Annual Technical Report 1995

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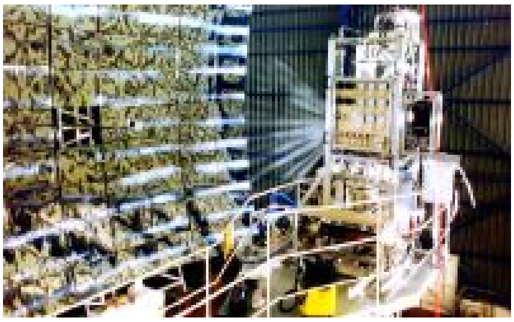

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PSA Annual Technical Report 1995

Preface

Solar thermal research, development and demonstration have been the joint focus of interest of DLR and CIEMAT cooperation at the PSA. In the course of the last fifteen years, the dish, trough and tower systems have reached such a maturity, that the World Bank together with the European community is now proposing a concerted international initiative to accelerate the commercialization of solar technologies. Mexico, Morocco and India have already directed funding applications to the World Bank. Meanwhile, the German Bank for Reconstruction (KfW) is carrying out feasibility studies for solar thermal plants in India and has earmarked funds for their realization. Within the Framework IV, Thermie and Joule programs, the European Union has also begun to support feasibility studies and research and demonstration projects in the field of concentrating solar thermal technologies (DISS, SOLGAS, THESEUS, SOLGRID, etc.) in Spain and Greece, and has recognized the importance of solar thermal technologies in the techno-economic context of cooperation with its Southern Mediterranean neighbors in the Maghreb, Egypt, Jordan and Israel. Electrical utilities in Spain, Greece, Israel and Morocco, as well as international industries are qualifying themselves for solar thermal plant projects. European power plant and key component manufacturers together with American firms, having gained solar thermal technological headway are now being joined by new partner countries like Egypt, Mexico and Brazil, which have expressed their desire to join the IEA-SolarPACES community.

Within this context of worldwide recognition of its real potential for industry, current solar thermal research, development and demonstration integrates these strategic goals:

- contribute to a sustainable world energy supply
- protect our climate, environment and resources
- develop a technological basis for European export industries
- as a means to carry out this long-range labor, task-sharing cooperation with research institutions, industry and electrical utilities
- further cost-reducing innovation leading to market acceptance
- become a key issue in North-South cooperation
- elaborate business strategies.

The Spanish-German Cooperation Agreement at the PSA represents the unique and only well-established test and demonstration site where European industry and utilities can test, train and show their solar technologies in a desert Mediterranean environment, with modern infrastructure and communications.

The cooperative CIEMAT/DLR effort to develop this technology has been more than justified in view of the achievements which are documented in this report. This effort continues and their further activities are also included as an integral part of the Programs and Projects for the next three or more coming years.

Finally, solar thermal technology complies with some of the prime objectives of EU Research Technology Department programs because:

- Its development will enhance the implementation of solar thermal power plants, thus protecting the environment and reducing the impact of the provision and use of energy, in particular the emission of CO_2.
- It will reduce the electricity generation cost of solar thermal plants, thus contributing to ensure durable and reliable energy services at affordable cost.

It will provide the European industry with a better technological basis, thus opening possibilities not only to the internal market of Southern European countries, but also to the export of equipment and services in the field of solar thermal power plants.

Michael Geyer　　　　　　　　Manuel Macías

ACKNOWLEDGEMENTS:

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

The current Directors of CIEMAT and DLR, Dr. F. Ynduráin and Prof. Dr. W. Kröll for their support of the German-Spanish Cooperation Agreement,

the former Director General of CIEMAT, Mr. José Angel Azuara Solís, who for more than ten years and until leaving CIEMAT in September, 1995, was an enthusiastic supporter of the Plataforma Solar de Almería, from the signing of the first Agreement and throughout its development,

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

the former Directors of PSA, M. Sánchez and W. Grasse for their long years of engagement and dedication to the PSA,

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

and all the institutions and private enterprises which have collaborated in our 1995 Program of Work, especially the DGXII - Human Capital and Mobility Program, personified in the support of Dr. M. Malacarne,

and Deborah Fuldauer for the composition of this report.

