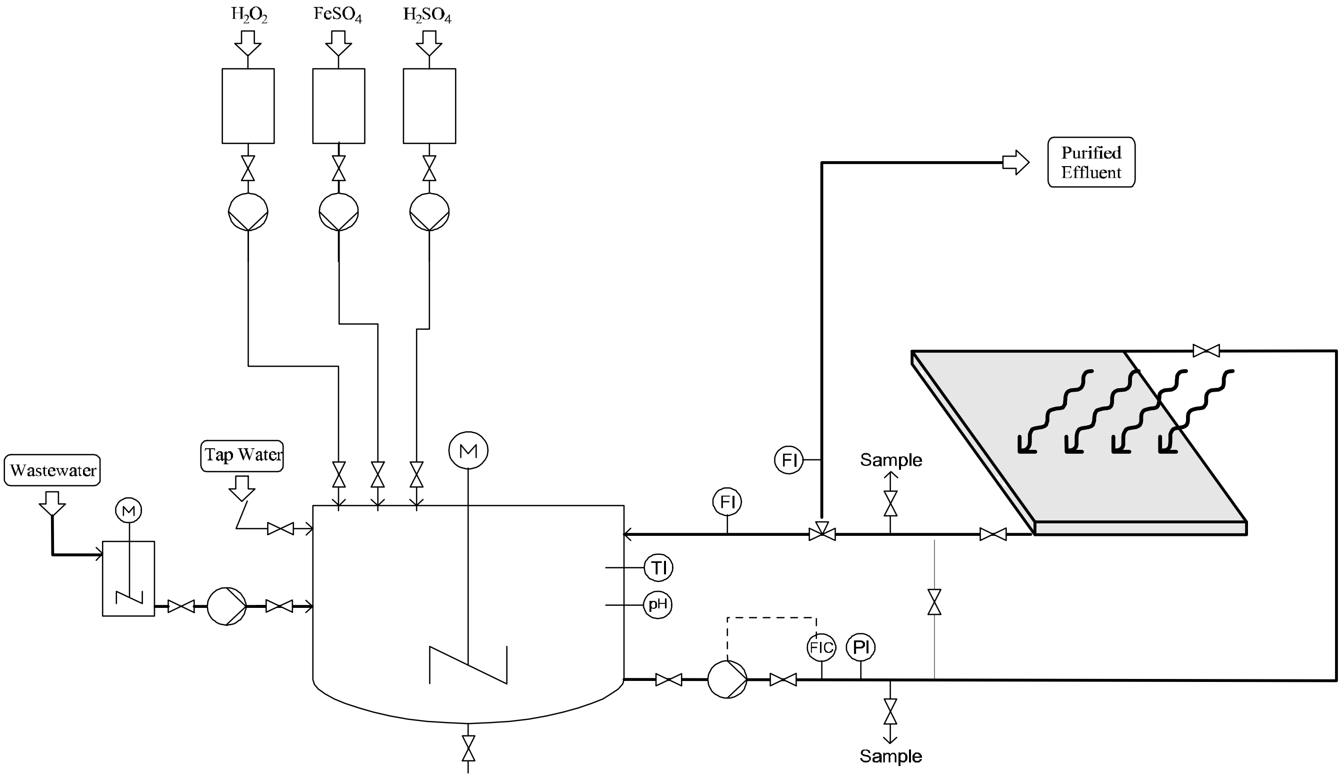


Fig. 2.5.5 Reactor to be constructed at PSA and to be tested during LAGAR Project.

2.5.4 Solar Detoxification Technology for Treatment of Industrial Chlorinated Water Contaminants (SOLARDETOX)

The project is funded under the European Union Brite-EuRam III Program Topic "Detoxification of water and Effluents" and started in June, 1997. The project is coordinated by CIEMAT-PSA. Four industrial partners (HIDROCEN, SETSOL, SCHOTT, ECOSYSTEM), three research partners (CISE, DLR, CIEMAT) and one educational partner (University of TORINO) are working together to develop a solar photocatalytic technology for the detoxification of real waste industrial waters up to a commercial level.

This solar technology is based on the well-known photocatalytic process effected by the ultraviolet irradiation of TiO_2. non-biodegradable C_1 and C_2 chlorinated hydrocarbon solvents (NBCS) are the center of interest. In various chemical processes NBCS play a major role and with state-of-the-art technology cannot be substituted by less toxic solvents. During the first period of the project, the photocatalytic degradation of NBCS is tested at laboratory scale and analytical methods and first kinetic models are developed. During these tests the efficiency of the newly developed TiO_2 catalyst is evaluated. At the same time, the reactor design is revised, especially such reactor construction materials as highly UV-transmissive glass (Fig. 2.5.6) and UV-reflective mirrors are improved.

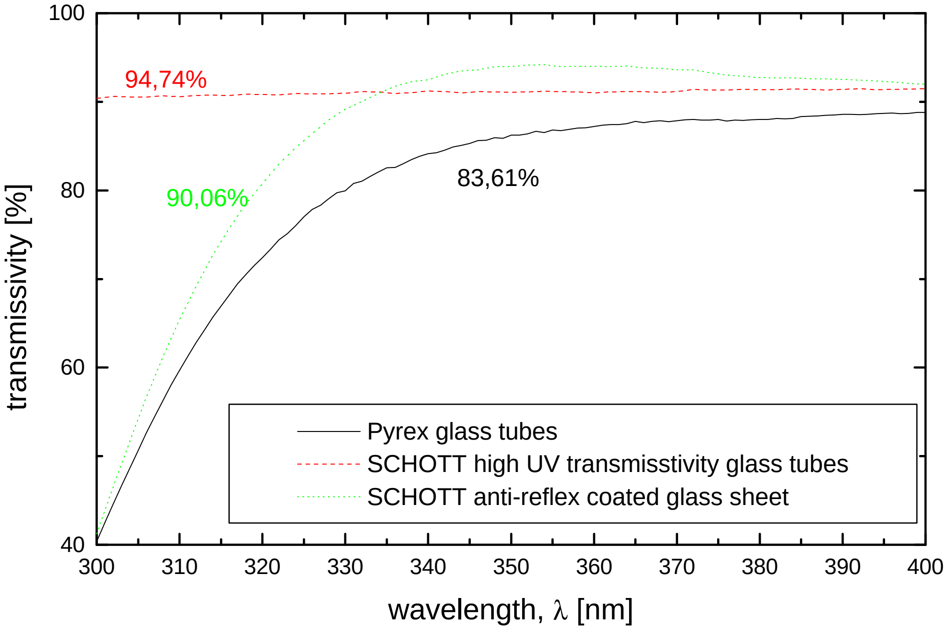


Fig. 2.5.6 Transmissivity of different kinds of glass in the UV spectral range.

After the first part of the project, the prototype reactors will be erected at the PSA and at the DLR in Cologne. When results of the outdoor prototype experiments under real solar conditions have been evaluated, the best working system can be scaled up to a small pilot plant on a firm footing. This completes degradation tests within the project. It is to be hoped that after three years of development, this project will lead to a commercial application for solar photocatalytic treatment of industrial waste waters.

2.5.5 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 light sources. In some cases solar light 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 Solfin Project, 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. In this way, a great variety of synthetic reactions are tested and promising candidates for further optimization can be identified. At the same time young graduate research chemists learn about the basic feasibility of directly applying solar radiation for photochemical synthesis.

Another small test loop was added to the Solfin facility during 1997 to allow preliminary testing with low total volumes of reaction mixtures. The photoreactor is a CPC mirror 1 m long and 0.2 m wide with an optical concentration of 2 (See Fig. 2.5.7). A 32 mm-OD Liebig-type glass cooler is mounted in its line of focus. The reaction mixture is irradiated by a small magnetically coupled centrifugal pump which circulates it through the outer compartment of the cooler while the cooling water is circulated through the inner compartment.

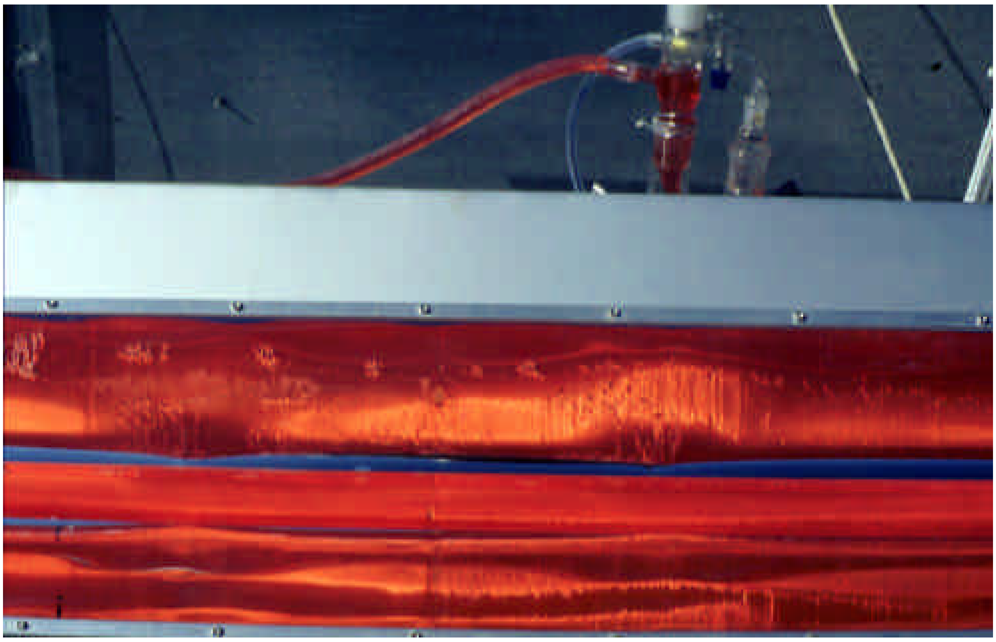


Fig. 2.5.7 View of the small-scale CPC concentrating photoreactor

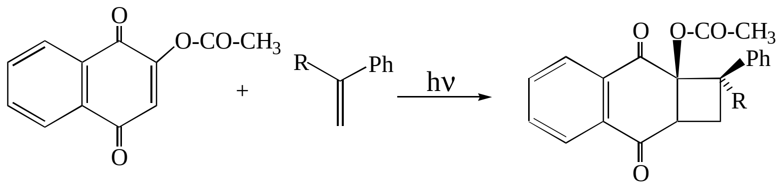
Five European photochemical research groups from France, England, Italy, Spain and Ireland received funding from the CEC-TMR Programme to perform the tests summarized briefly in the following.

CNRS- ICSN, Gif-sur-Yvette (France)

The main objective of the tests performed was the selective oxidation of hydrocarbons using decatungstate-anion ($W_{10}O_{32}^{4-}$) as the photochemical catalyst. After tests with adamantan, cyclohexane was chosen as an interesting target for this type of oxidation, as its products are important precursors in the industrial synthesis of Nylon. The tests showed best results at the highest cyclohexane concentrations (10% in Acetonitrile as solvent).

Dep. of Chemistry, The University of Reading (England)

The photoaddition of ethenes to 1,4-quinones was chosen to yield a product with appreciable potential for ready conventional elaboration and exploitation towards high value chemicals. More specifically 2-acetoxynaphtho-1,4-quinone- arylethene systems to yield 4 were studied to assess the potential of this reaction for initiation by sunlight, and allow studies to progress towards the targeted skeleta of two series of biologically active molecules and the compounds for molecular electronic devices responsive to different stimuli. The tests were extremely successful, yielding a total of 90 grams of more highly pure 4 than in laboratory tests.



4, R = H, **5**, R = Ph

Fig. 2.5.8 Photoaddition of the 2-acetoxynaphtho-1,4-quinone - arylethene

Dip.Chimica Organica, Universita di Pavia (Italy)

Radicalic alkylations of electrophilic multiple bonds were investigated with two different systems, by chemical sensitization using benzophenone as the sensitizer and by semiconductor photocatalysis, using TiO_2. Fig. 2.5.9 shows the results of a test with alkylation of maleic acid by isopropanol to form terebic acid, an additive for polymers.

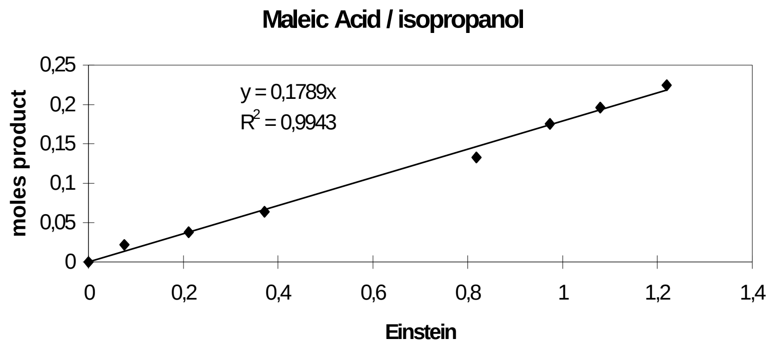


Fig. 2.5.9 Solar photochemical synthesis of Terebic acid

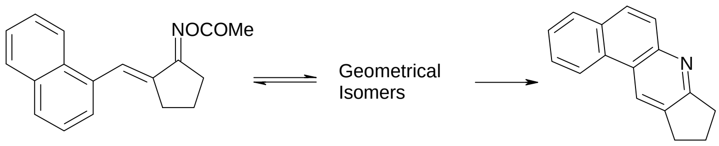
Depto. Química Orgánica I, Universidad Complutense de Madrid (Spain)

Pyrethrin insecticides are important in agriculture because they relatively innocuous to mammals and are biodegradable. The aza-di-π-methane rearrangement of suitably substituted β-γ-unsaturated oximes was studied to provide the precursors of the cyclopropyl carboxylic acid moiety with the main structural feature responsible for the biological activity of pyrethrin insecticides.

Conversion to the desired products was good with the different oxime ethers tested as starting materials after about 1-2 hours of irradiation.

School of Chemical Sciences, Dublin City University (Ireland)

The allyl oxime ether of 2-benzylidenecyclopentanone undergoes smooth cyclisation on photolysis in methanol, via a photoequilibrium involving all four of its geometrical isomers, to give cyclopenta [b] quinoline.The process provides a convenient synthetic route to annulled quinolines and related materials from inexpensive readily-available starting materials. The examples of this reaction type proceeded well during solar irradiation, though somewhat slower than using laboratory UV-lamps. Fig. 2.5.10 shows as an example the reaction formation of 2-(1-naphthylidene) cyclopentanone oxime acetate. The corresponding product was obtained in a high purity without the necessity for further chromatographic purification.



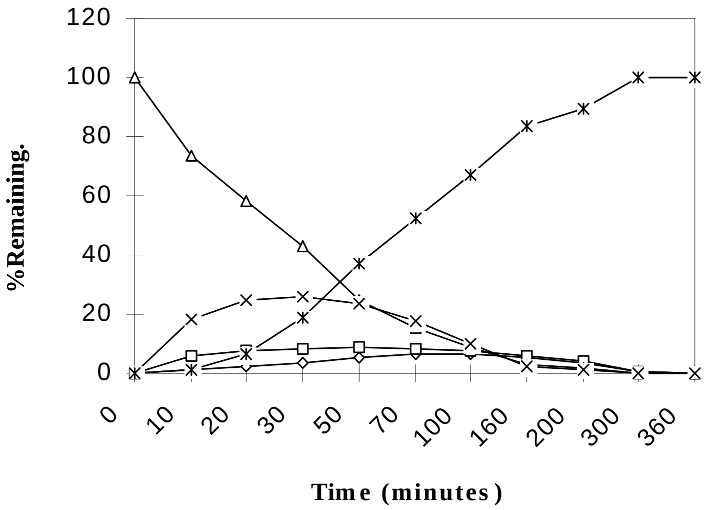


Fig. 2.5.10 Reaction of 2-(1-Naphthylidene) cyclopentanone oxime acetate

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2.6 *Materials treatment*

Under the EU-DGXII "Training and Mobility of Researchers-Access to Large Scale Facilities" program, four European research groups have performed different types of tests in the PSA High Flux Concentration Facility Solar Furnace (HCF).

The Finnish Helsinki University of Technology and the Portuguese Instituto Superior Tecnico have tested several different ceramics and metals, while the Spanish Universidad de Sevilla tested four control algorithms and the Portuguese Instituto Nacional de Engenharia e Tecnologia Industrial verified the performance of a secondary concentrator (SSC).

Diego Martínez
Area Head

Solar Furance

2.6.1 High Flux Concentration Facility (Solar Furnace)

Completed in 1991, the Solar Furnace was planned to be the necessary tool for penetration into the field of very high temperatures, thus allowing the PSA to cover all the ranges of concentrated solar energy temperature and flux densities.

Since its inauguration, the PSA Solar Furnace has been devoted to materials testing for the European Union "Access to Large Scale Scientific Installations" program.

Its main components are:

- A heliostat field of 4 MBB heliostats with a 53.61 m^2 reflecting area and 90% reflectivity, which reflect the sunlight onto the concentrator dish. Sun tracking is computer controlled.
- An 11.5 m-x-11.2 m louvered shutter regulates the incoming light onto the concentrator, with 15896 posi-

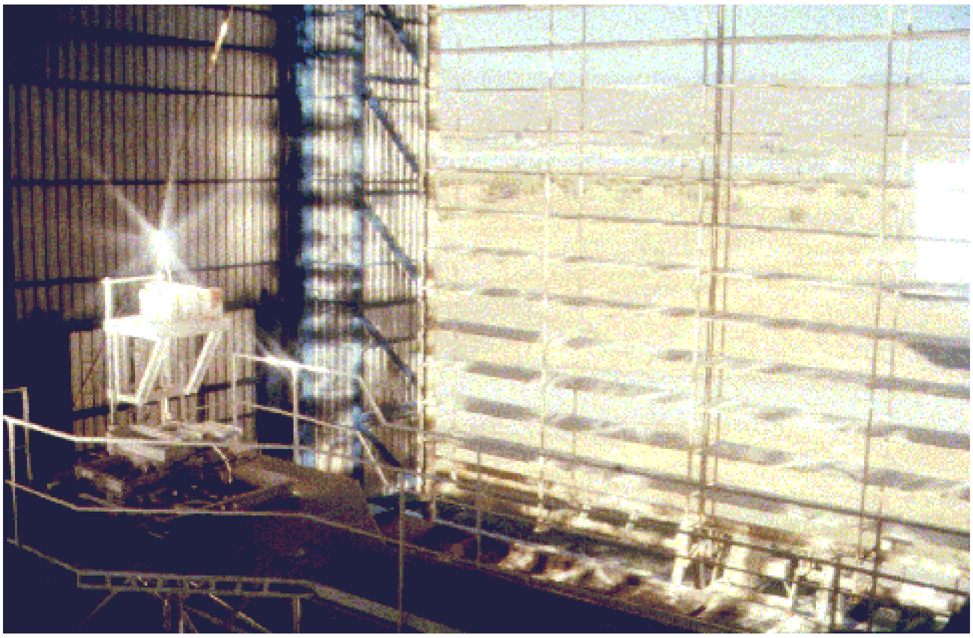


Fig. 2.6.1 Test table, shutter and heliostats

tions between 0º (open) and 55º (closed) an accuracy of 0.003º and minimum closing time of 10 seconds.

- A 0.91 m-x-1.21 m concentrator consisting of 89 spherical sandwich-type facets, total reflecting area of 98.5 m^2 and reflectivity of 94%, focal length 7.06 m, focal height 6.09 m, peak concentration of 3000, peak power 60 kW and 22-cm focus, concentrates the incoming sunlight on a test table.
- A 0.7 m-x-0.6 m test table for samples allows 3-axis displacement on x=0.86 m, y=0.6 m (along optical axis) and z=0.5 m.

2.6.1.1 Improvements in the Solar Furnace during 1998

The "Minivac" mini vacuum chamber tested for the Instituto Superior Tecnico of Lisbon, consisting basically of a small chamber with a quartz window allowing concentrated light to enter, was installed on the test table and connected to the Solar Furnace vacuum chamber and gas system.