1 - PSA Solar Thermal Technology 1995 Milestones and International Cooperation in Solar Power Development

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2 - Technical Description and Project Achievements

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3 - Summary of Operation Hours

Operating activities in PSA facilities during 1995 adjusted to the respective plans of work foreseen in each area.

Table 3.1 shows the operating hours per project in each facility.

Facility	Hours-1995	Hours-1994
CESA-1		
Collector System	2010	1469
TSA	308	269
HERMES	18	104
Turbine	0	36
A.S.M.	201	0
CRS		
Collector System	1463	1178
CatrecII Receiver	68	109
Cor-Rec	19	0
RAS	57	26
DCS		
ACUREX	590	404
Desalination Plant	115	283
Detoxification	1187	614
HFC		
Collector System	1555	1123
Shuttle&Table	1317	1043
North Dish	1499	2124
Center Dish	1195	1769
South Dish	1042	1583

Table 3.1: Summary of operation hours 1994-1995

Antonio Valverde

José Rodríguez

Javier León

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4 -Training and Educational Activities

Training, dissemination and education form an integral part of a long-term strategy of implementation of Solar Energy applications and have consequently always played an important role in PSA activities. In the future, these efforts will be intensified even more, and the PSA will seek additional funding of educational, training and R&D projects involving students and guest scientists from Mediterranean, Middle & South America and the Third World sunbelt countries. With regard to education and tutoring of academic thesis work, the PSA will join forces, share laboratories and facilities and exchange teaching personnel with the recently founded University of Almeria (UAL). The increased collaboration with the University of Almeria during 1995 also covered the joint selection of the Spanish and German students who participated in the PSA Student program, one of the most important parts of the PSA training and educational activities.


Andrés López

The following Table lists the students who participated in the PSA Student Program in 1995. 30 Students were trained in the different areas of Solar Energy applications and contributed a total of 113 man-months to the work performed on the PSA during 1995 at a total cost of 9,040,000 Ptas.

Name	University	Months	Project PSA	Tutor
Alarcón Padilla, Diego-César	Univ. Granada	3	Materials	D. Martínez
Andrade Jiménez, Patricia	Univ. Almería	3	Solar Chemistry	J. Blanco
Balsa Escalante, Pedro	E.T.S.I. Minas Madrid	6	Control	E. Zarza
Bernecker, Axel	Univ. Bremen	3	Solar Chemistry	J. Blanco
Böttcher, Oliver	Univ. Regensburg	3	Solid Particle Receiver	G. Weinrebe
Broszio, Jan Markus	Univ. Hannover	3	TSA	M. Haeger
Calvo Aller, Sergio	Univ. Complutense	6	Morocco's Case Study	M. Geyer
Carreras, Frederic	I.U.T. Montluçon	3	Materials	D. Martínez
Esteban Rodrigo, María Cruz	E.T.S.I. Madrid	3	Materials	D. Martínez
García Pozo, Pablo	Univ. Complutense	6	LECE	G. Schwartz
Guzmán Dominguez, Juan de Dios	Alcalá de Henares	6	LECE	G. Schwartz
Hainzlmeier, Franz	FH Regensburg	3	TDC	B. Ebel

Held, Hannes	FH München	3	TDC	B. Ebel
Herreras Lebrato, Teodoro	Univ. Politécnica Madrid	3	DISTAL	H. Blezinger
Höschele, Britta	Univ. Stuttgart	3	Solar Chemistry	J. Blanco
Kimmel, Ralf	Univ. Stuttgart	3	DISTAL	H. Blezinger
López-Anglada Arribas, Noemí	Univ. Vigo	4	RAS	M. Haeger
Martínez Moya, Antonio	Univ. Stuttgart	3	Materials & Flux Meas.	D. Martínez & G. Weinrebe
Mateo Garcia, Inés	Univ. Almería	3	LECE	G. Schwartz
Meyer, Carsten	Univ. Hannover	4	DISTAL	H. Blezinger
Morán González, Jorge Carlos	Univ. Vigo	3	TDC	B. Ebel
Muñoz Gandolfo, Andrés	E.P.S. Jaén	1	DISTAL	H. Blezinger
Rauscher, Jochen	Univ. Stuttgart	3	SSC	D. Martínez
Reinig, Melanie	FHT Mannheim	6	Heliostats	G. Weinrebe
Rühl, Ingo	FH Rheinland-Pfalz	3	TSA	G. Weinrebe
Santander Martín	E.P.S. Jaén	4	DISTAL	H. Blezinger
Torrecillas Padilla, Pablo	Univ. Granada	3	Solar Chemistry	J. Blanco
Trillo Cabrera, Fernando	Univ. Almería	3	Volumetrics	M. Haeger
Vorweg, Niko	TU München	3	Infrastructure	D. Weyers
Zipp, Matthias	GH Kasel	7	DISTAL	H. Blezinger