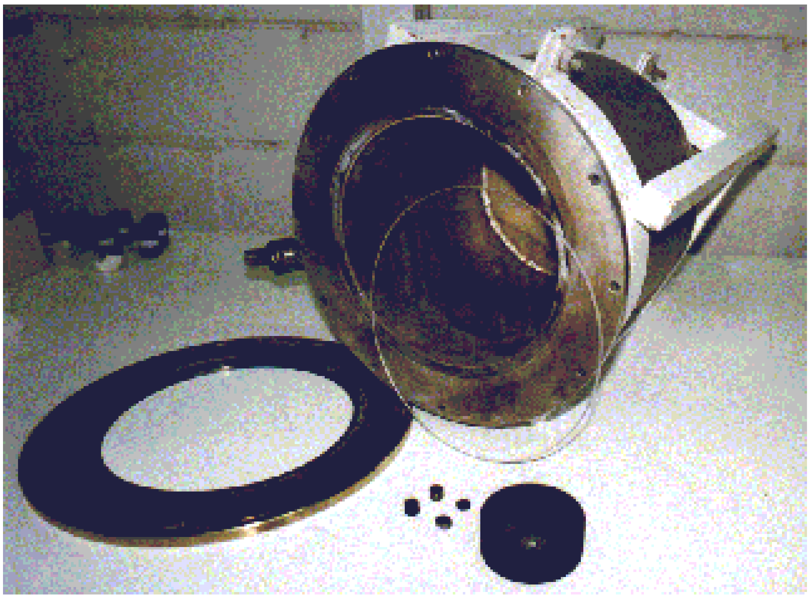


Fig. 2.6.2 Minivac, quartz window, crucible and samples

The Minivac permits horizontal treatment of specimens by using a mirror tilted 45º to vertically reflect the incoming horizontal rays under controlled atmosphere.

A fast shutter, usually placed on the test table for testing under ambient pressure conditions, has been adapted for use with the vacuum chamber in order to deliver, in less than a second, the concentrated light of the focal spot onto specimens inside the vacuum chamber.

2.6.1.2 Tests carried out in the Solar Furnace

The Solar Furnace has been fully devoted to the European Union DG-XII "Training and Mobility of Researchers-Access to Large Scales Facilities" program, running from January, 1996 to December, 1998.

As a continuation of 1996 activities, specimens of different kinds of metal and ceramic have been treated at high temperatures. The following research groups also tested a secondary concentrator and several control algorithms:

Department of Engineering Systems, ESTII, Univ. Seville. Manuel Berenguel, Responsible Scientist.

As a material treatment facility, the Solar Furnace requires controlled specimen temperatures over time for a wide range of thermal treatment tests.

Four algorithms for automatic shutter aperture control developed by the University of Seville were tested on ceramics and metals during 1997:

- A Predictive Controller with excellent performance added to all the control schemes neatly improves system behavior.
- A PID classic controller with very good behavior, although not over very wide temperature ranges, presents certain operating difficulties because it has to be readjusted for every test specimen material.
- A PI adaptive controller, which did not need to be adjusted for different materials and is suitable over a wider temperature range.
- A Fuzzy Logic Controller (FLC) was tested, showing quick non-oscillating response, but further testing is required in order to verify its viability.

Instituto Nacional de Engenharia e Tecnologia Industrial (Portugal)
Joao Farinha Mendes, Responsible Scientist.

The combination of conventional focusing optics with non-imaging second-stage concentrating optics is a good solution that increases the performance of the primary concentrator.

The secondary concentrator not only corrects the optical inadequacies of the primary, but might also bring the whole system close to the thermodynamic maximum.

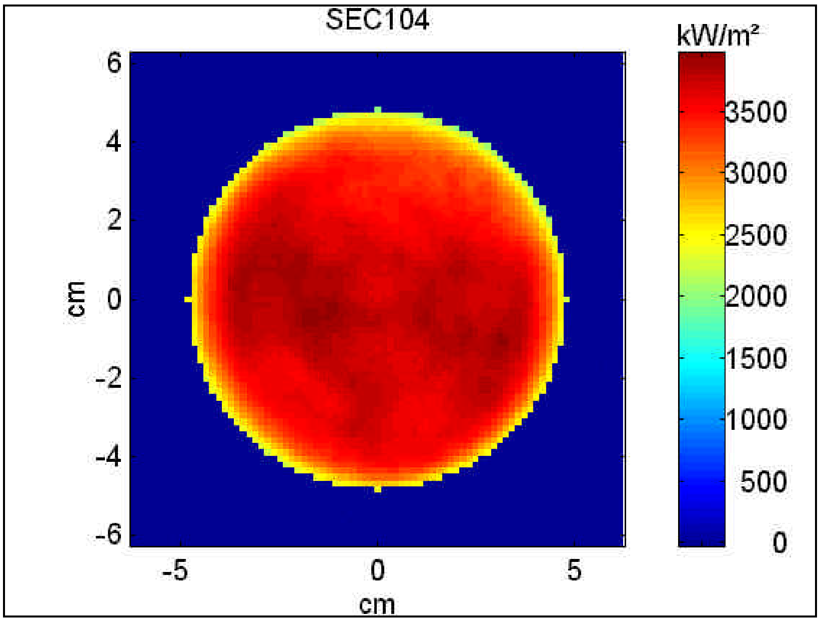


Fig. 2.6.3 Flux density at the TERC exit

A Tailored Edge Ray Concentrator (TERC)-type Second Stage Concentrator (SSC) design based on non-imaging optics was fabricated in Portugal and tested in the PSA Solar Furnace.

The flux density provided by the TERC has been measured by the Solar Furnace Theta image processing system, which includes a slow-scanning CCD camera, a water-cooled lambertian target and radiometer that serve as reference for system calibration.

The TERC improves the working conditions of the Solar Furnace, increasing the concentration ratio by a factor of 1.4 and the available power output to about 24 kW in a 96-mm-diameter circle, corresponding to an average flux density of 3440 kW/m^2.

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

Several methods of calculating the distribution of hardness in quenched steel specimens have been developed by HUT for use in modeling surface hardening:

- Modeling of Temperature distribution
- Modeling of thermal cycles in tools
- Modeling of thermal stresses

A fast shutter fitted to a pneumatic cylinder was installed in front of the Test Table in order to carry out thermal cycles on metal specimens.

Samples of hardened H13 Nitride, H13 Chrome and H13 TiN-coated steels were subjected to thermal fatigue testing in the Solar furnace in two different cycles. In the first case, the specimens were exposed to the focal spot and shaded alternatively for 5 seconds during 3 to 15 minutes. In the second, the specimens were subjected to from four to eight cycles at temperatures from 500ºC to 750ºC.

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

The production of d-transition metal carbides such as SiC, TiC, ZrC and WC was attempted by IST. The first goal was to obtain a synthesis of refractory metal carbides (SiC, TiC, ZrC, WC) employing a non-graphitic (amorphous) active carbon as the carburizing medium. In conventional furnaces, this process consumes a large amount of time and energy. A high-capacity solar furnace such as this one is an excellent tool for this process.

Compact 1-cm diameter cylindrical pellets 0.5 cm high were exposed in the Minivac in N_2 or Ar atmospheres for 30 minutes at temperatures of approximately 1600ºC.

The XRD pattern showed full conversion of Si to SiC in those specimens treated in an Ar atmosphere, while those treated in N_2 showed only partial conversion

3 Operation & Maintenance

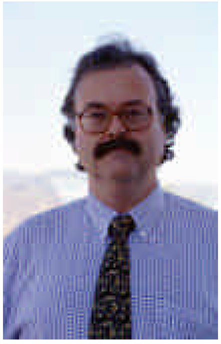
The Operation and Maintenance team, which depends directly from the Directorate in the CHA-PSA organization, provides most of the experience, know-how and manpower to carryout the experiments in close cooperation with the Area Heads and other PSA teams. The task implies the **operation** of facilities, **maintenance** and **construction / modification** of the projects

Activities in 1997 were carried out on schedule, with the exception of attending to damage done in a storm on September 21st, especially to electronic cards.

Within the COLÓN SOLAR project, the O&M team shared in writing and revising documents and installing the heliostat, local control, etc.

J.A.Rodriguez Povedano
Head of O&M

Antonio Valverde



Javier León

José Rodriguez

3.1 Summary of Hours of Operation

Operation activities at the PSA facilities in 1997 were in line with the program of work foreseen. Some deviations from the schedule were due to bad weather especially

CESA-1	**Hours-1996**	**Hours-1997**
Collector	2132	2193
TSA	206	434
ASM-150	283	174
GM-100	93	574
Turbine	261	39
GRAAL	133	87
REFOS	0	46
STAMP	261	0
CRS	**Hours-1996**	**Hours-1997**
Collector	1609	1577
Cor-Rec	196	112
RAS	84	32
Hit-Rec	0	82
DCS	**Hours-1996**	**Hours-1997**
ACUREX	621	677
Desalination	367	672
Detoxification	1483	1101
ARDISS	544	576
HTL (LS-3)	0	113
HFC	**Hours-1996**	**Hours-1997**
Collector	1569	1605
Shuttle&T.	1318	1572
North Dish	1287	1053
Center Dish	1300	1276
South Dish	1152	1134

Table 3.1 Summary of Operation Hours 1996-97

during the last quarter of the year. Fig. 3.3 shows the hours of operation per project in each facility for the last two years.

3.1.1 CESA-1 Facility

On-axis canting started in late 1996 was completed by the middle of this year and the substitution of the SENER heliostat elevating mechanisms by commercial mechanisms began during the last quarter. The REFOS project heliostat configuration is completely finished.

A new automatic control for offset adjustment is being developed with the University of Seville. The aim of this new control is to make it possible to adjust the heliostat offset even while testing, using a video camera and a graphic card. This new algorithm will be implemented at the beginning of 1997.

Heliostats

The two PHOEBUS-type heliostats, ASM-150 and GM-100 were compared in a test campaign. The ASM-150 control software is under development and will be installed shortly.

TSA Project

Testing under the TSA project evaluated the new absorber element installed at the end of 1996. After this, the main objective of the project was normal operation for electricity production. The TSA was connected to the existing CESA steam turbine system and power produced was fed into the Spanish grid although, as the sizes of the systems do not fit very well, only a power output of about 200 kW resulted.

The operators were trained in system, receiver, steam generator and turbine in May and June. The operating personnel requirement has been reduced 50% because of the successful behavior of the automatic aiming-point strategy.

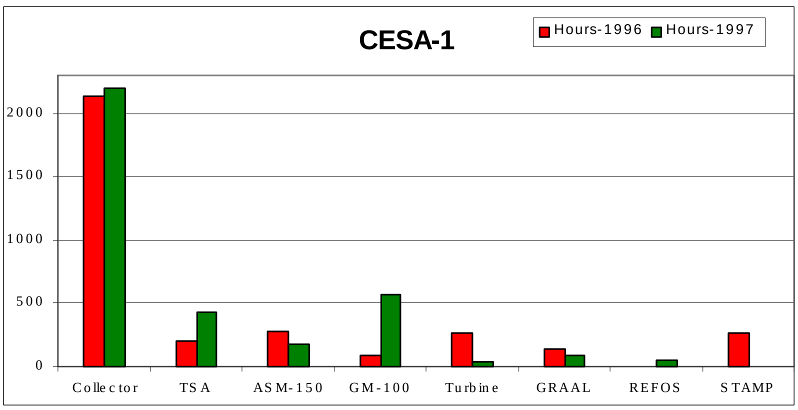


Fig. 3.1. Comparison of hours of operation in the CESA-1 test facility

TSA routine operation was hindered by bad weather during the last quarter of the year, preparation of the land for the DISS project, which reduced the mirror reflectivity 50%, and interference with REFOS project assembly tasks in the CESA-1 tower.

REFOS

The operating hours assigned to this project are those of the collector system used to calibrate heliostats for simulation purposes, and those of running the cooling systems to be used with REFOS project to check the functioning of the equipment.

GRAAL

The GRAAL tests were carried out successfully in February and March. Although testing was done at night, operating activities during daylight hours are necessary to prepare the heliostat field for this project.

3.1.2 SSPS Facility

Central Receiver System (CRS)

Receptor Avanzado de Sales (RAS Project.)

The system finished the test campaign which completely covered the flux density range, including the nominal level of 400 kW/m^2. The front of the receiver was repainted to improve absorptivity. Some experiments for calculating panel and lambertian target reflectivity were carried out using the Hermes-II system visible-spectrum camera.

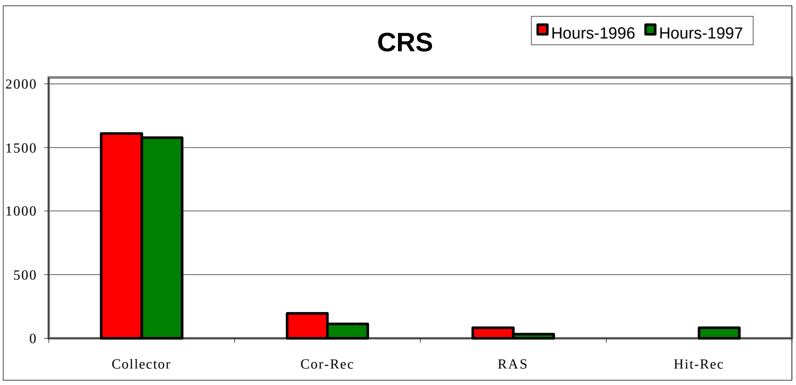


Fig. 3.2 Comparative operation hours in the CRS test facility

Volumetric Project.

Two volumetric absorbers were tested during the year:

- Second phase Cor-Rec receiver testing was carried out in 1997 after changing the air-flow distribution and, consequently, the temperature distribution. The behavior was more homogeneous than in the first phase, and the expected air temperature could be reached.

- The Hit-Rec receiver was mounted in 1997 after Cor-Rec testing was finished. During the first test period, a **new** record was achieved in the test-bed when the air temperature behind the absorber exceeded 900°C.

Distributed Collector System (DCS)

Acurex

The year was devoted to the EU-TMR program, test plan of which was completed. Testing during the year was distributed among the following organizations, University of Seville (AICIA), Instituto de Engenharia de Sistemas e Computadores (INESC), University of Firenze, University of Oulu and University of Bochum. In all cases, the response of the oil system to the various controls was checked. A certain amount of the energy collected by the system was used for desalinating water.

Heat Transfer Loop (LS-3)

During the year, half an LS-3 collector was mounted in a closed oil loop and has operated for performance of all preoperational testing, including oil-drying.

Desalination Plant

The Desalination Plant was also included in the CEC-TMR last year and was operated regularly during the campaign. The principal user was the University of Ulster. Besides this, the continuous production of distilled water was used to feed PSA Projects such as Detoxification, TSA or for more general uses such as cleaning mirrors or as cooling water.

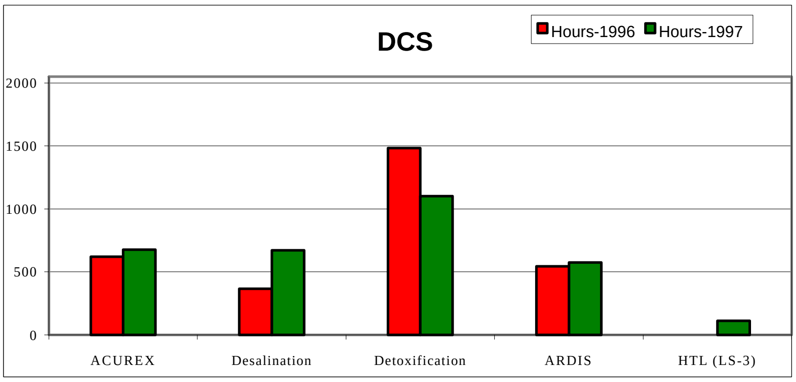


Fig. 3.3 Comparative operation hours in the DCS test facility

3.1.3 High Concentration Facility (HCF)

Solar Furnace

Within the European "Training and Mobility of Researchers-Access to Large-Scales Facilities" program four research groups carried out different kinds of tests in the Solar Furnace:

- The Finnish Helsinki University of Technology, which has developed several methods for calculating the distribution of hardening in quenched steel specimens, carried out testing on H13 Nitride, H13 Chrome and H13 TiN-coated hardened steel specimens by subjecting them to thermal cycles.
- The Instituto Superior Tecnico of Lisbon tested specimens of compacted pellets of refractory metal carbides (SiC, TiC, ZrC, WC) inside the mini vacuum chamber (Minivac) in N_2 and Ar gas atmospheres. The specimens were exposed for 30 minutes at temperatures of about 1600ºC.
- The University of Seville developed four control algorithms, PID, PI adaptive, Fuzzy Logic Controller and Predictive Controller, which control shutter aperture, allowing the reflected light of the heliostats to reach the concentrator and afterwards, the specimen, thereby automatically controlling the temperature of the specimens.
- The Instituto Nacional de Engenharia e Tecnologia Industrial tested a TERC (Tailored Edge Ray Concentrator)-type Second Stage Concentrator (SSC). With the TERC, the concentration ratio is increased by a factor of 1.4 and the average flux density is about 3440 kW/m^2 within a 96-mm diameter circle at its exits, allowing larger samples to be treated at higher temperatures.

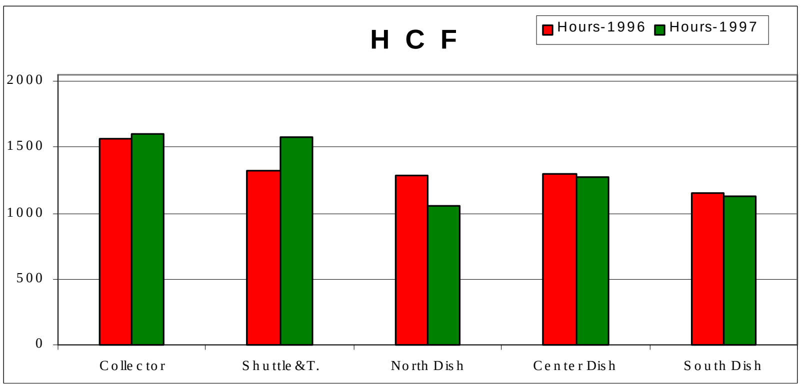


Fig. 3.4 Comparison of operating hours in the HCF test facility

DISTAL

Routine operation of DISTAL I continued. More than 11,400 kWh gross power and about 3,500 operating hours were accumulated by the three dishes in 1997, totaling more than 100,000 kWh gross power produced and about 29,000 operating hours from the start of the project in 1992.

DISTAL II has started with the mounting and pre-operational testing of three new 8.5-m-diameter dishes with a gross power output of 10-kWe each.

DETOXIFICACION

Activity in this project was mainly focused on the TMR program and the Pesticide Detoxification Project in El Ejido (Almería).

Within the TMR project, the University of Poitiers and the CNRS Lyon tested TiO_2, photo-Fenton and a TiO_2 electrode as catalysts and Phenol, 4-Clorophenol and Malic acid as contaminants in the Collector Loop. In the CPCs, the University of Wien (TUV), the Institut für Solarenergieforschung GmbH Hannover (ISFH) and CNRS Lyon tested contaminants such as 4-Chlorophenol, Atrazine, Malic acid, pesticides and olive-mill waste water with TiO_2 and Photo-Fenton as catalysts.

The Pesticide Detoxification Project in El Ejido used the CPC's to carried out tests on pesticides with TiO_2 catalyst.

A total of 85 experiments were carried out in the CPCs on 114 days of operation and 20 tests were performed on 26 days in the Collector Loop.

ARDISS

In January, the new ARDISS absorber pipe called the Advanced Receiver for Direct Solar Steam generation, was mounted on the free arm of the ARDISS collector and tested in February and March.

Afterwards, the Parex02 absorber was modified and improved, carrying out reliability tests until July. In the second half of the year operation was focused on testing "naked tubes", which are basically metal absorber pipes without the glass cover.

41 collector on-track efficiency tests and 34 thermal loss tests with the collector in stow position were carried out.

3.2 Maintenance Plan for 1997/98

José Manuel Molina

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

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 1994. Construction activities tended to develop in parallel as in former years. A significant effort was exerted in corrective tasks, mainly to repair storm damage.

Fig. 3.6 presents the distribution of work by activity in 1997 versus 1996, 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 1997 than 1996, at the expense of preventive maintenance work.

Fig. 3.7 shows the distribution of maintenance workload history devoted to "general" in the specific classes, preventive, corrective and construction. "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.

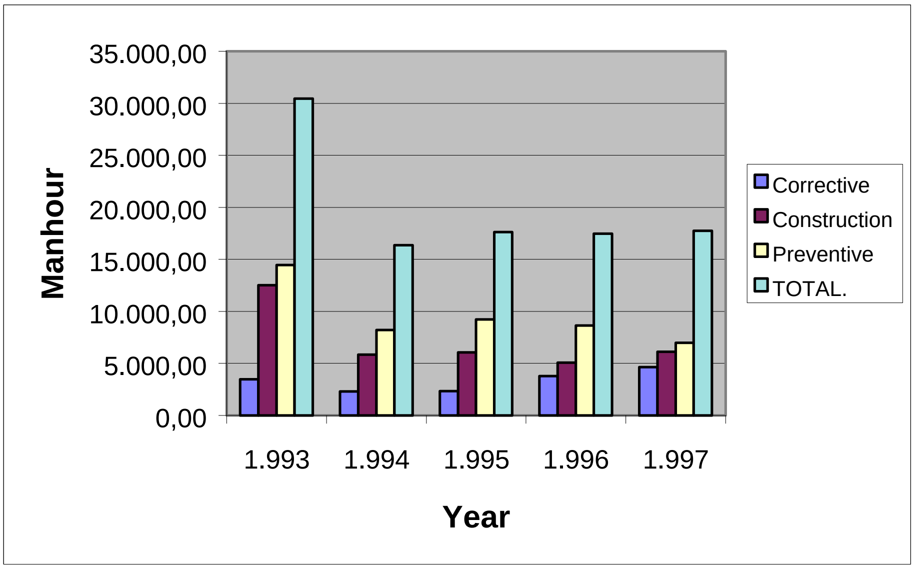


Fig. 3.5 Distribution of work done under the GMP since 1993

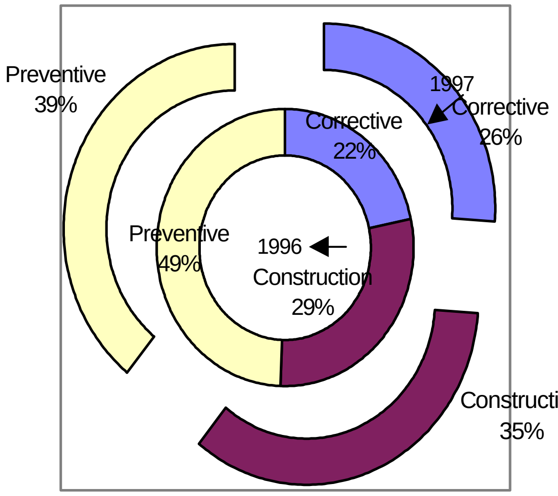


Fig. 3.6 Distribution of work by activity in 1997 versus 1996

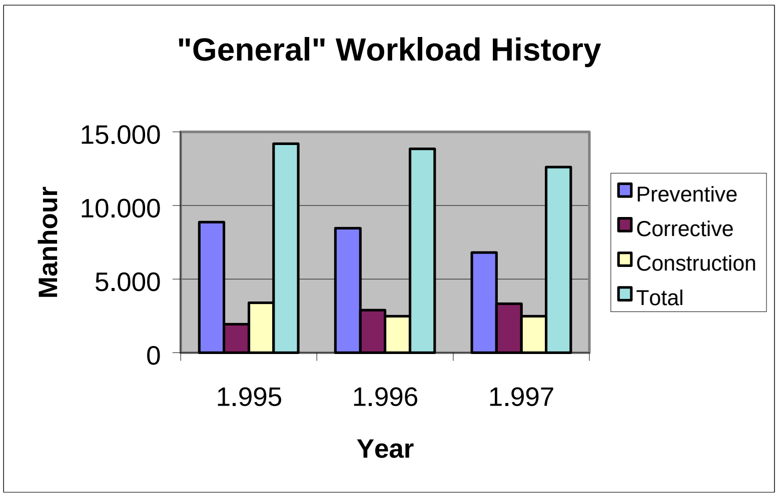


Fig. 3.7 Historical distribution of “General” maintenance workload by preventive, corrective and construction

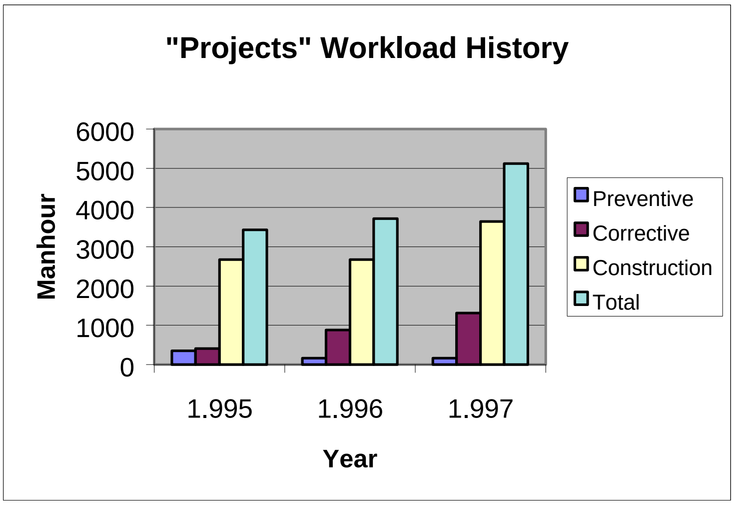


Fig. 3.8 historical distribution of the project maintenance workload

3.2.1 General

- Installation of a water supply-line from the DCS facility to the LECE project.
- Laying of optical fiber and UPS electrical line from the CESA 1 to the Entrance building and installation of communications network and UPS in this building
- New water supply line to Laboratories.

CESA 1

REFOS

- Removal of Hermes cooling water and reconditioning of test room, as well as modification of the former receiver support structure and construction of a concrete mat for the new REFOS project.
- Erection of a steel mast to support the infrared control camera.
- Replacement of elevation worms in 40 SENER heliostats, to be continued and finished in 1998.

COLON SOLAR

- Preparation of infrastructure; finding geographic coordinates; power supply; control; several tasks involved in matching the mechanism; canting the facets; etc.

LS-3 LOOP

- Various specific tasks for installation of auxiliary equipment, piping, signal cables, erection of facets, electric board, etc.

DISS

- Installation of underground network, erection of Hermes crane in BOP building, *in situ* fabrication of distribution trays for electricity and control.
- Electrical engineering tasks.
- Site preparation, load and unload of units.

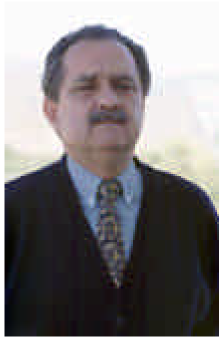
Volumetric Receivers

- Dismantling of COR-REC receiver, and flux measuring system for reparation.
- Erection of new "HIT-REC" receiver; previous replacing of new thermocouples.

4. Engineering Department Activities

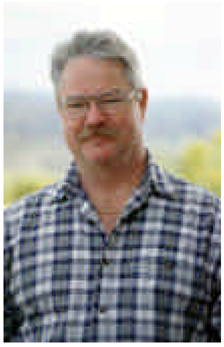
The Engineering Department handles general supporting services for all the projects, such as flux measurement, instrumentation, computer services, safety and drafting are concentrated in this department which has 12 persons. At the beginning of 1997, two doctoral thesis students were integrated to the department staff.

Andreas Holländer (Area Head)



Bernabé Calatrava Infrastructure/Safety

Mr. Anselm Kröger-Vodde is assisting with flux measurement for heliostat control systems. As the operation of Tower power plants requires intensive operator attention due to the possibility of up to 30% efficiency loss from tracking errors, automation of heliostat control is a high priority. The strong pressure to further reduce the investment required supports this because of the poor accuracy of low-cost support.



Dieter Weyers DISS (Ball joints)

Angel Soler (Draftsman)

Mr. Miguel Angel Rubio is in charge of improving the PSA's weather station. For all projects, the availability and reliability of meteo data is important to evaluation of results. A local radiation simulation tool for the Almería area is also planned to improve simulation code results.

Miguel Angel Rubio (Doctoral Student)

Rosario Domech (Secretary)

The most work was for the DISS project, for which the main equipment was purchased, the control and instrumentation designs were reviewed, the site, detailed engineering and material tenders were prepared. Furthermore the LS-3 parabolic collector was erected and tested and a new local heliostat control prototype, developed by the Engineering staff, was very successfully tested on it. The PSA computer system has been updated concerning the approved budget and some important steps forward in Internet-connection and communication have been made. Some new data acquisition systems have also been developed and integrated in project control and evaluation. Important advances were made by the flux measurement group which developed specific macros for the Optimas image processing and acquisition software code for use in conjunction with a new 12-bit CCD camera system. Work done during the year is presented in detail below:

Juan A.Camacho (Computer Services)

Jaime Aranda (Computer Services)

4.1 Overview of the Computer services

As the PSA is located in a decentralized area in the south of Spain, electronic communication is very important to establish access to other scientific centers. Within this, the World Wide Web (WWW) has become the new standard. All important publications of the PSA like the Annual Technical Reports, TMR information packages, project information and Student Program procedures are put on the WWW. A new state-of-the-art technology Windows NT server, sophisticated electronic-mail system and remote telephone access have been installed. With these changes the execution of on-line CIEMAT administrative programs via Internet have been enabled as well. Consequently, the amount of external data received was nearly twice that in 1996, although the amount sent was nearly the same, as shown in the following figure (Fig. 4.1).

In order to set up the above mentioned external communications, the internal network to all the PSA buildings has also had to be improved and enlarged. There are now about 120 computers connected to the local network. Nearly all printers are now connected to the local network, providing more flexibility in the use of printers and access to special color printer. More than 100,000 pages have been printed with the network printers, Nearly twice as many as last year, as shown below.

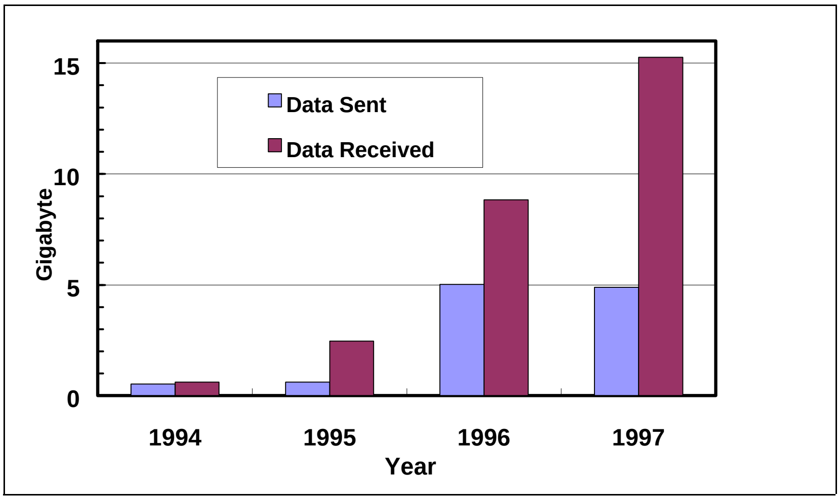
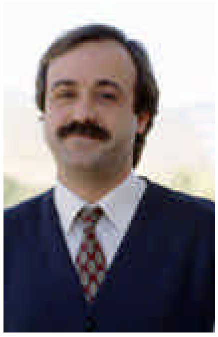


Fig. 4.1 PSA Data Exchange in 1997

As part of routine work some of the older Data acquisition systems have been modified or reconfigured for the new infrastructure and some new data bases have been designed.

4.2 Control, Instrumentation and Monitoring



Ginés García
(Instrumentation)

Andrés Egea
(Instrumentation)

The most important work carried out in 1997 was the adaptation of the local heliostat control system developed by PSA to the LS-3 and DISS parabolic trough loops and the ABENGOA prototype heliostat for the Colon Solar heliostat field.

The first thing done for the DISS project in the Engineering Department was the erection of the LS-3 test loop. The conventional system and the control system were designed and supervised and work began in 1997. The local control device, based on the GM-100 heliostat control GA 2696A card, was changed and adapted to the requirements of parabolic trough systems. The following figure shows the new control unit designed by PSA.

During the year, the control was very successfully tested and as a result, it was decided to implement this system in the new DISS collector in 1998. With the new system, the philosophy of local control devices has also changed from the conventional cell-controlled tracking to an advanced high-precision optical encoder control which also gives better results in handling the device and solves some problems found in connecting the old system. Figure 4.2 shows one of the twelve local control systems in the DISS-Test loop.

All the results of design and testing in these projects have been integrated in the development of the latest generation of local heliostat controllers for production in series. Since the PSA has been placed in charge of the Colon Solar project solar system, especially its control, these design activities have been strengthened. The Colon Solar power plant requires reliable controllers with commercial, economical components. The local control, developed for the GM-100 heliostat prototype was used as the basis for the design of such a reliable, low-cost control for solar tower plants. Some commercial components of the local control, like speed and rpm controllers will facilitate system maintenance.

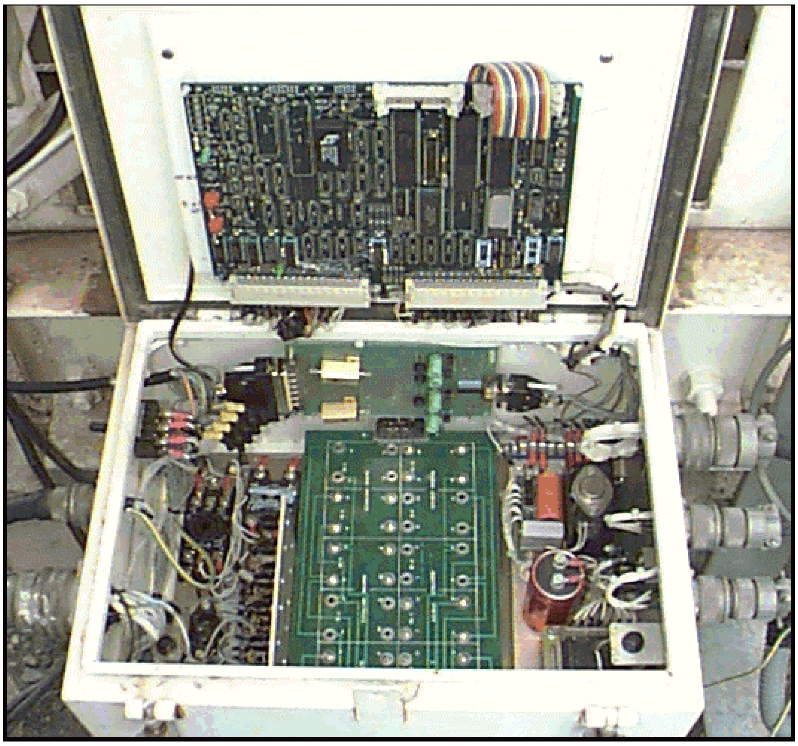


Fig. 4.2 The new local-control box for the LS-3 parabolic-trough loop

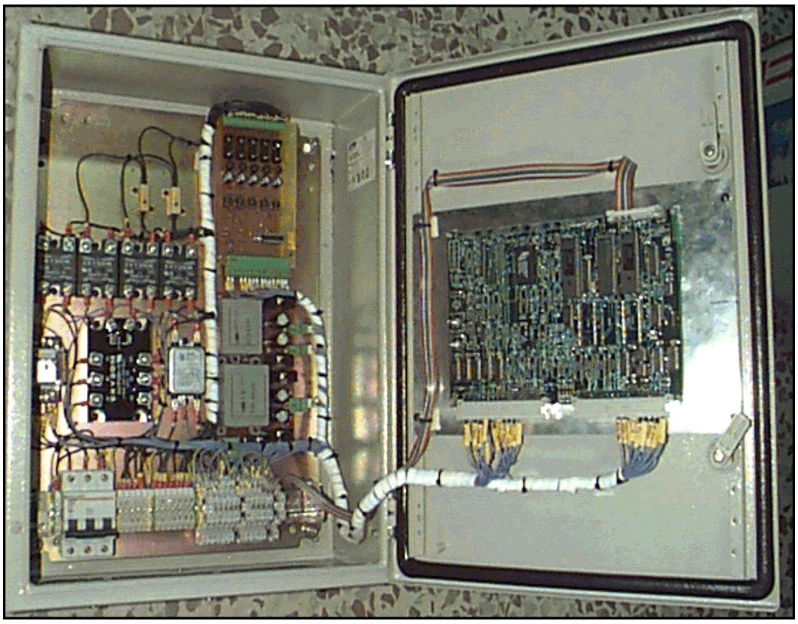


Fig. 4.3 Inside of the DISS local control box

Apart from these special tasks, routine work has been carried out, for the other projects:

- Automation of the Solar Furnace "guillotine"
- Fabrication of thermocouples for the furnace
- Modification of the control logic of the CESA-1 project
- Disassembly of special instrumentation in the CESA-1 tower

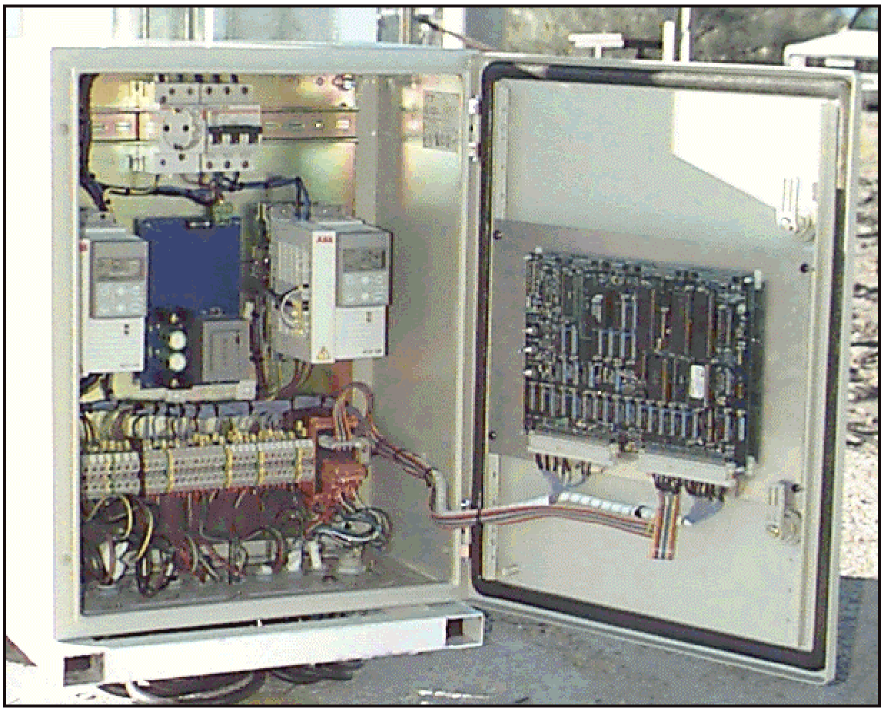


Fig. 4.4 Local-control box for the two-axis solar tower plant heliostats

4.3 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 system
- The new 14 bit PC-based PROHERMES video system

Both are currently operative in the SSPS and CESA-1 heliostat fields.

The Theta-1 system, consisting of a 12-bit CCD camera and specialized software under DOS, was operated for the dishes. During 1997 the following measurement campaigns were carried out.

- **Receptor Avanzado de Sales RAS (Spain) with Hermes II**
  In January, 1997, several infrared and video measurements were taken to evaluate the front panel temperature (around 600ºC), and incident flux (around 570 kW with densities up to 400 kW/m^2). The data were used to calculate power and receiver efficiency.