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5 - Maintenance Plan for 1995/1996

The General Maintenance Plan of the Plataforma Solar de Almería in effect since June, 1994, has been followed normally and revised with satisfactory results as expected. The Optimization subprograms have been written and will continue to be perfected with the support of standard planning programs for activities related to project or setup modifications.

José Antonio Rodríguez Povedano

José Manuel Molina

Maintenance work is illustrated in Figs. 5.1, 5.2 and 5.3. Table 5.1 presents a comparison of personnel and total hours worked in 1993, 1994 and 1995. Table 5.2 presents the distribution of Manpower for 1996 according to the Maintenance Plan.

Fig. 5.1 analyzes the distribution of work by activities in 1993, 1994 and 1995. There was 7% less construction work (36%) than in 1993 and 2% less than in 1994. Keeping in mind that this item includes PSA Projects and General Installations, in comparison to Fig. 5.2, it may be deduced that the dedication to work of a general nature (Preventive, corrective, construction), represented 80% of the total in comparison to 20% for Projects, which was one of the objectives outlined for the year 1994: 80% General Maintenance, 20% Projects.

The distribution of maintenance work by areas is shown in Fig. 5.3, where it may be observed that one of them (Central receiver) has absorbed the greater part of the maintenance effort. Another four with between 200 and 500 hours and two with less than 100 hours worked are grouped together under "Others".

- Indirect labor is included in the first column.
- "General" contains virtually all the preventive and general infrastructure work and work on the three test facilities.
- General
    - Set up and startup of a new UPS.
    - Installation of a camera in the tower for control of the ACUREX and MAN I fields and heliostat field.
    - Checkup and replacement of the DCS fire extinction system (SCI) and installation of a water pipe near the junk store.
    - Cleaning and maintenance of the desalination plant.
- CRS
    - RAS (Advanced Salt Receiver). In 1995, several modifications and repairs were made on the receiver (dismounting to send to Madrid to repair the tensors and reassembly on top of the tower afterward), and the heat exchanger. The flux measurement bar

  was also installed.
  - Volumetric Receivers. The CATREC II (Siemens/EMITEC) receiver was taken down and the new CORREC absorber with modification of the air passage surface was installed.
- CESA-1
  - Facet replacement. Throughout the year, facet replacement in the CESA-1 heliostat field has continued as delivered from Madrid.
  - Repainting of facet backs.
  - Installation of a service door in the new UPS as well as fabrication, installation and setup of a new distribution board for the UPS.
  - Installation of two cameras (one in the heliostat field and the other in the tower) to facilitate control and operation.
  - New water pipes to W.C.
  - Assistance with installation of new 100 m^2 heliostats.
- HCF
  - Development of a preventive maintenance plan.

  Detoxification.
  - Installation of the CPCs and modification of corresponding connection pipes, control panel and non-concentrating collector.

  ARDISS
  - Area infrastructure was complemented and the Helioman was prepared for use with different types of collectors.

  Materials testing
  - Dismounting of the IVTAN vacuum chamber.
  - Services for several modifications of water lines, control, electrical installation, etc.
  - Small but careful work for tests such as mall mechanical pieces, thermocouples, etc.
  - Contribution to the installation of secondary concentrators, flux measurement device, lambertian target, etc.

  Dishes. Help when necessary as requested.
- PSA maintenance and infrastructure
  - Installation of telephone lines between the CESA-1 buildings and the main entrance
  - Installation of different water supply, electricity and telephone services to the remodeled laboratories
  - Contribution to the remodelling of the guard house at the main entrance
  - Conditioning of a dining room in the CESA-1 workshop for employees of the maintenance company.

- Cleaning septic tanks
- Clean-up of building façades
- Improvement and installation of collectors in water mains
- Cleaning out gulleys
- Clean-up of temporary outbuildings in front of CESA-1
- General gardening and creation of new areas

Preparation of a document listing and evaluating damage from the electrical storm of 23.09.95.

Plans for 1996

Among other activities planned:

- Remodelling of the SSPS dining room.
- Fabrication of a new power supply distribution board for the Directorate Building and CESA-1 workshop
- Repair and readaption of a large number of SENER heliostat mechanisms in order to avoid buying new drive shafts
- General following of Maintenance Plan.
- Quality control improvement.

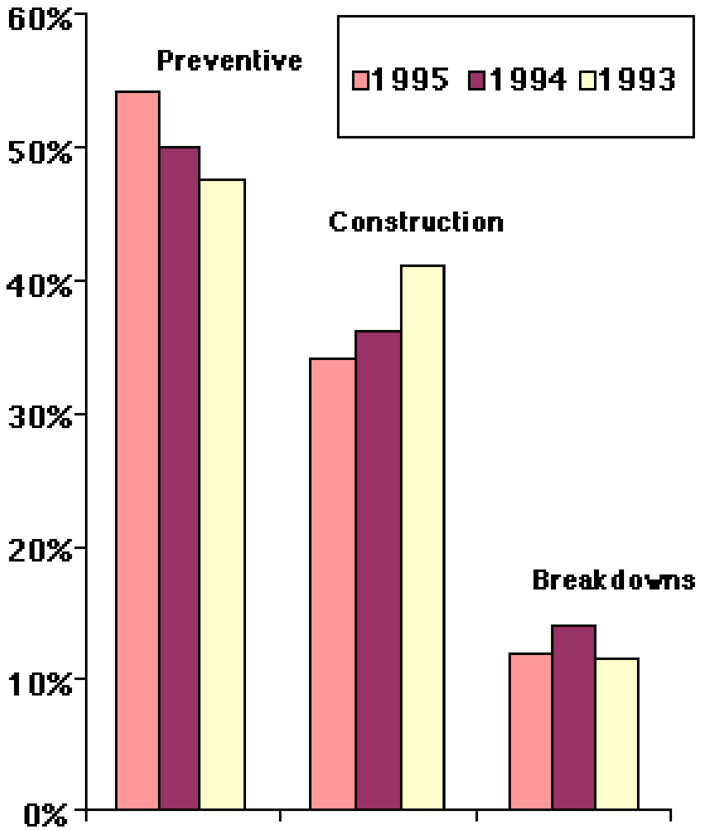

Fig. 5.1: Analysis of direct labor by type of work

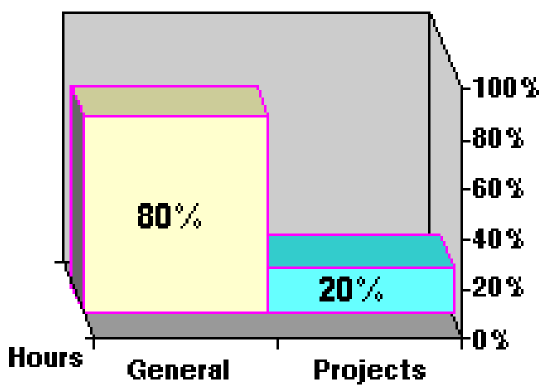

Fig. 5.2: General distribution of tasks

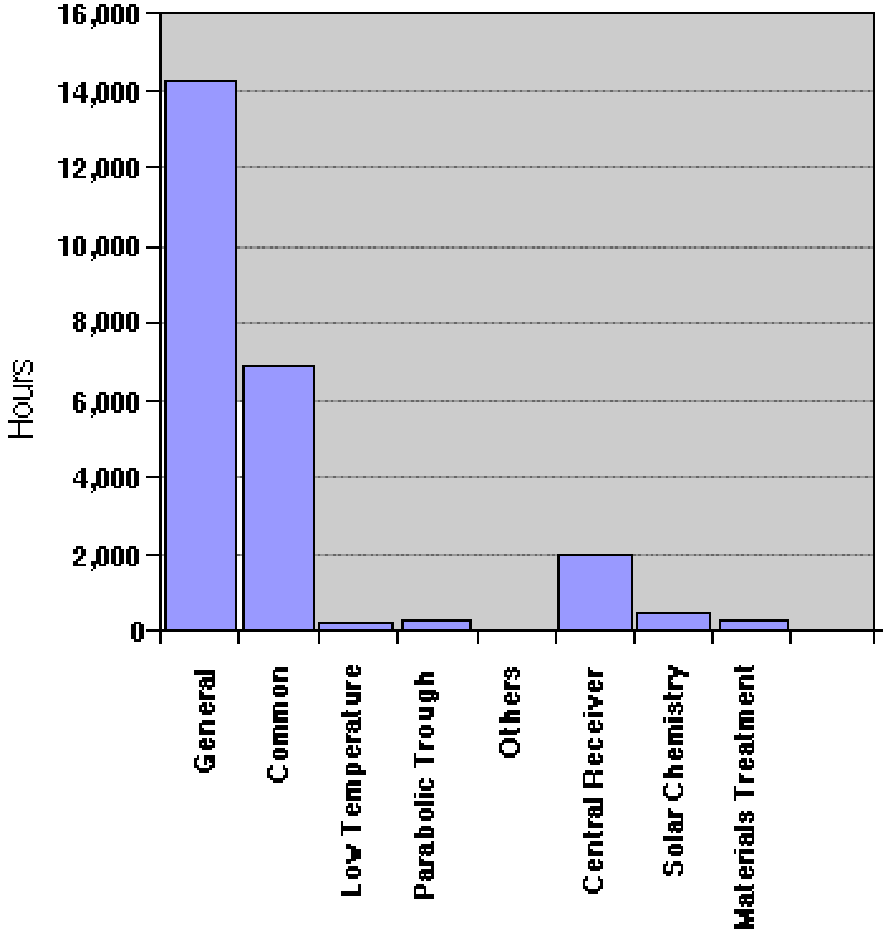

Fig. 5.3: Maintenance plan allocation by area

Category	No. Persons			Hours		
	1993	1994	1995	1993	1994	1995
Skilled workers	11	5	5	18617	7815	8836
Labourers	7	5	5	11838	7747	8818
Total Direct Labor	18	10	10	30455	15562	17654
Maintenance Manager	1	1	1	1808	1733	1624
Medical Assistance	1	1	1	1336	1808	1760
Office Cleaners	3	2	2	5373	3258	3528
Clerk	1	-	-	1799	-	-
Total Indirect Labor	6	4	4	10316	6799	6912

Table 5.1 Total hours of maintenance by category of personnel

	Electronics technician	**Mechanic**	**Electrician**	**General**	**Infrastruct.**	**Assistance**
CESA	500	650	400	240	200	2200
CRS	300	200	200	200	120	800
DCS	250	250	200	80	100	500
Solar Furnace	90	50	50	50	40	100
General	200	250	400	700	840	4000
Projects	460	400	550	530	500	1400

TOTAL	1800	1800	1800	1800	1800	9000