- **CORREC and HITREC Volumetric Air Receivers (Germany) with Hermes II**
  The Corderite ceramic receiver consists of 33 modules in an arc-like structure with individually adjusted flow rates. Flux measurements taken in 1996-97 were

Rafael Monterreal (Flux measurement)

Anselm Kröger-Vodde (Doctoral Student) around 200 kW with a maximum flux density of 500 kW/m^2.

During 1997 the following measuring campaigns performed:

- **Installation and testing of the PROHERMES system itself**
  The equipment consists of a 14-bit CCD Theta-Systems camera and the customizable OPTIMAS image-processing software. Many OPTIMAS macros have been specially designed, programmed and continuously enhanced for the necessities of the PSA driver in order to obtain a tailor-made software for solar energy applications. With these macros, image acquisition is reliable with live picture, saturation control for frequent measurements and moving-bar sequences. Fast-image conditioning in preparation for further calculation is processed by other specialized macros for heliostat beam characterization, heliostat tracking or sun shape and the results can be exported directly to charts in programs like Excel. The macros are easy to handle, save operating time and significantly decrease the supervision time required for operation. Furthermore, valuable manuals for various flux measurement tasks have been prepared.

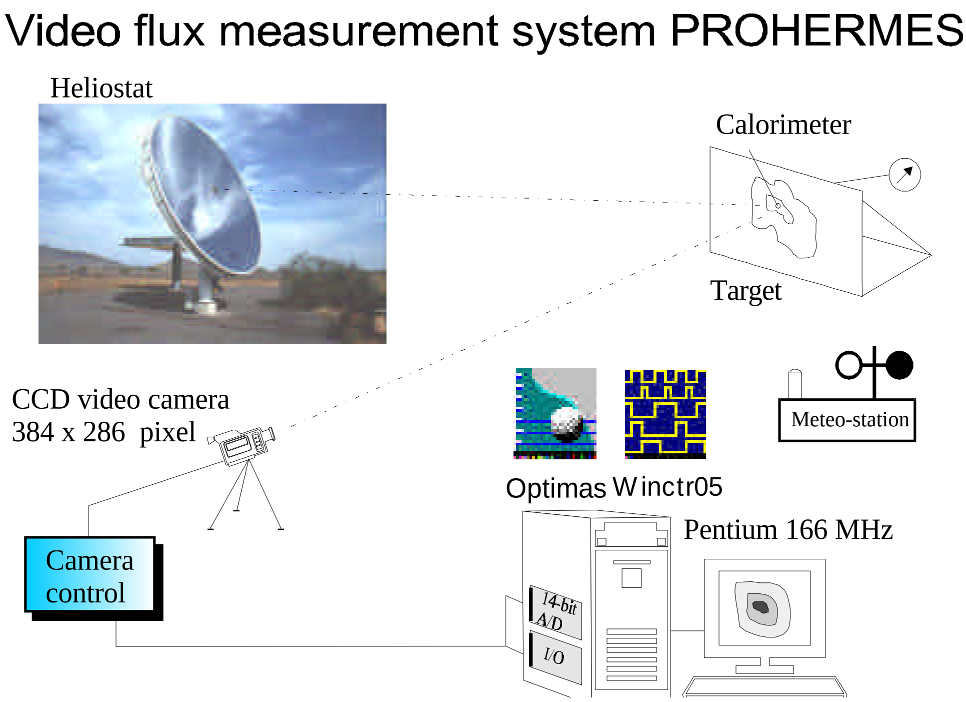


Fig. 4.5 Schematic of video flux measurement system PROHERMES

- Comparative testing of two large-area heliostats, the ASM150 and the GM100a, has been carried out and the following characteristics of both heliostats were evaluated:
  - tracking
  - beam quality
  - effects of wind disturbances

Further details on results are explained in PSA internal report R09/98-RM, November, 1997.

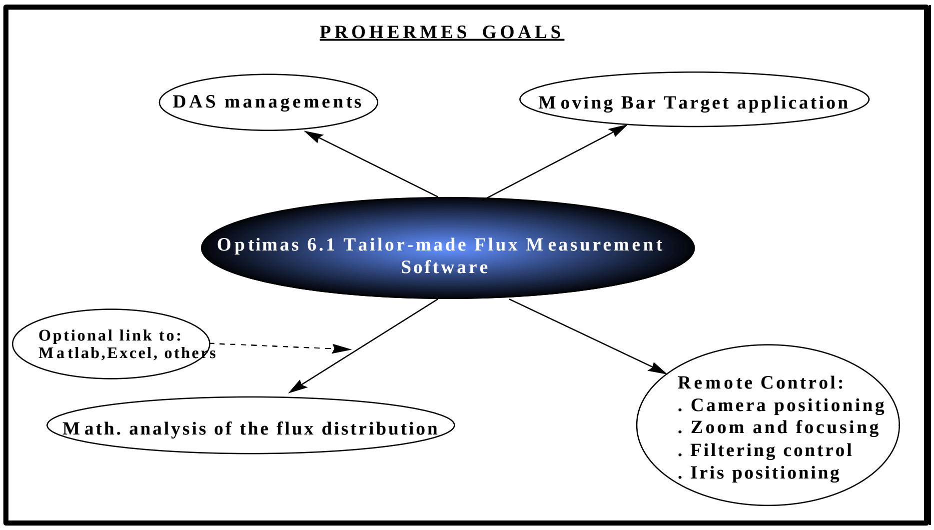


Fig. 4.6 Goal of the PROHERMES Flux Measurement system

- **Initial heliostat performance characterization campaign for the REFOS project**
  In the last quarter of 1997, the 90 heliostats foreseen for operation of the new REFOS receiver were selected and their performance evaluated. The high performance of the effective area computed was demonstrated. The focus shapes show good canting with point of maximum irradiation nearly congruent with the center of flux distribution. The peak irradiation has been evaluated between 7 and 80 suns depending on the heliostat row. Measurement will continue and will be revised to improve precision of the data acquired. The following figure (Fig. 4.8) is an example of the resulting representation of a particular heliostat. The gray center and point of peak irradiation are shown. The target area and effective area of this 40 m² heliostat are also included. The flux distribution of two cuts through the gray center can be read from diagrams. After smoothing the image of the focus with an Average-filter, different effects can be highlighted depending on the selected assignment of colors to tones of gray (i.e., Luminance Tables).

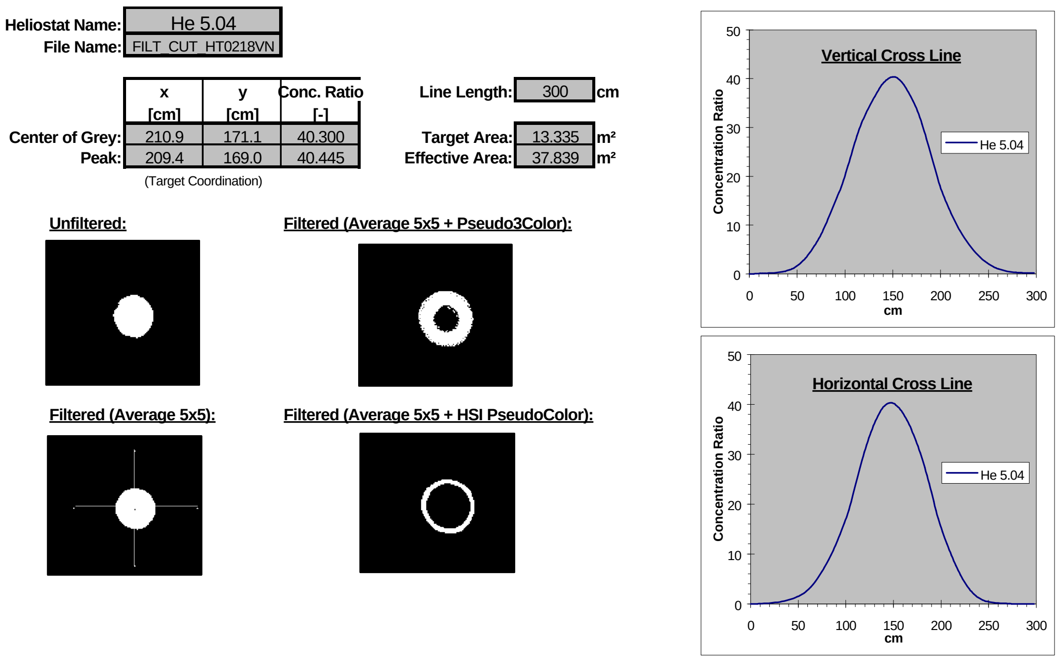


Fig. 4.7 Result for characteristics of a heliostat used in the REFOS-project.

- **Colón Solar heliostat tests campaign**
  An intensive test campaign was carried out to the end of 1997 to investigate the main features of the Colon-Solar heliostat prototype. The following figure shows focus at solar noon.

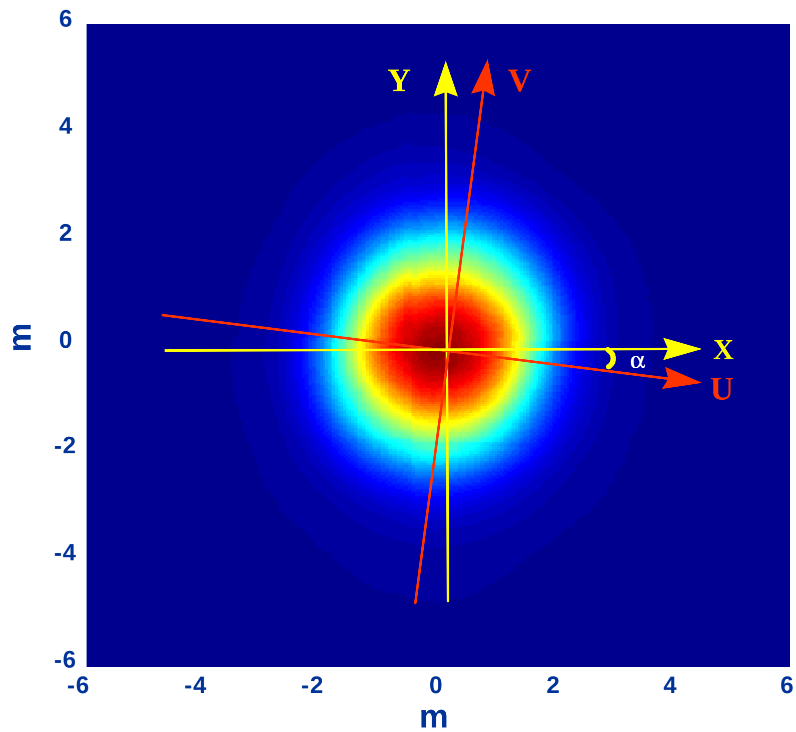


Fig.4.8 Colón Solar heliostat focus at solar noon

The following points have been analyzed in detail:

- Local Control
- Beam Quality
- Tracking accuracy
- Electrical consumption
- Flux distribution onto lambertian target
- Behavior under wind conditions
- Mirror surface status

- **Activities with the Thetal system**

With the help of a cooled, Amer-coated target on a moving cross, first performance measurements of the recently erected DISTAL II dishes were carried out in June and July, 1997. The measurement system was developed especially for this task and is run by customized *C* procedures. The flux density was evaluated in 11 shots of planes behind and in front of the center focal point at a dish pressure of –20 mbar. The location of the focal plane has been determined for pressures between -15 and –30 mbar. The results, retrieved by special procedures, show particular irregularities of the dish surface. Densities up to 17,000 kW/m^2 lead to a maximum thermal power of about 50 kW.

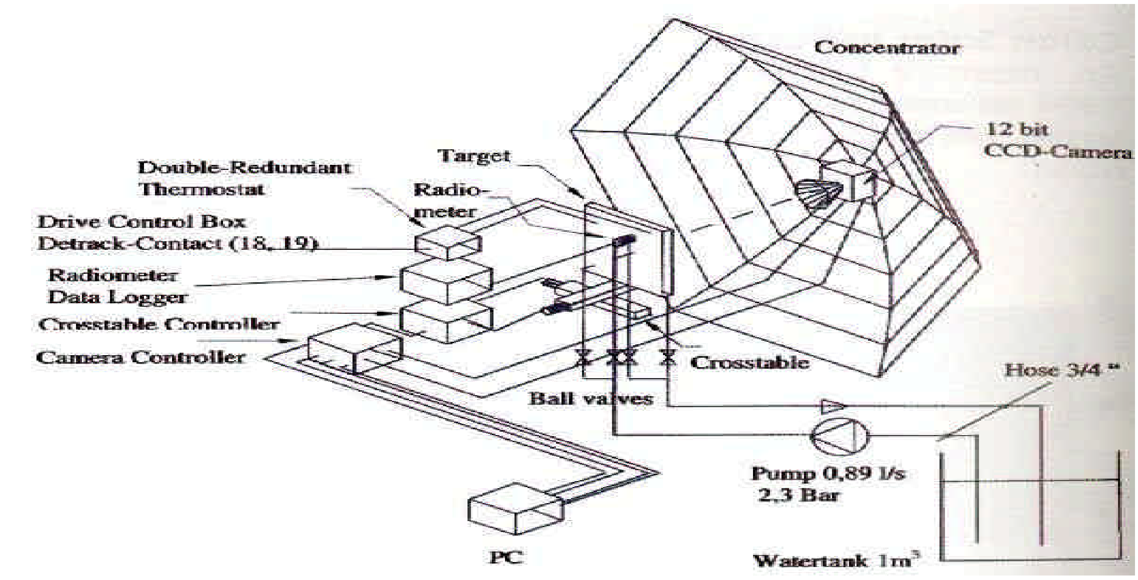
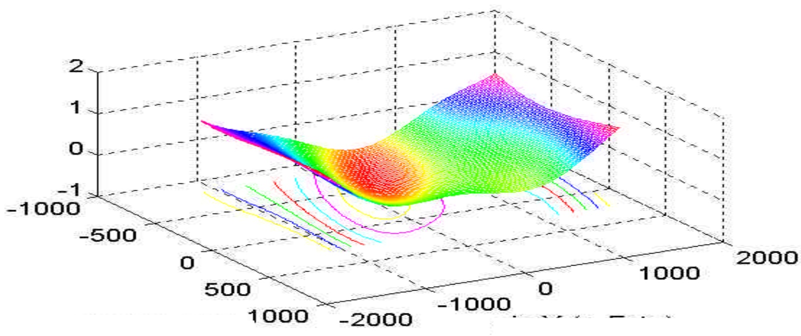


Fig. 4.9 Theta 1 measurement installations at DISTAL II.

- **Other activities**

Some other activities of the flux group, such as a new computer code for solar concentrator simulation were developed throughout the period. The new code developed by the PSA is based on precise knowledge of the sun shape, which is captured by a 14-bit-resolution-depth CCD imaging device and transformed into a matrix representative of the spatial distribution of the sun intensity. This contrasts with most other simulation codes, which use either analytical or poor resolution



Modeled mirror features

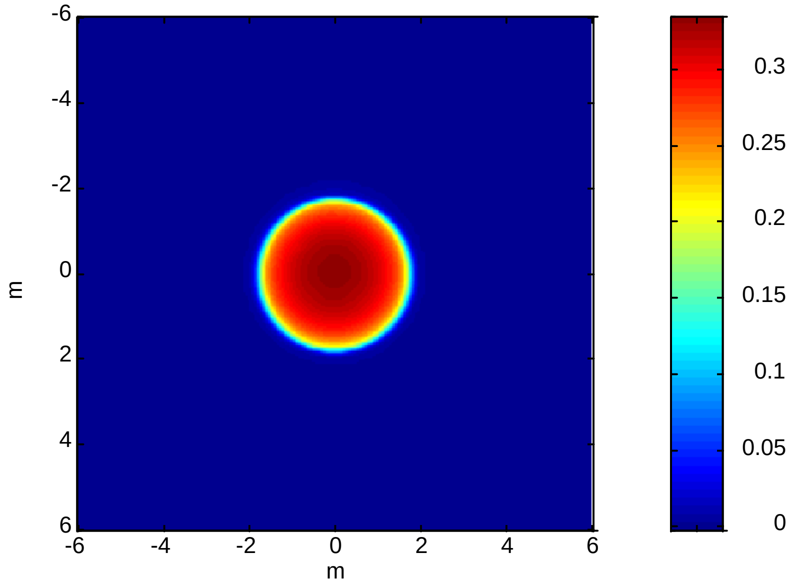


Fig. 4.10 Modeling of Mirror Features with the New Computer Code

experimental sun shapes for input data. This matrix is projected onto the receiver by a discrete mirror, following the law of reflection and assuming the *ray-cone* approximation for every area element. For a single mirror the reflecting surface is initially modeled using 11 basic parameters, which are sufficient to describe the morphology, geometry and mirror waviness. For more complex catoptrics the user can increase the number of modeling parameters unaided, making a *tailored* mirror, like a heliostat, a solar furnace parabolic mirror, dishes, etc. Users will certainly find a flexible and very precise code able to simulate both the behavior of solar reflecting systems or augment its optimum parameters for optical qualification purposes.

Outside collaboration

As a part of the scientist exchange program, Mr. S. A. Jones, of SANDIA National Laboratories (USA), has closely collaborated in DISTAL II dish evaluation with a new laser-based optical measurement system called V-SHOT. The schematic of the measurement system is shown in the following figure (Fig. 4.11). Moreover, Mrs. B. von der Au of DLR-Cologne has also collaborated with the PSA, in synchronous measurement of the sun shape by applying some recently created OPTIMAS-macros based on the exchange of knowledge.

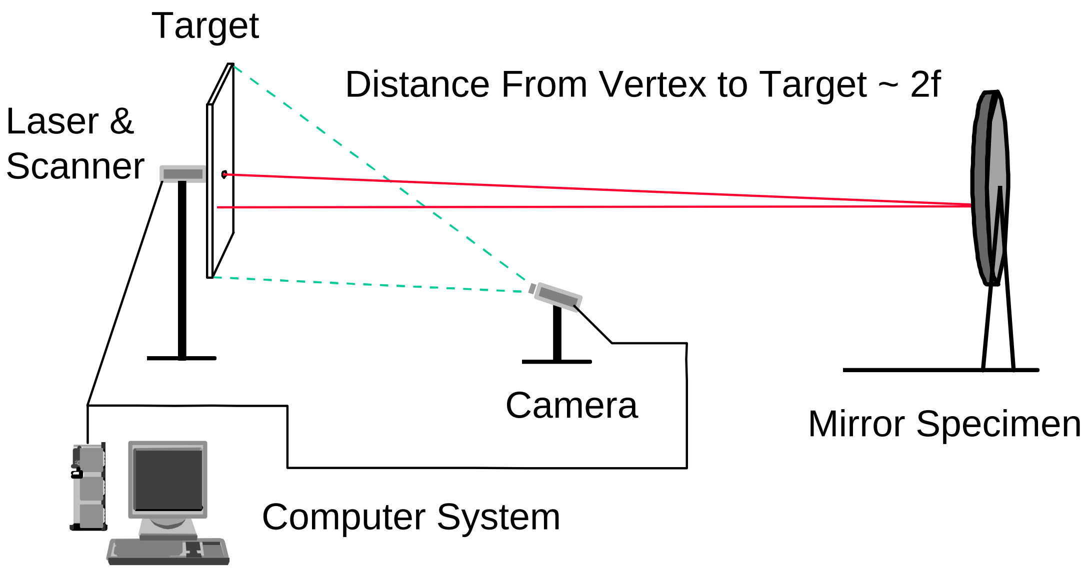


Fig. 4.11 Schematic of the V SHOT-System

4.4 Supervision during the erection of the LS-3 Test loop

The Heat Transfer Fluid Test Loop (HTF) was installed during the first half of 1997. The test loop will be used to evaluate improved parabolic trough components under solar conditions. The loop consists of a 50-m LS-3-type parabolic-trough collector, and an independent 1,000-l oil circuit containing Syltherm oil as the heat transfer fluid. The specifications of the system components are as follows:

- LS-3 collector: aperture area, 272.5 m^2, 50 m long, 5.76 m wide, outer absorber tube diameter 0.70 m, inner tube diameter 0.42 m, focal point 1.71 m.
- 250-kW Oil/Air cooler located at the outlet of the collector. The blower speed may be controlled manually or automatically to regulate the oil temperature.
- A 1.5-m^3 oil tank is the system expansion vessel. The tank is pressurized with nitrogen up to 40 bar.
- 20-kW auxiliary heater at the inlet of the collector to compensate system thermal losses.
- Oil pump, 8 liters/sec with magnetic coupling and heat-resistant up to 390ºC. Speed is controlled by a converter.
- SYLTHERM 800 heat transfer fluid, max. operating temperature 400ºC, no crystallization point. Density at 300ºC is 672kg/m^3 with a specific heat capacity of 2,087 J/kgK.

The maximum and minimum operating parameters of the heat transfer fluid test loop are the following:

Solar irradiation	0-1000 W/m^2
Test loop temperatures	70ºC-427ºC
Inlet	300ºC-391ºC
Outlet	300ºC-427ºC
Temperature difference in/out	+/- 50º K
Pressure of the test loop	0 bar - 40 bar
Operating pressure	approx. 20 bar
Flow rate of the test loop	0 - 8 liter/sec.
Operating flow rate	approx. 2,5 - 7 liter/sec.

Test loop Control

During normal operation, the inlet temperature of the collector is controlled automatically by the cooler. After startup, the inlet temperature is kept constant at an adjustable level.

The pressure is controlled in the expansion tank by a local pressure control.

A flow meter in a control loop keeps the flow rate constant during operation.

The operating parameters are set at the control panel in the control room of the nearby SSPS building.

4.5 Infrastructure improvements in 1997

The major part of the budget for infrastructure activities was spent on the improvement of site access roads. Nearly 40% of the roads were repaired.

The following infrastructure activities were carried out during the report period:

- Enlargement of chemistry labs
- Installation of an emergency exit in the solar oven
- Construction of a new office in the CESA-1 tower
- Renovation of some air conditioning equipment
- Laying of electrical cabling to the CESA storeroom, workshop and several other buildings
- New presentation equipment purchased
- Renovation and extension of the internal roads

6 Training and Mobility of Researchers Program

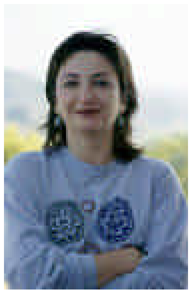
6.1 The Program

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 Commission of the European Communities Directorate General XII for Science, Research and Development and comprises four activities:

- Research Networks to promote transnational co-operation 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.

Diego Martínez (TMR Program Manager)



Cruz Ma. López (Secretary)

6.2 PSA Participation in European Commission Access Programs

As one of the main PSA goals is to promote the use of solar thermal energy throughout Europe, it has long been interested in participation in European Commission Access programs, as a suitable way to disseminate the advantages of the 'solar option' within the European scientific community.

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

	LIP	HCM	TMR
PERIOD	1/1/90 -30/06/93	1/1/94 - 31/03/96	1/1/96 - 31/12/98
FACILITIES OFFERED	3	5	9
WEEKS OF ACCESS	231	290	168

Fig. 6.1 PSA participation in CEC-DGXII Access Programs

6.3 Current Activities

PSA now has a three-year 'Access to Large-Scale Facilities' contract CEC-DGXII concerning the activity of the program.

We are also involved in two other activities within the program:

Under Activity 3, *'Training through Research'*, the PSA currently hosts two 'Marie Curie Research Training Grant' holders, who participate actively in the Solar Chemistry and DISS projects.

There is also a new initiative, concerned with activity 4, '*Accompanying Measures'.* The CEC-DGXII has proposed three different options for 'meeting fora' to provide a flow of knowledge between young and experienced researchers: Euroconferences, Summer Schools and Practical Training Courses.

The PSA applied this year for a 'Summer School' which is fifty-fifty pure academic and training events. The European Commission has approved the PSA initiative, so a Summer School will be held during 1998. The title is '*Solar Thermal Energy: The Clean Way for Electricity Generation and Chemical Production'.*

It will be composed of two weeklong courses, the first one is to be held from the 13^{th} to 17^{th} July 1998, and its title is '*Solar Thermal Electricity Generation'.* The second one is to be held from 21^{st} to 25^{th} September 1998, and is entitled '*Industrial Applications of Solar Chemistry'.*

The courses are to be of a European dimension, meaning that the teaching staff as well as students must come from as many different European countries as possible. This is well defined by the rule that stipulates that of the maximum number of 40 students allowed per course, no more than 1/3 may come from the same country.

Most of the students attending will do so with EC financial assistance covering travel and accommodation expenses, as well as 50% of the course fee. These grants are to be given mainly to four target groups of researchers established by the European Commission:

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

The days will be organized as follows: in the morning there will be two two-hour theoretical classes, and in the afternoon, a practice session at a PSA facility. In addition, two round tables will be held in the late afternoon during each course. At those round table sessions, it is intended for the speakers of the day, the PSA staff and the students to exchange ideas, experience and knowledge on the topic of the day.

6.3.1 The PSA Commitments

Regarding the current '*Access to Large-Scale Installations'* contract, and in order to guarantee its successful performance, fairness and compliance with Commission objectives, the PSA has assumed a series of commitments.

The tightest constraints imposed by them concern the User Selection process, beginning with the Call for Proposals and concluding with the Selection Panel itself.

6.3.1.1 Users Selection Process

After issue of the 'Call for Proposals', which must be widely publicized, its publication in certain scientific magazines of European diffusion being mandatory, a Selection Panel must meet to select the coming year's Users from the proposals received.

This Panel must be composed of at least 10 experts, six of whom are not from CIEMAT, and who should remain the same throughout the program. The Panel must have a European scope.

This aspect of the program has improved this year. In 1996 it was noticed that information on this opportunity was not sufficiently well broadcast outside of Spain and Germany. This year, an intensive 'Internet' campaign sent the text of the 'Call' to over 300 institutions and university departments. The information was also published in the PSA's 'Web Page' and was presented in all forums attended by a PSA representative.

In the charts (Figs. 6.2 and 6.3) below a comparison of the distribution by country and the number of proposals received can be seen.

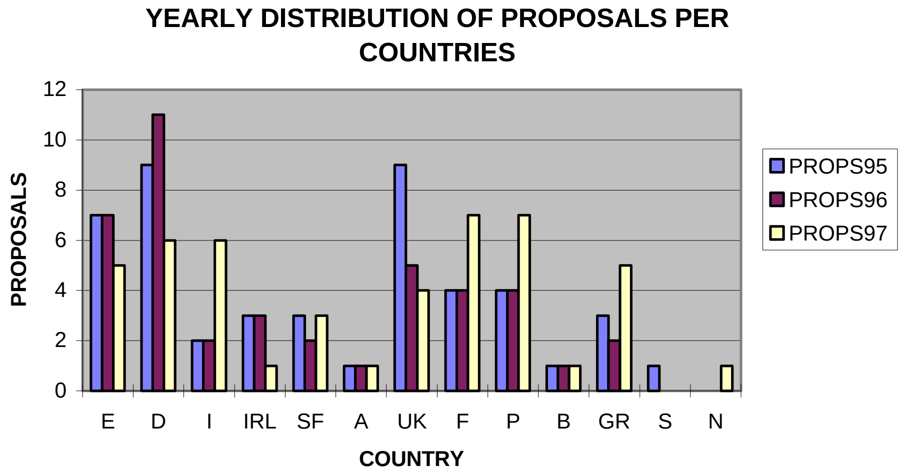


Fig. 6.2 Yearly Distribution of Proposals per Countries

This has the consequent effect on the distribution of groups granted access:

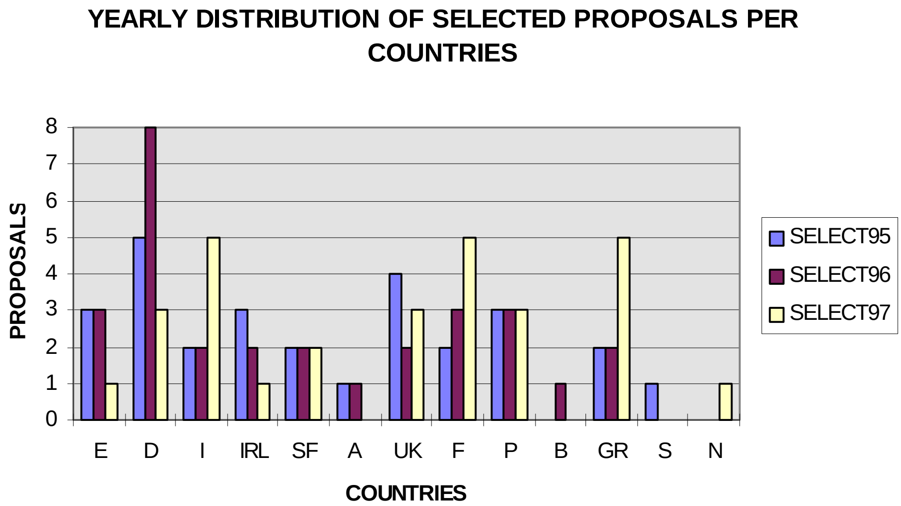


Fig. 6.3 Yearly Distribution of Selected Groups by country

6.3.1.2 Amount of Access Committed

For the entire three years of the contract, the following facilities and access time are offered:

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

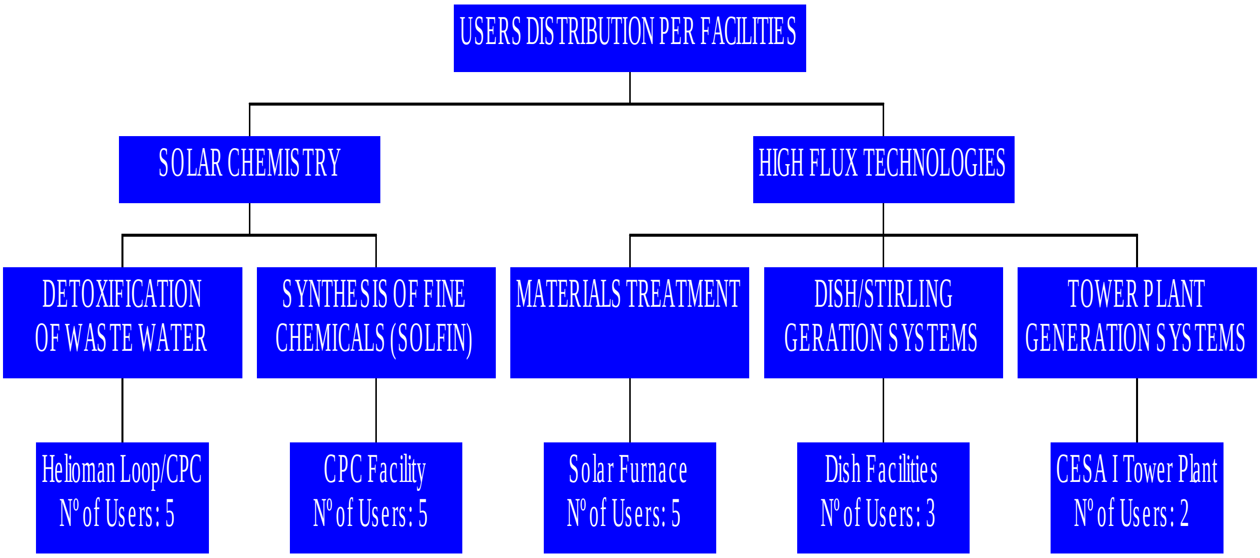


Fig. 6.4 Users Distribution per Facility (I)

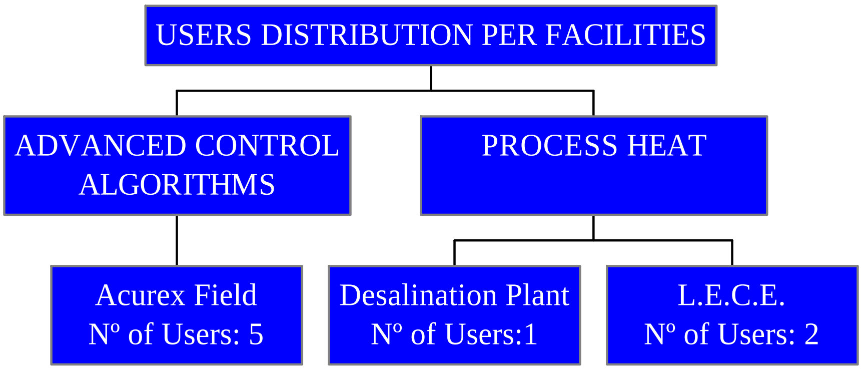


Fig. 6.5 Users Distribution per Facility (II)

'Access' means not simply the use of the facility, but also all the infrastructural, technical and scientific support that is normally provided to external users of the PSA.

A minimum of 28 groups of users must be given access per year, with a minimum of 50 different groups by the end of the program.

Access is limited for Spanish and German groups to a maximum of 15% between them. To meet this requirement some special care in the Selection processes is necessary, as most of the proposals still come from those two countries. evolution of this parameter over time is shown below (Fig. 6.6):

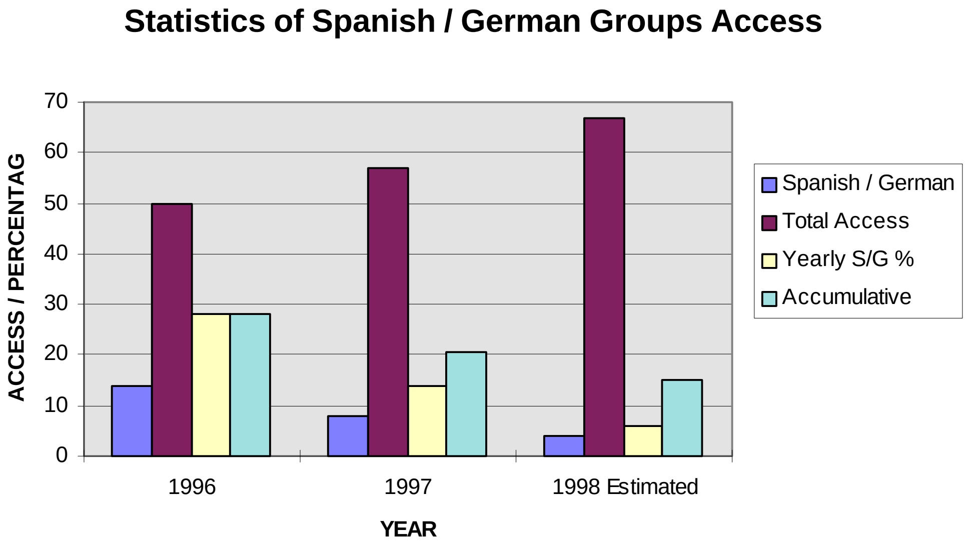


Fig. 6.6 Statistics of Access by Spanish / German Groups

6.3.1.3 Other Commitments

Besides those related to access and Users, some other commitments are assumed by PSA program management:

- Participation in the Round Table for European Facilities performing Energy-related Research:

  The Commission attempts to bring together those facilities participating in the Program under similar topics of research. Preparations of joint-research proposals as well as the exchange of experience in access management are the key points of this initiative. The next such Annual Meeting is to be hosted by the PSA in September 1998.

- Preparation of an Annual Progress Report in which access statistics and activities must be described, as well as a bibliography of publications generated through the program, cost statement, and any other relevant information arising from the program during the year.

- The Midterm Review: It is foreseen in the contract that a meeting with DGXII officers must be arranged by PSA management in order to review the program degree of progress and to take the necessary measures or perform the necessary modifications, if any. This meeting is now fixed to be held next September, using the annual meeting of the Round Table.

- The Annual Users Meeting: Every year, before the start of access activities, a general Users meeting must be organized at the PSA. The main objective of that meeting is to offer the users a first contact with the facilities and on-site project-leaders. A detailed explanation on how the program is run is also given.

6.3.2 Activities in 1997

The main activities supported by this contract during 1997, apart from regular User visits to the PSA, were the following:

Second Annual Users Meeting. All 28 groups selected were invited to this meeting held at the PSA on February 6th and 7th. The main objectives were discussion of the access schedule and a first visit to the facility. The PSA and the program itself were presented in general sessions, followed by parallel sessions in which the users met their project leaders and other users of the same facility.

Round-Table Meetings. In 1996, the PSA was invited by the European Commission to attend a series of large-scale energy research facility Round Table discussions. During 1997 this Round Table activity took the form of a 'TMR-Concerted Action', incorporated in the contract. It was held in Paris, on 12th November, hosted by the CNRS-FAPS. The Commission's Scientific Officer explained what DGXII expects from this Concerted Action, as well as some guidelines about the upcoming V Framework Program. All the participants presented facility reports and some general topics for possible cooperation between facilities were discussed. The next meeting is to be held in Cardiff (UK) in April 1998, and the regular Round Table will be hosted by the PSA in September.

Fig. 6.7 The Annual Users Meeting in February

Third User Selection Panel. The panel met in Almería on October 30th to select the users to be given access during 1998. On this occasion, as some of the former members could not attend the meeting, some experts from the Round Table facilities were invited, thus giving them an opportunity for close contact with our facilities. In any case, the composition respected the proportion of CIEMAT members stipulated and was kept international.

First Annual Users Workshop. The object of this new activity was to give the users the opportunity to meet after their test campaigns and present their results for discussion. It was held on November 18th and 19th at Aguadulce, a coastal village near Almería. About 40 researchers attended the event, which was split in two parallel sessions, one of them on solar chemistry and the other on control of solar thermal applications, thus covering all the PSA research lines within the program.

All the presentations have been compiled and a book of the CIEMAT series has been published.

7. Summary of 1997 Meteo Data

The main PSA weather station has a complete set of sensors for all the important meteorological variables normally measured by world meteorological institutes, like wind speed and direction, air temperature, relative humidity, precipitation and pressures. The PSA follows WMO standards when any new equipment is purchased or sensors calibrated. However, it should be clear that the data measured by the PSA are not considered official within Meteorological Standards.

Andreas Holländer

The station also measures some variables of special importance for the work at the PSA. These are global, direct, diffuse and ultraviolet radiation, inclined global, ultraviolet and UVB radiation and ground temperature are also registered.

Miguel Angel Rubio (Doctoral Student)

Sensor values are reported every two seconds with extremes and averages every five minutes. Since 1988, about 150 Mbytes have been stored and evaluated for further use by projects.

Apart from the PSA station, the Spanish centre, Instituto Nacional de Meteorología, has an independent meteo station at the PSA which is not considered in this summary.

7.1 Evaluation of 1997 Meteo Data

7.1.1 Distribution of Direct Radiation

Fig. 7.1 shows that this year's direct radiation has not been very high. The direct radiation was highest at the end of winter and during the summer. The peaks at the beginning of the year are due to the good weather enjoyed in February and March. At the end of the year the weather worsened as demonstrated by the decrease in direct radiation.