	Electronics Technician	**Mechanic**	**Electrician**	**General**	**Infraestruct.**	**Assistance**
Routine	1400	950	1300	1200	1100	6200
Breakdowns	400	350	300	150	200	1300
Assembly	-	50	20	450	500	1500
TOTAL	1800	1800	1800	1800	1800	9000

Table 5.2 Maintenance plan for 1996. Distribution of manpower

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6 - Infraestructure Activities in 1995 and a View of Prospects 1996

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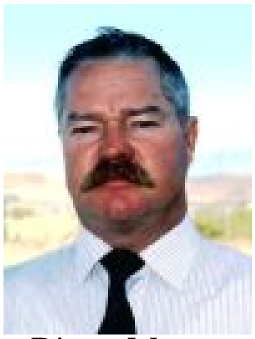
6.1 - Tasks Carried Out in 1995

The infrastructure activities were strongly affected by budget cuts. Instead of the 38 million Pts. planned in the last Annual Report, only 13 million Pts. were allocated in 1995. Therefore, a lot of facility improvements required for area projects such as the HCF heliostats or the CESA I facility osmosis plant had to be postponed. The main expense was in computer hardware and networking, enabling the Plataforma to maintain its up-to-date technical know-how in this field and an adequate computer pool. The work carried out until the end of the year was as follows:



Dieter Weyers

Bernabé Calatrava

General infrastructure
Maintenance of buildings, improvements of equipment and replacement of old technologies

TOTAL	5.2 million Pts.

Safety
Incorporation of new fire detection system

TOTAL	0.5 million Pts.

Engineering
Calibration of instruments, extension of the net server and software, new equipment

TOTAL	3.3 million Pts.

LECE
Erection of new laboratories and connection to other facilities

TOTAL 3.7 million Pts.

SOLAR FURNACE
New isolation and improvement of the roof

TOTAL 5.2 million Pts.

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6.2 - Tasks Proposed for 1996

For the next year a budget of only about 7 million Pts. was approved, so that a lot of important improvements will again have to be postponed to the following years. The work proposed is as follows:

General
Building Improvements

TOTAL 2.6 million Pts.

Engineering
New heliostat control system, extension of the net capacity, software

TOTAL 3.6 million Pts.

LECE
Improvement of the low voltage net

TOTAL 0.8 million Pts.

The remaining amount will be approved on short-term and at request of the projects.

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7 - Summary of 1995 Meteorological Data

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7.1 - Introduction

Martin Stegmann

Bernabé Calatrava

The PSA meteo station is one of the most complete in Spain. About 15 sensors report their values every two seconds to the central computer, where the extreme and average values are stored every 5 minutes.

Since 1988 about 120 Mbyte of weather data were accumulated and stored on a CD-ROM. With this treasure of data a TEST REFERENCE YEAR (TRY) is going to be created and made available to the public for computer simulation of year-round performance of solar energy systems and building heating and cooling loads.

Besides its own Central Meteo Station the Spanish "INSTITUTO NACIONAL DE METEOROLOGIA" uses the PSA infrastructure for its measurements.

Even the best meteo stations have some failures during the year resulting in missing data. This problem, which occurs mainly in the holiday season in August, was solved by using the data from the independent projects running on the PSA, especially DISTAL.

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7.2 - Meteo Data 1995

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Appendix 1 - Project Descriptions

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Appendix 2 - List of Collaborating Insitutions and Companies

ARCHITECTURAL ASSOCIATION SCHOOL OF ARCHITECTURE (AASA)
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London WC1B 3ES
United Kingdom
Tel: (44-171) 636 0974
Fax: (44-171) 414 0782

BELGIAN BUILDING RESEARCH INSTIUTE TEST CENTRE (BBRI)
Av. P. Holoffe, 21
B-1342 Limelette
Belgium
Tel.: (32-2) 653-8801
Fax: (32-2) 653-0729

BEN-GURION UNIVERSITY OF THE NEGEV
P.O. Box 1025,
84105 Beer-Sheva, Israel
Tel.: 972-7-461943
Fax: 972-7-271612

CENTRE DE DEVELOPMENT DES ENERGIES RENOUVABLES
Rue Machaar Elharam,
Kuart.ISSIL
B.P. 509
Marrakech
Morocco
Tel.: 212-4-309821
Fax: 212-4-309795

CENTRE DE DEVELOPMENT DES ENERGIES RENOUVABLES (CDER)
B.P. 62 Bouzareah
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L&C STEINMÜLLER GmbH
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NEW AND RENEWABLE ENERGY AUTHORITY
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27th Building Project
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Nasr City, Cairo
Egypt
Tel.: (20-2) 273 3176/271 3174
Fax: (20-2) 273 7173

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Walton Hall
Milton Keynes, MK7 6AA
England
Tel.: 44-1908-653155
Fax: 44-1908-653744

PHOTOCATALITYC PURIFICATION GmbH (PCP)
Otto Hahn Strasse 2
D-64839 Münster
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Fax: 49-6071-33172

PILKINGTON SOLAR INTERNATIONAL
Mühlengasse 7
D-50667 Köln
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Tel. (49 221) 925 970 0
Fax: (49 221) 258 11 17

PROPLAN LTD.

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190 09 Athens
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Tel. (30 1) 60 39 900
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Appendix 3 - Publications 1995

CONTENTS:

EU-DGXII Human Capital and Mobility and JOULE Thermie '95

Publications written under CIEMAT contracts No. CHGE-CT93-0038 and No. JOU2-CT93-0299.

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1.1 - PSA - The European Solar Thermal Test Center

The history of the "Plataforma Solar de Almeria" (PSA) as the European test center for solar thermal technology began, when in 1981/82 the two 500 kWe IEA Small Solar Power Systems (SSPS) and the Spanish 1.3 MWe solar power plant CESA-I went into operation (See Fig 1.1). Since 1986 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 "Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V." (DLR). Spanish-German cooperation at the PSA is based on the "Convenio Hispano Alemán..." signed by CIEMAT and DLR, in 1986 and now extended to the end of 1998.