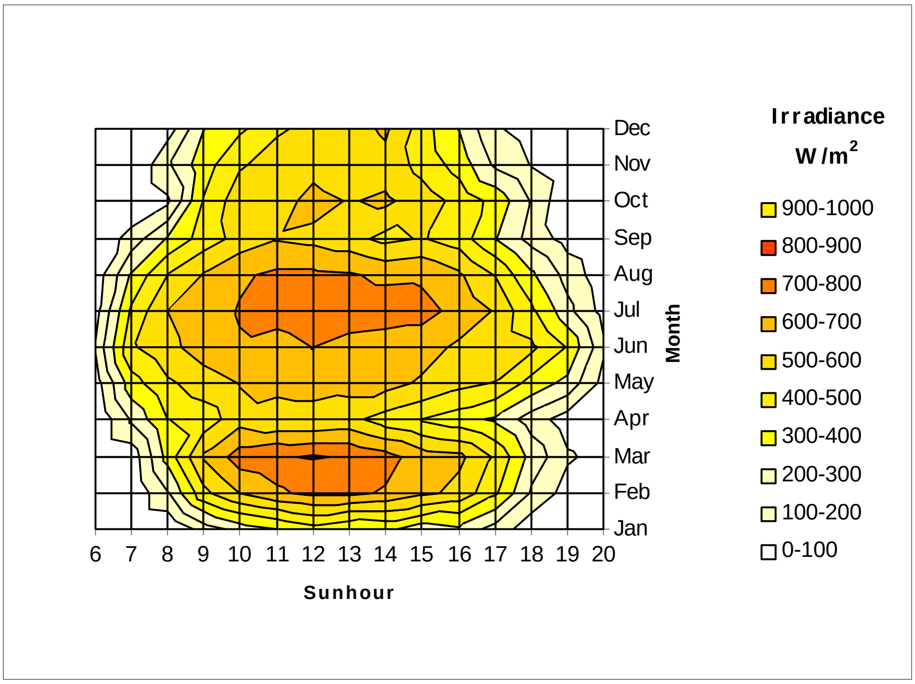


Fig. 7.1 Hourly averages values of Direct Radiation at PSA

During winter, the sky is more transparent in Tabernas due to the low aerosol levels, which allows a high direct radiation as shown is Fig. 7.2. The maximum of 1,021 W/m^2 was measured on the first of March.

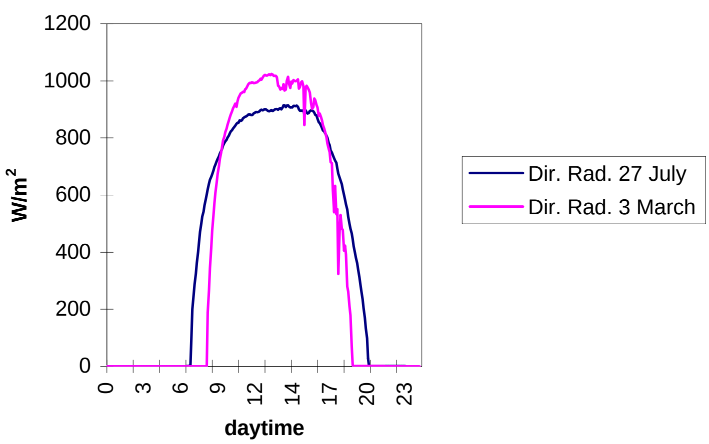


Figure 7.2 Direct Radiation on a cloudless day in winter and summer

In 1997 there were 3,016 hours with an average direct radiation over 300 W/m^2, which is an important value for solar thermal energy systems. This value is slightly lower as in previous years, due to the bad weather at the end of the year.

7.1.2 Global radiation conditions

Fig. 7.3 shows the yearly distribution of global radiation during the period. The maximum global radiation of over 900 W/m^2, occasionally over 1,000 W/m^2, was reached at midday in summer and peaking on the first day of June at 1,080 W/m^2. In February and March, due to the good weather conditions, over 800 W/m^2 were also reached.

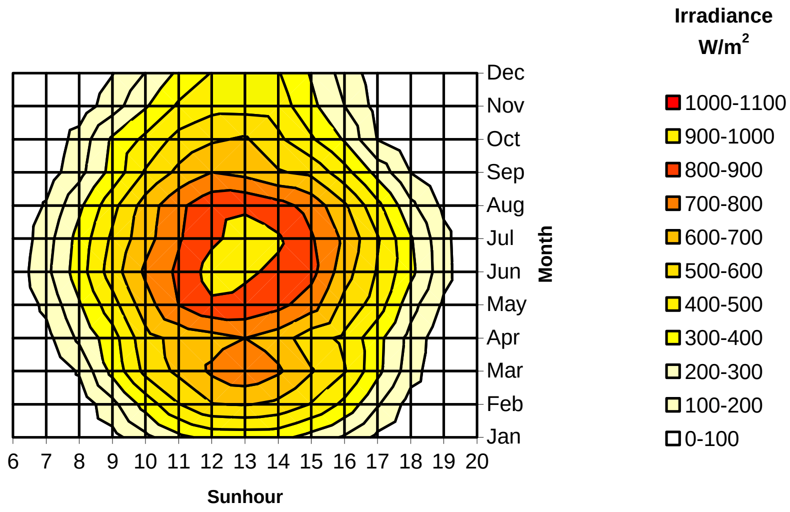


Figure 7.3 Average hourly and monthly value of Global Radiation

7.1.3 Temperatures

The diagram in figure 7.4 shows hourly average values of temperature in 1997. Comparing the behaviour of the temperature of the air at ground level and the global radiation the diagram shows that they are strongly correlated. The coldest time of the day is the early morning from 6 to 8 o'clock a.m., and the hottest is about 4 p.m. in the afternoon.

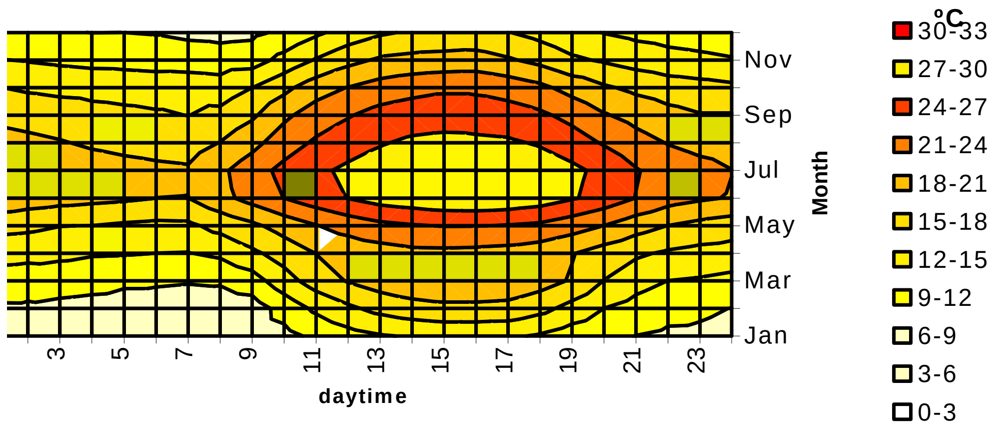


Figure 7.4. Monthly and Hourly averages of temperature

The minimum temperature was 2ºC, measured on the 7th of January. The maximum was 36.8ºC on the 27th of July. This year the range of temperatures was slightly lower than in 1996. The average temperature in 1997 was about 17.1ºC almost the same as the year before. The following graph shows the month minimums, averages and maximums.

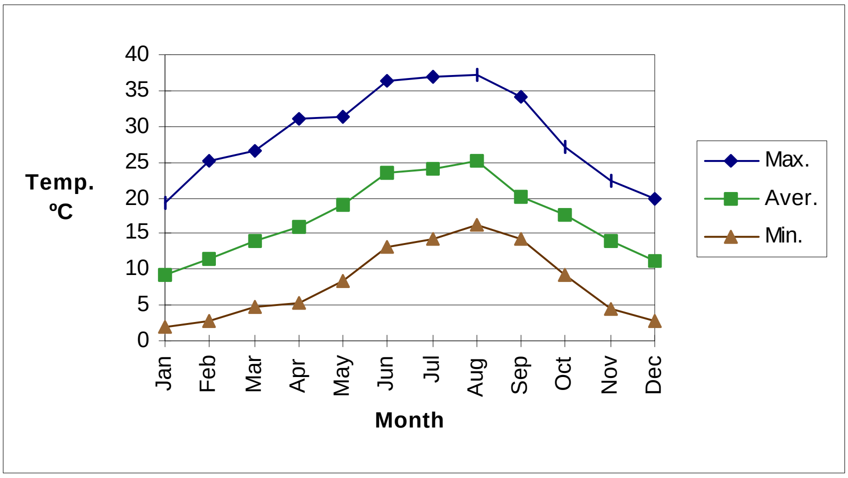


Fig. 7.5. Extreme and average values of temperature in 1997

7.1.4 Distribution of Relative Humidity

Observing Fig. 7.6, the amount of relative humidity in the air is related to the temperature at the location. The driest period is being the period with higher temperatures, around 4 p.m. in summer. The first hours in the morning at the end of the year have been very humid due to the bad weather we have had. The lowest value of stored relative humidity at the station is 22.9 % on the first of March.

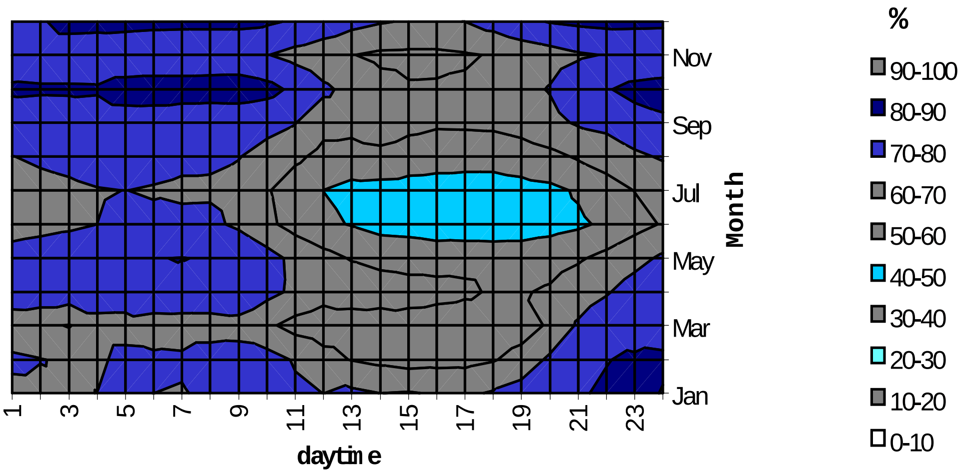


Figure 7.6. Monthly and Hourly averages of Relative Humidity

7.1.5 Wind Distribution in Tabernas

Fig. 7.7 shows the distribution of wind speed during the year. No strong winds are measured before noon and the strongest winds are from 3-6 p.m. The windiest season was summer.

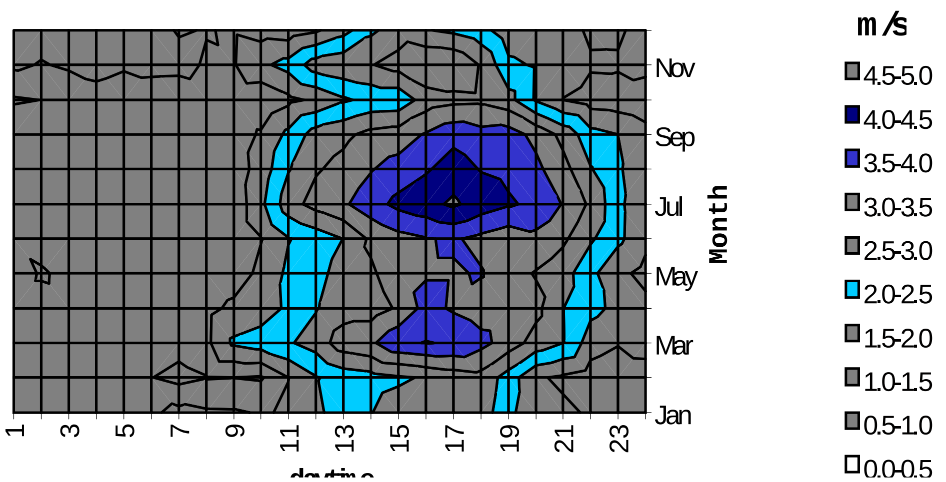


Fig. 7.7 Monthly and hourly averages of wind speed at 2 meters

In the following figure (Fig. 7.8), the relative frequency of the wind direction is shown. Almost 45% of prevailing winds blow from the Northeast and East and 22% from the Southwest. This pattern has been constant at the PSA since the meteo station was erected, probably because of the distribution of the surrounding hills.

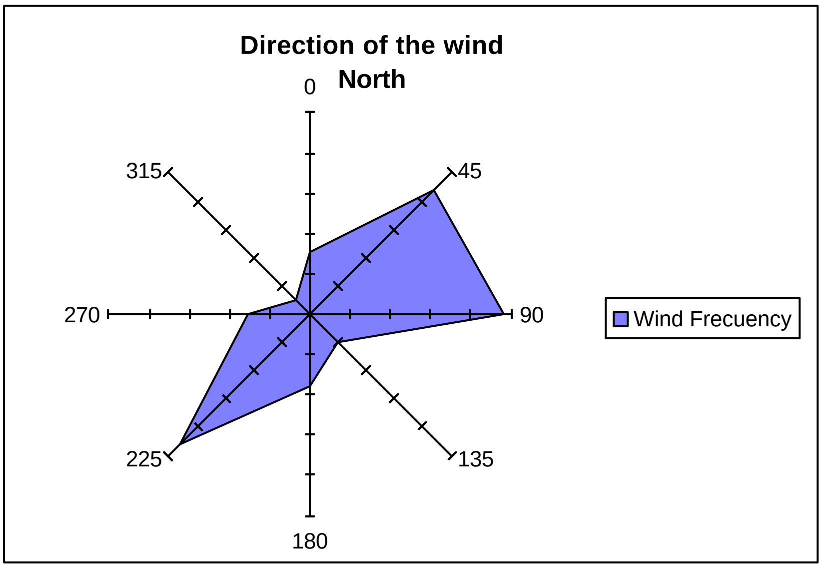


Figure 7.8 Relative frequency of the direction of the wind

ANNEX 1
PROJECTS

ARDISS
(Advanced Receiver for Direct Solar Steam)

Test Engineer: P. Balsa (on site)

Participants: CIEMAT
CONPHOEBUS
European Union DGXII
INETI
ZSW

Duration: **From**: December, 1994
To: March,1997

Funding: 1 MECU

Source: DG-XII
Partners

Objectives:

The objectives of this project are to analyze the constraints of Direct Solar Steam Generation in parabolic trough collectors and to develop an advanced receiver fulfilling the requirements of this process.

ARDISS is being developed with the financial support of the JOULE-II program. The project coordinator is the CIEMAT Institute of Renewable Energies (Madrid) and the PSA is only provides technical and experimental support. The specific project objectives are:

- The design, construction and testing of the concentrator/receiver.
- The theoretical and experimental analysis of Direct Steam Generation.
- The simulation of the solar power production system.

And the expected achievements are:

- Based on experimental research in the thermodynamics of direct solar steam generation in pipes, establish a basis for the development of an advanced parabolic-trough collector for solar power plants, enabling the thermohydraulic design and layout of a test-stand at the PSA.
- The assessment of the theoretical and experimental performance of the receiver with a second-stage concentrator and its effect on the DSG process.
- Assessment of the electricity production potential of the DISS concept and the concentrator receiver at different electricity loads in different locations and economic scenarios.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1996	0.2	0.27	0.1	0.2
1997				

BRITE-EURAM III Solardetox Project

Project Leader: J. Blanco

Test Engineers: S. Malato, B. Milow, C. Richter

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	Eng./ Main.	Oper.	Project Relat.	Students, etc.
1997	0.1	0.1	1.5	1.0
1998	0.2	0.3	2.0	0.5

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 by:

- Employing a high UV-transmissivity glass reactor (up to 90 %, 1-mm wall thickness) in the solar UV range (310 to 400 nm)
- Upgrading the solar collector design to minimize land required while avoiding losses from collector shadowing.
- Upgrading and supporting of catalysts
- Employing a highly UV-reflective surface (up to 95 %)
- Demonstrating technical and economic feasibility under real conditions.

Description:

C_1 and C_2 Non-Biodegradable Chlorinated hydrocarbon Solvents (NBCS), such as methylene chloride, trichloroethylene, tetrachloroethylene, chloroform and methyl chloroform, etc., are difficult to replace because they affect the process reaction and are compatible with most substrate materials. The traditional removal methods used in industrial process water such as stripping, adsorption by activated carbon, biological treatment, thermal or catalytic oxidation and chemical oxidation also have important disadvantages or limitations in the treatment of low concentrations of organic pollutants (from 20 to 50 ppm). Industry currently minimizes or eliminates solvents to cut down on the cost of hazardous wastes 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 go 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 a simple, inexpensive and efficient non-concentrating solar collector technology, such as the compound parabolic collector or flat collectors with tubular photoreactors, which seem to be the best technological solution. Such static collectors can capture the diffuse UV as well as direct sunlight (the diffuse component may represent up to 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 minimum 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. Under these circumstances, hydroxyl radicals, OH^o, which attack oxidizable contaminants, producing a progressive break-up of molecules into carbon dioxide, water and diluted mineral acids, are generated.

In addition to assessing its capacity for destruction, the 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 has derived from the solar thermal technology with only some minor modifications, the state of the art still requires specific technological developments which could significantly increase its efficiency.

Industrial systems are expected to be available within two years after termination of the project, and typical applications will use a field of up to a few hundred square meters. First market estimates show a huge potential in a large number of possible applications.

Status and Plans for 1998:

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

Main activities planned for the next period are the design and construction of collector prototypes which will be tested within the third 6-month period of the project. Main decisions defining the necessary hardware boundary conditions have already been taken.

Therefore the

- collector engineering and design will be done by CIEMAT, SETSOL and INETI,
- specific tests carried out at prototype systems and standardized conditions will be defined,
- production of the glass tubes of the collectors will be manufactured by SCHOTT, manufacturing of prototypes will be started by SETSOL
- 3 kg of new Cise catalyst will be produced to for the tests.

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 Electricidadm Sevilla
ENDESA, Madrid
Electricidade de Portugal, Lisbon
ABB
INABENSA, Sevilla
Babcock Wilcox Española, Madrid
PROET, Lisbon

Duration: **From**: 1997
To: 2000

Budget: 41.7 M ECU

Source THERMIE
Utilities (Sevillana, Endesa)

Man Power / Year:

Year	Main.	Oper.	Eng.	Project Related
1997	0.2	0	1	1.7
1998	0.2	0.1	1	1.7

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/m^2) and a field of 489 heliostats, each with 70 m^2 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:

At the end of 1997, the major parts of the first phase of the project had been finished and the engineering details had been specified. The prototype heliostat has been installed at the PSA (Plataforma Solar de Almería, Spain) and successful testing nearly completed.

Plans for 1998:

The main objective planned for 1998 is to start building the plant and to demonstrate its feasibility at full scale. So, the principal activities for the next year will be:

1. Manufacture
2. Erection

DISS-Phase I
DIrect Solar Steam in Parabolic Troughs

Project Leader: E. Zarza

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

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

Funding: 6,35 MECU

Source: DG-XII
Partners
IBERDROLA

Man Power/Year:

Year	Main	Oper.	Eng.	Proj-ect Relat.
1997				
1998	3	1	3.3	1.5

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 to transfer heat from the solar field to the conventional power block. The DISS RD&D project includes not only the development of a new technology (Direct Solar Steam generation in the absorber tubes), but also the improvement of the solar collectors and the overall system integration in order to increase the competitiveness and efficiency of this type of solar power plant.

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 thermal power plants. LUZ was able to continually increase efficiency while reducing costs. Unfortunately, these efforts were insufficient to withstand the reductions in conventional fuel costs and tax subsidies and the company collapsed. By that time, however, LUZ had identified a number of improvements that would have reduced 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 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 will be 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, Solel) 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 the design and implementation of such a real-scale test facility to be erected at the PSA.

Status:

The detailed design of the DISS test facility was 95% completed in 1997, and most of the equipment has been purchased by CIEMAT. System implementation started in June, 1997, and finalization of system assembly is expected by July, 1998. Technical constraints, imposed on the DISS test facility by the wide operating flexibility and peculiar working conditions to be experimentally validated, were studied and solved in 1997, though a delay in project planning was unavoidable. Part of the solar field foundations and the steel BOP building structure were also finished by the end of 1997.

Samples of ball joints designed and manufactured for high temperature/pressure have been tested in Almería. The positive results obtained have proven the technical feasibility of these components to allow rotation and thermal expansion of DSG absorber pipes.

The test stand to be used in future phases of the project to evaluate components for parabolic trough collectors under real solar conditions was implemented at the PSA. This flexible test stand, called the HTF test facility, is composed of half an LS-3 collector and a complete oil circuit (i.e., oil pump, oil cooler, oil heater and oil tank) able to operate up to 400°C.

Encouraging results in new selective coatings and antireflective films based on the Sol-Gel technique have been obtained by CIEMAT. Also, possible heat-transfer enhancement mechanisms in the DSG absorber pipes were studied and the analysis of inner porous coatings was started.

Plans for 1998:

The main work planned for the PSA DISS test facility 1998 is:

- finalization of the detailed engineering
- Erection
- Start up with preliminary trials

DISTAL II
(Dish Stirling Almería)

Project Leader: M. Stegmann, P. Heller

Test Engineer: W. Reinalter

Participants:

- Schlaich, Bergermann und Partner, Stuttgart
- Solo Kleinmotoren GmbH, Sindelfingen
- Klein & Steckl, Stuttgart

Duration: **From**: Jan. 1995
To: Dec. 1998

Funding: 4.5 Mio. Ptas (1997)

Source: PSA Basic Budget

Objectives:

The main objective of the project is to demonstrate the 'ready for market' design of the technology. As a third generation Dish/Stirling system, these dishes represent a big step toward optimized performance, automatic operation and cost.

Description:

The three systems consist of a 55 m² parabolic concentrator manufactured using the 'stretched membrane' technology. The concentrator tracks the sun with separate azimuth and elevation movement. At the focal point, a Solo V161 Stirling engine converts the solar energy into electricity. The system is designed for full automatic operation according to the current weather conditions.

Status:

The new systems were put into operation and first qualification testing was done. About 1000 hours of operation should be accumulated by the end of the year.

Plans for 1998:

Qualification testing will be continued and new improved components will be installed.

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1997	0.1	0.8	0.1	1.4
1998	0.1	0.3	0.2	1.4

El Ejido Solar Detox Project

Test Engineer: J. Blanco

Participants / Project Consortium:

- Ciemat-PSA
- Asociación Empresarial para la Protección de las Plantas (AEPLA), Madrid.
- Ibacplast S.A., Almería.
- Ecosystem S.A., Barcelona.
- Diputación Prov. de Almería
- Council of Adra, Almería.
- Council of Almería.
- Council of Berja, Almería
- Council of Dalías, Almería
- Council of El Ejido, Almería
- Council of La Mojonera, Almería
- Council of Níjar, Almería
- Council of Roquetas de Mar, Almería
- Council of Vícar, Almería

Duration **From**: 1995
To 1998

Funding: 0,8 million Pts. (in 1997)

Source: Consortium

Man Power / Year:

Year	Eng. / Main.	Oper.	Project Relat.	Students, etc.
1997	0.2	0.2	0,5	0.2
1998				

Objectives:

Feasibility study for a solar detoxification plant for the treatment of wastewater from the industrial washing of plastic herbicide containers

Description:

Agriculture activities in the Mediterranean area clearly represent a very important sector of the economy. Moreover, in the last decade, this has significantly increased with the expansion of greenhouses and intensive agricultural techniques. As its productivity and economic importance have risen, the sector has also become more complex with associated problems that strongly threaten the environment. This is particularly reflected in the contamination of water by the extensive use of chemicals and pesticides, and their removal is a pressing ecological problem. Such persistent organic chemical contaminants include pesticides, solvents, detergents and a variety of industrial chemicals which, due to the combination of their chemical stability, resistance to biodegradation and sufficient water solubility, penetrate deep into the soil to groundwater.

The Spanish province of Almería is a perfect example of important economic growth during the last 15-20 years, chiefly due to large numbers of greenhouses, for which it has an excellent climate and which, unfortunately, is also accompanied by intensive use of a wide variety of pesticides. One aspect of this is an increasing problem of empty plastic herbicide containers (in Almería alone, around 1.5 million of these containers per year), which are usually burnt or buried. Recently, a parallel rise in environmental consciousness is concerned about their recycling. However the recycling process includes washing the shredded plastic containers, which contaminates the water used with relatively small amounts of highly toxic persistent compounds at concentrations of several hundred mg/l total organic carbon content.

Solar photocatalytic detoxification with TiO_2 would appear to provide a very promising and economical solution to this problem, which has no clear alternative solution since the biological purification of water polluted by organic micropollutants is quite inefficient at low substrate levels. Solar photocatalytic detoxification, however, using the interaction between ultraviolet radiation and the semiconductor catalyst, titanium dioxide (TiO_2) to promote a strong oxidation reaction, mineralizes low to medium concentrations of organics present in water, making it reusable.

Its strong potential for the industrial destruction of toxic organics in water has been widely demonstrated in recent research. The most energetic part of the solar spectrum, the ultraviolet wavelength under 400 nm, photoexcites the semiconductor catalyst in the presence of oxygen, promoting a strong oxidation reaction and hydroxyl radicals (OH^o), which attack oxidizable contaminants, are generated, progressively breaking up the molecules into carbon dioxide, water and dilute mineral acids. The most commonly used catalyst, TiO_2, is the semiconductor titanium dioxide, a non-toxic, cheap and abundant product commonly used in the manufacture of paint. In principle, the process is able to oxidize almost any chemical substance.

The PSA, has promoted the formation of a consortium of municipalities and private companies to set up a complete pesticide container recycling process in which the water needed is treated and reused. This includes detoxification testing of waste water samples, and the design and construction of a solar detoxification plant at the recycling center.

Status:

Phase I was concluded at the beginning of 1997 and Phase II is currently under study. In this second part of the El Ejido Solar Detox Project a new Solar Photocatalytic Facility is going to be built on the bottle-recycling site to test real wastewater at Pilot Plant level.

The wastewater treatment plant and the plastic recycling plant are going to be connected in series during this period in order to obtain more realistic results. With the information obtained during Phase II the dimensions of the installations could be predicted. This pilot plant is to be enlarged to definitive size at the end of this phase. This is possible due to the modularity of this kind of Solar facility. By adding more collectors and related equipment, the First Solar Photocatalytic Detoxification Plant can be put into operation.

Heliostat Technology Program (ASM-150, GM-100)

Project Engineers: P. Heller, R. Monterreal

Participants:

Ciemat (Design and control GM100)

- Pujol Muntala (drive mecanism GM100)
- JUPASA (construction and erection GM100)
- L&C Steinmüller (Design and construction ASM150)
- Schlaich Bergermann und Partner (Design ASM150)
- Fichtner Development Engineering (control ASM150)
  PSA (Tests and Evaluation)

Duration: **From**: Jan. 1996
To: Dec. 1997

Funding: 4.7 Million Ptas (1997)

Source: PSA Basic Budget

Objectives

Test and comparison of two new large area

Description:

Within the "Heliostat Technology Program", two large heliostats were investigated from 1994 to 1997:

- GM100, with 100 m² mirror area, 32 rectangular metal-glass facets
- ASM150, with 150 m² mirror area, circular stretched membrane

The 100-m² GM-100 and the 150-m² ASM-150 both comply with Phoebus power tower specifications. After erection, their optical quality, energy consumption, wind-load behavior and costs were compared.

Status:

In 1997, measurements demonstrated the very high optical quality of the ASM-150, a still acceptable quality for the GM-100 and a reasonable energy consumption of both during operation. A new canting procedure developed at the PSA helped adjust the GM-100 facets with greater precision. The costs of both heliostats are on the order of US$200-270 per m² for a 30 MW power plant.

The project was finished with the final internal report describing both heliostats and the results of their comparison.

Plans for 1998:

Having completed the project in 1997, the heliostats will be operated for demonstration purposes only.

Man Power / Year:

Year	Main.	Oper	Eng.	Project Relat.
1997	0.1	0.3	0.5	0.2
1998				

HYHPIRE
(Advanced Hybrid Heatpipe Receiver)

Project Leader: M. Stegmann, P. Heller

Test Engineer: W. Reinalter

Participants:

CIEMAT, Madrid
DLR-TT, Stuttgart
IKE, Sweden
Intersol, Sweden
Schlaich, Bergermann und Partner, Stuttgart

Duration: **From**: Jan. 1996
To: Dec. 1998

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 burner for propane gas and to demonstrate the maturity of the technology. Additional tasks are the development of a cost effective manufacturing method for porous structures and a study about the market potential for hybrid Dish/Stirling systems in Marroc.

Description:

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

Status:

The design of the receiver is terminated and most parts are completed so that the heat pipe can be assembled, filled and tested in early 1998. After laboratory testing of the receivers they will be packaged with a SOLO V161 engine and shipped to PSA.

Plans for 1998:

The preparation of the test site (DISTAL II test facility) will be completed. As soon as the new packages will arrive they will be put into operation and will be evaluated.

Man Power / Year:

Year	Main.	Oper	Eng.	Project Relat.
1997	0	0	0	0.4
1998	0.1	0.5	0.1	0.4

LAGAR Project

Test Engineer: S. Malato

Participants:

- 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: 2000

Funding: 0,94 million ECU (total budget)

Source: UE DGXII

Man Power / Year:

Year	Eng. / Main.	Oper.	Project Relat.	Students, etc.
1997				
1998	0.1	0.1	0.5	0.2

Objective:

Our objective is the development of the best (e.g. cheapest) possibility of utilizing solar photochemical detoxification of wastewater for the mineralization of recalcitrant phenolic contaminants typically found in the soluble organic fraction of olive mill wastewater (OMW) on a pilot-plant scale. The basic idea is that Advanced Oxidation Processes can be used to pretreat olive mill waste waters (OMW), since the toxic aromatic compounds are preferably mineralized by AOPs.

Description:

The efficiency of four different photochemical reactors using solar irradiation captured by simple, inexpensive and efficient non-concentrating solar collector technology for the detoxification of olive mill wastewater (OMW) by oxidative photocatalysis will be compared with regard to both technical and economic aspects, and those selected will be installed in a small pilot plant under the real industrial conditions found in two factories, one in Portugal and another in Greece. At the end of the project, the treatment systems will be economically assessed considering the relationship between process cost, degree of detoxification achieved and final destination.

This project is part of the development of a new process to convert olive mill wastewater into fertilizer. The same process can be used for fish-processing wastewater thus eliminating a major problem of such small and medium industries.

One common problem of the AOPs is the high electrical demand of ozonizers or UV-lamps. Therefore the total costs of these processes are usually high. A very promising possibility for cost reduction would be the application of solar irradiation to the photochemical processes. This is only possible for the Photo-Fenton reaction and TiO_2, because O_3 and H_2O_2 alone do not absorb λ>300nm light, which is the main precondition for the use of sunlight.

In summary, the energy efficiency (with sunlight) and the innocuousness of the chemicals applied may be said to make

Photo-Fenton with TiO_2 the ideal method for wastewater treatment.

Status:

The Project was approved in 1997 and will formally begin in 1998.

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

Test Engineer: M. J. Jiménez

Participants: CIEMAT
DLR
EU DGXII
Univ. Politécnica de Madrid
Univ. Politécnica de Cataluña

Duration: Continuous CIEMAT action since 1987

Funding:

Source: CIEMAT
DLR
EU
Industry
University

Man Power / Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1997	1		0.2	6	2
1998	1.8		0.2	6	2

Objectives:

- Testing of construction materials and passive solar components or techniques using real-scale outdoor test cells to asses the reliability of these elements for saving energy in buildings.
- Study of the thermal transfer process in passive solar energy applications as well as climatic resources for use in natural air conditioning techniques.
- Establishment of standard testing and quality procedures for the integration of the LECE Laboratory into the ENAC network.
- Participation in studies on the integration of solar active energy systems (photovoltaic tiles, solar collectors, etc.) into buildings.
- Market survey of passive solar components and buildings materials suitable for energy optimization in buildings and publication of passive solar techniques.

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 cells 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. Besides it has participated and is participating in CIEMAT initiatives for third parties, such as the Junta de Andalucía, Universidad Politecnica de Madrid, Universidad Politecnica de Cataluña or 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 1998:

In 1998 three main projects under the JOULE program will be undertaken, the ROOSOL project, for passive cooling technique, the PV-Hybrid project, for the caracterization of photovoltaic modules and APISCO which studies the application of plants for the thermal quality improvement in buildings.

There is also one agreement with the Polytechnic University of Cataluña to characterize four types of special bricks and one agreement with the Polytechnic University of Madrid to contribute in the regulations for this type of laboratories.

The LECE will also be in constant renovation to adapt itself to the new market demand, one of the field in which we plan to take this task is the area of the translucid components 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

Objectives:

The overall aim of the MEDUCA project is to demonstrate that energy-efficient educational buildings, where the requirements for an attractive and healthy indoor environment are fulfilled, can be designed and built. This is to be achieved through new construction and refurbishment combining conventional and innovative technologies. The aim is to create educational buildings, which stand out as 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 co-operation.

Description:

The project will be implemented in the University of Almería. This University is situated a 100 meters away from the sea shore. The peak average temperatures on the area are of 28ºC. The lowest average temperature is of 16ºC. The humidity levels are around 60% of relative humidity in the summer.

The project consists on the refurbishment of four buildings by construction, on top of the patio they constitute, an atria. The aim is the climatization of the patio and the buildings that conform it. The buildings that will be used in the project are not surrounded by any other sun light obstacles that could project any shade into the atrium. The dimensions of the patio are a floor of 400 m^2, with a height of 12 meters. There are four doors, of approximately 2 x 2 m, that give entrance to the patio and that will be used as access for the air currents needed for the refrigeration phase, as well as for air-recirculation openings and heat re-distribution areas

Man Power / Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1997	0	0	0.1	0.1	0
1998	0	0	0.1	0.1	0

during the winter. There are also a number of windows that will be used to recirculate the air and hence climatise to a certain degree the buildings.

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

In winter, ventilators driven by photovoltaic energy, will recirculate hot air accumulated close to the atrium toward the bottom of the patio. Also will be used to this end the calculated cross ventilation currents, generated naturally by the pressure difference, created by the temperature difference, of the patio with respect to the buildings and the outside.

Status:

During 1997 the PV installations and the refrigeration unit were designed. The procurement of equipment will be done at the beginning of 1998.

Plans for 1998:

Finalize system installation and startup of operation and evaluation.

PAREX

Test Engineer: P. Balsa (on site)

Participants: CIEMAT
DLR

Duration: **From**: 1995
To: 1998

Funding: German Ministry projectct

Source: 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 or direct steam generation.

Description:

A number of new receiver concepts will be evaluated by analytical and numerical methods to select promising configurations to be built and tested. These concepts comprise:

- secondary concentrators
- linear cavities
- heat pipe
- multiple pipes

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

Tests were performed as planned at the PSA´s ARDISS test loop facility. During 1996, three PAREX prototypes PAREX 00b, PAREX 001 and PAREX 002 were evaluated.

Since up-scaling of promising concepts to a commercial size collector (LS-3) is desirable, the 400ºC HTF oil loop, consisting of half an LS-3 collector, will be used to perform the second test campaign of similar larger-sized prototypes at the PSA.

REFOS Project
(Volumetric receiver for solar-hybrid gas-turbine and combined-cycle systems)

Project Leader: R. Buck, DLR

Project Engineer PSA: P. Heller, E. Lüpfert

Participants: DLR Stuttgart

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

Funding: 99.000 ECU (PSA 1997)
2.8 million ECU total project

Source: BMBF, Germany
DLR, Germany

Objectives:

The aim of the REFOS project is to demonstrate the feasibility of the modular pressurized volumetric receiver concept with modules having a nominal power rating of 350 kW each. This modular receiver concept enables power scale-up as required.

Description:

The project includes design, construction and testing of 3 modular pressurized receiver units, each with a secondary in front. The receiver modules will be tested at up to 1 MW_{th} power under representative operating conditions (air inlet/outlet temperatures: 400°C / 800°C; pressure 15 bar_{abs}).

Status:

- Test site at 60-m-level on CESA-1 prepared with new cooling cycle and radiation protection shield
- Structure, secondary concentrator and calorimeter mounted
- Equipment, measurement devices and data acquisition ready to operate

Plans for 1998:

- Test campaign for secondary concentrator output power and performance for different aiming-point strategies
- Erection of first closed receiver module
- Test campaign for first receiver module
- Evaluation and reporting

Man Power / Year:

Year	Main.	Oper.	Eng.	Project Related
1997	1	0.5	1	2
1998	1	1	2	2

SolWin
(A performance and financing tool for solar thermal power plants)

Test Engineer: Frank Schillig

Participants: DLR, SunLab (USA)

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

Funding: None

Source: Not Applicable

Man Power / Year:

Year	Mai	Op.	Eng	Project Relat.	Stu-dents, etc.
1997				0.1	2
1998				0.1	2

Objectives:

Development of a software tool for the technical and economical evaluation of solar thermal power projects. This tool is directed to users that are not familiar with solar thermal technologies introducing the user to the technology and providing information on the various technical and financial aspects. Furthermore, it is intended to develop a standardised tool to be used widely amongst the engineers and scientists who are involved in solar thermal power project development.

Description:

The core of SolWin is a detailed cash flow model, so that all important project parameters, such as the Internal Rate of Return (IRR) and the levelized electricity costs (LEC), and the financial viability of solar thermal power projects may be examined. Further intermediate results are technical performance data, environmental benefits and resource consumption of the power project. In addition, it also enables sensitivity analysis and the optimization of technical and economic parameters.

Status:

In 1997, database access and software file and project management structure were programmed. Moreover, a graphic interface for displaying data and simulation results has been completed. A unit transformer to facilitate the use of different unitary systems (SI and US) was implemented. The economic and cash flow model for project financing was developed. a model for power tower projects was also developed and programmed.

Plans for 1998:

Trough and dish plant cash flow models will be implemented in 1998. Within the scope of a scientist exchange program between PSA and SunLab (USA), two guest scientists from Sunlab will stay at the PSA for approximately 3 months each to help with development, in particular, trough and the dish performance models. Furthermore, the final design of the user interface will be completed.

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

Test Engineer: Frank Schillig

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 the EU project, THESEUS, is the implementation of the first large-scale (50-MW_e nominal capacity) European parabolic trough power plant on Crete, to be designed, licensed and erected within 4 years, starting beginning of 1997.

Description:

The proposed THESEUS project consists of a nominal 52-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 in the county of Sfakia. 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 52 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:

In 1997, significant work was performed on the political and regulatory framework required for project implementation. Further work concentrated on site and engineering preparatory to conceptual plant design. Collector cost estimates were refined and a preliminary economic analysis, based on rate structures reflecting the Cretan power system time-of-use preference was also carried out. Thorough research has been done on the potential ownership structure in light of the latest interpretation of the law and liberalization of the Greek power system which is progressing well.

Plans for 1998:

The following elements of the project are to be completed within the next six months:

- Final decision on site location,

Man Power / Year:

Year	Main.	Oper.	Eng.	Project Relat.	Students, etc.
1997				0.9	1
1998				0.9	1

- Completion of conceptual plant design for power block and BOP, site analysis, solar field structural design and drawings and civil engineering design,
- ownership structures and related legal negotiations and clarifications.

The following tasks already initiated will be continued:

- preparation and submission of site approval application,
- preparation and submission of environmental impact assessment
- request for bids for major equipment, detailed cost estimate and economic analysis,
- formation of supply consortium,
- execution proposed dissemination strategy,
- completion of environmental and social impact studies.

TMR
(Training & Mobility of Researchers Program)

Project Manager: Diego Martínez

Participants: Commission of the European Communities-DG XII

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

Funding: 264 Million Pts.

Source: CEC-DGXII

Man Power / Year:

Year	Main.	Oper.	Eng.	Project Relat.
1997	-	-	-	0.8
1998	-	-	-	0.8

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 currently has 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 offers 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 includes all infrastructure, logistic, technical and scientific support that is normally provided to external users of the facility.

A minimum of 50 different groups will benefit by the end of this contract, with a minimum of 28 groups to be given access per year.

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

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

Two types of access are offered:

- **Access-to-Research:** The research group is 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 two weeks to two months.
- **Access-for-Training:** This option is addressed to individual users who receive a comprehensive overview of all the industrial applications of solar energy currently under development at the PSA and have the oppor-tunity to take part in ongoing projects. Typical duration is between three and six months.

Status:

The program is now in its third year at PSA. By the end of 1998, 50 different groups will have participated.

Plans for 1998:

In addition to the 'Access to Research' activity, four researchers were accepted in the last 'Selection Panel' meeting for 'Access for Training'.

A 'TMR Users Workshop' similar to the one held in 1997, but with wider scope and longer duration, is planned for 1998.

Under activity number 4, 'Accompanying Measures', the organization of a Summer School will also be undertaken in 1998. This 'Summer School' will be composed of two week-long courses, one in July devoted to electricity generation and the second in September, concerning solar chemistry.

The 'TMR Concerted Action' Round Table for energy research facilities will also be holding meetings and perhaps, in 1998, joint research activities.

TMR Desalination

Test Engineer: P. Balsa

Users 1997:

University of Ulster (UK)

Heliostat Ltd. (Gr)

Duration: **From**: 1996 to 1998

Funding Source: CEC DGXII: Training and Mobility of Researchers Program.

Objectives:

The shortage of drinking water affects many countries in the third world, which also lack conventional energy resources. The desalination plant market has greatly increased during recent decades. Many plants have been installed worldwide, achieving a total daily production capacity of $13x10^6$ m^3 of desalted water in 1989 (this is taking into account only those plants with a capacity equal to or greater than 100 m^3/day).

For the above mentioned reasons the solar desalination plant was included in the TMR proposal in order to promote solar desalination among European Countries.

Description:

The solar collector test bed supplying heat to the PSA desalination plant was checked by Heliostat Ltd. They consider it of even better quality than the one currently installed in Greece for testing the innovative solar collector designed by Heliostat.

University of Ulster analyzed the full solar desalination plant energy chain. This study demonstrated the low pollutant emissions level of the plant in comparison with conventional ones.

TMR Detoxification Project

Test Engineer: S. Malato

Participants:

- INETI (Instituto Nacional de Engenharia e Tecnologia Industrial), Portugal.
- ISFH (Institut für Solarenergieforschung GmbH Hannover), Germany.
- TUW (Institut für Physikalische Chemie. Technische Universität Wien), Austria.
- CNRS (Ecole Centrale de Lyon. Photocatalyse, Catalyse et Environement), France
- Other EU Institutions for the next years

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

Funding: 4,5 million Pts. (in 1997)

Source: UE DGXII / PSA

Man Power / Year:

Year	Eng. / Main.	Oper.	Project Relat.	Students, etc.
1997	0.2	0.5	1	0.2
1998	0.2	0.5	1	0.2

Objectives:

1. Determine the best conditions for degradation of organic substances by Solar Photocatalysis.
2. Optimize the change of scale from laboratory to pilot plant.
3. Train UE research groups in solar photocatalysis.

Description:

The photocatalytic degradation of organic compounds with illuminated TiO_2 is very well documented in the literature. The illumination of TiO_2 (band-gap energy, E_G = 3.2 eV) in water with less than 387-nm-wavelength light generates excess electrons in the conduction band (e^-_{CB}) and positive "holes" (h^+_{VB}) in the valence band:

$$TiO_2 + hu\ (\geq E_G) \longrightarrow e^-_{CB} + h^+_{VB}$$

•OH radicals are extremely reactive and readily attack organic molecules degrading them to CO_2 and H_2O (and inorganic ions when the organic molecule contains other atoms).

Due to environmental concerns and reasonable expectations for this process’s technical and economic feasibility causing a rising interest in Solar Detoxification research, the PSA and other UE research groups with long experience in basic research, but lacking pre-industrial development, are carrying out R&D programs on Solar Water Detoxification. The aim of this Project is to go from laboratory to pilot scale developing effective systems to destroy toxic compounds in industrial wastes by means of solar radiation. This step is essential to make practical applications feasible, which seems attainable in the near future thanks to its technical and economic attractiveness for sunny locations.

Two different PSA facilities are used in this project: medium concentrating systems (parabolic collectors, PTC) and low concentrating systems (compound parabolic collectors). In both cases, a slurry of contaminated water and catalyst (titanium dioxide, TiO_2) is prepared in tanks and fed into the photoreactor. The systems are operated in a discontinuous manner by recirculating the slurry solution through an intermediate tank with a centrifugal pump.

High flow rates are used because of the slow kinetics of degradation, and a complete-mixture regime is assumed (that is, the contaminant concentration is the same everywhere in the system at any given time). Under these experimental conditions, photodegradation of all the experimental mixtures is sufficient to evaluate feasibility of the data treatment. Three sensors for UV-light measurements are used, one for global UV over the horizontal surface installed normal to the earth's surface, a second for global UV over a 37º-inclined surface installed on the CPC support frame and the other for direct UV (International Light-SED 400), mounted on a sun-tracking platform. Global and direct UV irradiance are measured throughout the experiments, permitting the evaluation of hour-dependent incident radiation, clouds, atmospheric turbulence and other environmental variations.

Parabolic Collectors. This photochemical reactor consists of a 12-module Helioman-type system (Man, Germany) with a total reflective surface of 29.1 m^2. Depending on system configuration, it is possible to calculate the residence time (t_R) as the relationship between the total volume of water in the reactor (V_T), the volume of the glass tubes (V_R) and reaction time (t): $t_R = V_R\ t\ V_T^{-1}$. The reaction time is the difference in time between the initial sample (initial concentration of the pollutant, t = 0) and samples collected during the experiment (t > 0).

CPC Collectors. The present configuration of the PSA CPC field has 6 modules (total reflective surface 8.9 m^2) connected in series and mounted on a fixed platform inclined 37º to maximize performance (the PSA is located at latitude +37º). Each CPC module (Industrial Solar Technology Corporation, Denver) is 1.22 m wide and 1.22 m long (See Figure 1) and consists of eight parallel CPC reflectors (152 mm wide) with UV-transparent tubular receivers (I.D. 48 mm). The acceptance angle for the CPC is 60 degrees either side of normal incidence. Polished aluminum is used as the reflective material because it is highly reflective in the UV range (0.829-300 nm, 0.861-325 nm, 0.834-350 nm, 0.810-375 nm and 0.890-400 nm) and fluoropolymer is used for the tube receivers because it is inert and has excellent UV stability and transmissivity (0.735-300 nm, 0.765-325 nm, 0.780-350 nm, 0.822-375 nm and 0.846-400 nm). The 6 modules are connected in series so that the water flows directly from one to the other and finally to the tank. A centrifugal pump then returns the water to the collectors. At the beginning of the experiments, with collectors covered, all the chemicals are added to the tank and mixed until constant concentration is achieved throughout the system. Then the cover is removed and samples are collected at predetermined times. The residence time (t_R) is calculated by the procedure explained above.

Status:

Activities during 1996 have been centered on solar degradation of different organic compounds with TiO_2 and a Photo-Fenton reagent. 4 different UE research groups have been at PSA for 1 month each. The future plan of work is focused on three goals, testing different catalysts, solar collector comparison and the training of researchers.

TMR Control

Test Engineer: P. Balsa

Users 1997:

- INTEGRAL Gmbh (Ger
- INESC, Lisboa (P)
- Univ. of Oulu (Fi)
- Univ. of Firenze (It)
- Univ of Ruhr-Bochum (Ger)

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

Funding Source: CEC DGXII: Training and Mobility of Researchers Programs.

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 only 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's DCS facilities and the flexible and reliable control software provide a very valuable versatile testbed which has been used by several research groups for this purpose, experimentally testing different control systems in these facilities.

TMR DISTAL

Project Leader: M. Stegmann, P. Heller

Test Engineer: W. Reinalter

Participants in 1997:

Schlaich, Bergermann und Partner, Stuttgart

Duration: **From**: Jan. 1997
To: Dec. 1997

Funding:

Source: PSA Basic Budget
CEC-DGXII

Objectives:

Within the EU Program 'Training and Mobility of researcher (TMR)' the PSA offers access to the Dish/Stirling test site (DISTAL I).

Description:

The DISTAL I test facility consists of three SBP Dish/Stirling systems with an nominal output of 9 kW_{el}. The parabolic concentrators with an diameter of 7.5 m use a 'polar' tracking system to follow the sun during the day. To the focal point a SOLO V160 Stirling engine is attached. The facility is equipped with a extensive measurement system.

Status:

The three Dish/Stirling units now have been operated for about 29.000 hours on the sun (about 3.500 hours within 1997). In 1997 the tracking accuracy of the dish/Stirling system was subject of evaluation of an enginieer of SBP during a one week stay supported by this EU program.

Plans for 1998:

Three users have applied for a stay at the DISTAL test site.

Man Power / Year:

Year	Main.	Oper	Eng.	Project Relat.
1997	0.1	0.2	0	0.2
1998	0.1	0.2	0	0.2

TMR Solfin Project

Test Engineer: C. Richter

Participants:

- CNRS-ICSN (Institut de Chimie des Substances Naturelles), France.
- Department of Organic Chemistry, University of Pavia, Italy
- Department of Chemistry, University of Reading, England
- Department of Organic Chemistry, Univ. Complutense, Madrid, Spain
- Chemistry Department, Dublin City University, Ireland

Duration **From:** 1996
To: 1998

Funding: 3,5 million Pts. (in 1997)

Source: UE DGXII / PSA

Man Power / Year:

Year	Eng. / Main.	Oper.	Project Relat.	Students, etc.
1997	0.2	0.3	1	0.2
1998	0.2	0.3	1	0.2

Objectives:

1. Train UE research groups in solar photochemical synthesis.
2. Identify photochemical synthesis with potential for further upscaling
3. Determine best chemical conditions for solar photochemical synthesis of fine chemicals
4. Optimize the change of scale from laboratory to pilot plant.

Description:

In recent years growing effort has been spent to apply solar radiation directly to the photochemical synthesis of fine chemicals with present or future market potential. Due to their selectivity, photochemical reactions frequently allow a clean pathway to the target compounds and this advantage can be increased considerably by direct application of a renewable energy source like the sun, if the spectral absorption characteristics of the reaction system are suitable.

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 as the SOLFIN photoreactor.

The photochemical receiver/reactor installed consists of a CPC-collector with aluminium reflectors and Duran glass-tubes with an optical concentration factor of 1, total aperture 2 m^2 and an irradiated volume of up to 10 l. It is connected by polyethylene and corrugated Teflon tubing in a closed loop with an overall volume of 10 - 20 l to a gear pump, process cooler, solvent supply vessel, gas supply and instrumentation to monitor temperature, pressure and flow within the loop.

In 1997, 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. The cooling water is circulated through the inner compartment of the cooler. The total volume of the circuit is 1 L, including the 250 ml glass bottle with bottom inlets for inert or reactive gases and a sampling outlet. All components are interconnected by flexible corrugated PTFE tubes.

The Solfin facility is used by various European research groups with funding from the EU TMR Program to test the feasibility of their synthetic reactions under these conditions. Thus a great variety of synthetic reactions are tested and promising candidates for further optimization can be identified. At the same time young graduate research chemists from these institutes learn about the feasibility of direct application of solar radiation for photochemical synthesis, in accordance with the guidelines of the funding EU.Program for Training and Mobility of Researchers.

TSA
Phoebus Technology Program Solar Air Receiver

Test Engineers: P. Heller, A. Valverde

Participants:

- L&C Steinmüller (Design, fabrication, assembly of new absorber elements)
- University of Seville (Automatic Aiming-Point Strategy)
- PSA (Tests in Cesa-1, Evaluation)

Duration: **From**: Jan. 1997
To: Dec. 1997

Funding: 2.2 Mio Ptas (1997)

Source: PSA Basic Budget

Man Power / Year:

Year	Main.	Oper.	Eng.	Project Relat.
1997	0.6	0.4	0	0.2
1998	0.5	0.2	0	0.2

Objectives:

- Test and evaluate the 22 new absorber elements
- Reconnect the TSA receiver system to the grid

Description:

At the end of 1996, 22 absorber elements were replaced with a new enhanced design and additional thermocouples were mounted for their evaluation. It had to be shown that the temperatures in the gap between the elements do not effect the efficiency of the receiver due to improper design. A 100-h test at moderate temperatures was performed to identify problem zones on the elements.

Status:

The tests could be finished in 1997. The measurements of the gap temperature between the new elements showed the intended behavior. The gaps closed with rising receiver temperature according their design. The temperature distribution received by measurement with the IR camera and thermocouples showed the potential of improvement by enhancing the manufacturing process of the wire mesh.

In June the TSA system was reconnected to the grid and is producing electric energy whenever the concurrent projects in the Cesa-1 tower allow for.

Plans for 1998:

Keep the TSA operational to demonstrate the reliability, the easy handling and the future potential of that system ready for market entry. The system will continue to be operated in grid connected mode.

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APPENDIX 2

LIST OF COLLABORATING INSTITUTIONS AND COMPANIES

LOW TEMPERATURE AREA

Belgian Building Research Institute Test Centre (BBRI)
AV. P. Holoffe,21
B-1342 Limelette
Belgium

Conphoebus
Zona Industriale
Casella Postale
I-95030 Piano d’Arci (Catania)
Italy

Departamento de Tecnología de la Edificación de la EUAT de la UPM
Escuela Universitaria de Arquitectura Técnica
Avenida Juan de Herrera, 6
E-8040 Madrid
Spain

Joint Research Centre Ispra
*Institute for System Engineering and Inform*atics (*JRC)*
Bldg. 45
I-21020 Ispra (VA)
Italy

Hunter Douglas, S.A.
Avenida de la Justicia 48
28100 Alcobendas (Madrid)
Spain

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

TNO Building and Construction Research
Dept. of Indoor Environment
P.O. Box 29
2600 AA Delft
The Netherlands

UMSICHT Institute for Environmental, Safety and Energy Technology
Osterfelder Strasse3
D-46047 Oberhausen
Germany

University of Patras
Department of Physics
Solar Energy Laboratory
26500 Patras
Greece

PARABOLIC TROUGH AREA

Deutsches Zentrum für Luft- und Raumfahrt e.V.
Inst. for Techn.Thermodynamics
(DLR EN-TT)
Pfaffenwaldring 38-40
D-70569 Stuttgart
Germany

Escuela Superior Ingenieros Industriales
Dpto. de Automática
Prof. Eduardo Fernandez Camacho
Avda. Reina Mercedes s/n
41012 Sevilla
Spain

Pilkington Solar International GmbH
Mühlengasse, 7
D-50667 Köln
Germany

Siemens AG Power Generation
Dept. NT31
Freyeslebenstr. 1
D-91058 Erlangen
Germany

SOLEL
Har-Hotzvim
P.O.B. 45033
Jerusalem 91450
Israel

UMIST
Department of Electrical Engineering and Electronics
Att.: Dr. F. M. Hughes
P.O.Box 88
Manchester M60 1QD
United Kingdom

ZSW
Attn.: Frank Lippke
Hessbrühlstr. 21 c
D-70565 Stuttgart
Germany

CENTRAL RECEIVERS AREA

L&C Steinmüller GmbH
Fabrikstrasse 1
51641Gummersbach
Germany

INABENSA
Instalaciones Abengoa SA
C/Manuel Velasco Pando, No.7
41007 Sevilla
Spain

Universidad Sevilla
C/Reina Mercedes, s/n
41012 Sevilla
Spain

Max-Planck-Institut für Physik
Föhringer Ring 6
80805 München
Germany

Center for Renewable Energy Systems (CRES)
19th km Marathonos Avenue
19009 Pikermi
Greece

OADIG
1866 Square & Kriari
73135 Chania
Greece

ENEL
Via Volta 1
20093 Cologno Monz
Italy

Fichtner GmbH&KoKG
Sarweystrasse 3
70191 Stuttgart
Germany

Sevillana de Electricidad, S.A.
Avda.de la Borbolla, 5
41004 Sevilla
Spain

ENDESA
Príncipe de Vergara, 187
28002 Madrid
Spain

Electricidad de Portugal, S.A. (EDP)
Av. Estados Unidos da América, 55
1700 Lisboa
Portugal

ABB STAL AB
612 82 Finspong
Sweden

AICIA
C/Dr. Antonio Cortés Lladó, 6
41004 Sevilla
Spain

Babcock & Wilcox Española, S.A. (BWE)
Alameda de Recalde, 27
48009 Bilbao
Spain

PARABOLIC DISH AREA

Schlaich Bergermann und Partner (SBP)
Hohenzollernstr. 1
70178 Stuttgart
Germany

SOLO Kleinmotoren GmbH
Postfach 60 01 52
71050 Sindelfingen
Germany

L&C Steinmüller GmbH
Fabrikstrasse 1
51641Gummersbach
Germany

Intersol Corporation
PL 416 Marbak
30594 Halmstad
Sweden

Institut für Solare Energieversorgungstechnik (ISET)
Königstor 59
34119 Kassel
Germany

HTC Technologie-Centrum Schwerte GmbH
Im Heiligen Feld 17
58239 Schwerte
Germany

SOLAR CHEMISTRY AREA

1. DETOXIFICATION

AEPLA
D. Luis Roy Parge
Almagro, 44 - 3º
28010 Madrid
Spain

Ayuntamiento de Adra
Concejalía de Agricultura
Puerta del Mar, 3
04770 Adra (Almeria)
Spain

Ayuntamiento de Almería
Unidad de Desarrollo Económico
Plaza de la Constitución s/n
04003 Almería
Spain

Ayuntamiento de Berja
Concejalía de Agricultura
D. José M. Villegas Cabrera
Plaza de la Constitución, 1
04760 Berja (Almeria)
Spain

Ayuntamiento de Dalías
Concejalía de Agricultura
D. Francisco Criado Gallegos
Plaza Ayuntamiento, 1
04750 Dalías (Almeria)
Spain

Ayuntamiento de El Ejido
Area de Agricultura
D. Antonio Escobar
C/ Cervantes, 122
04700 El Ejido (Almeria)
Spain

Ayuntamiento de La Mojonera
Concejalía de Agricultura
Plaza de la Constitución, 6
04740 La Mojonera (Almeria)
Spain

Ayuntamiento de Roquetas
Concejalía de Agricultura
D. Nicolás Pimentel
Plaza de la Constitución, 1
04740 Roquetas de Mar (Almeria)
Spain

Ayuntamiento de Vicar
Concejalía de Agricultura
D. Antonio Osorio
Avda. Andalucía, 34
04738 Vicar (Almeria)
Spain

CNRS/Ecole Centrale de Lyon
Photocatalyse, Catalyse et Environement
Dr. P. Pichat
B.P. 163
69131 Ecully Cedex
France

Diputación Provincial
Area de Fomento,
Infraestructura, Medio Ambiente
D. Gonzalo Bermejo/
D. Jorge Angulo
Hnos. Machado, 27 Edf. B
04004 Almeria
Spain

Ecosystem
D. Martin Vincent
08392 Llavaneras (Barcelona)
Spain

INETI
Dr. Joao Farinha Mendes
Azhinhaga dos Lameiros a
Estrada do Paço do Lumiar
1699 Lisboa Codex
Portugal

Institut für Solarenergieforschung GmbH (ISFH)
Sokelanstrasse, 5
D-Hannover
Germany

Technische Universität Wien (TUW)
Institut für Physikalische Chemie
Dr. R. Bauer
Getreidemarkt 9/156
A-1060 Wien
Austria

Universidad de Almería
Dept. Ing. Química, Dept. Física Aplicada
Cañada de San Urbano
04120 La Cañada (Almeria)
Spain

Universidad de Barcelona
Facultad de Química
Dept. de Ingeniería Química
Dr. Jaime Giménez
C/Martí i Franqués, 1
08028 Barcelona
Spain

2. SOLARDETOX PROJECT (BRITE-EURAM)

CISE
Dr. Mirella Musci
Casella Postale 12081
20134 Milano
Italy

HIDROCEN
Camino del Valle, 12
Pol. Ind. Finanzauto
28500 Arganda del Rey, Madrid
Spain

INETI
Mr. Joao Farihna Mendes
Estrada do Paço do Luminar
1699 Lisboa Codex
Portugal

Schott Rohrglas GmbH
Erich-Schott-Strasse
Postfach 1180
95660 Mitterteich
Germany

SETSOL
Mr. Joao Correira de Oliveira
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APPENDIX 3

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