Michael Geyer

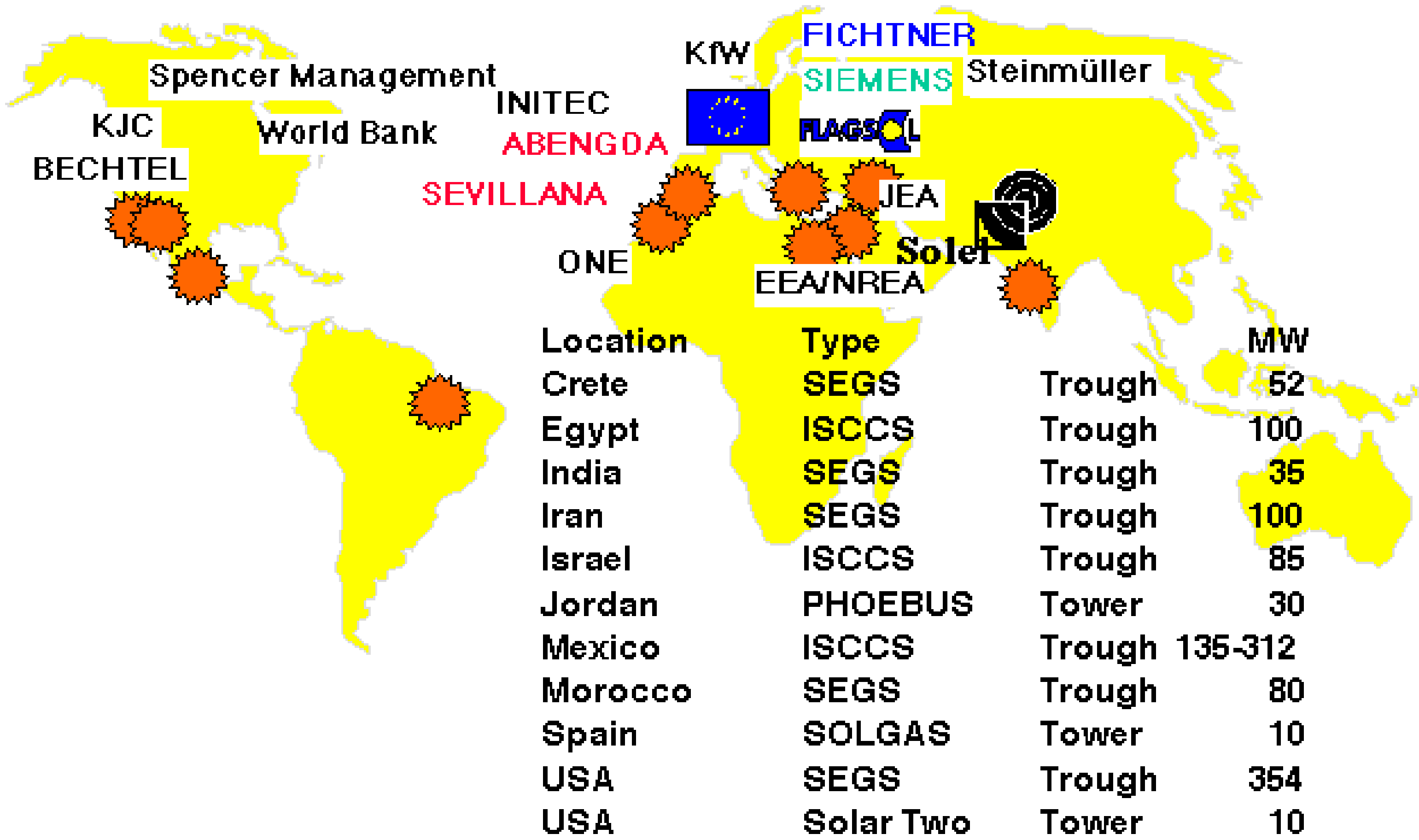
Manuel Sánchez

Fig. 1.1: Aerial View of the Plataforma Solar de Almería
(56 kb)

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. However, the collapse of oil prices in the mid-1980s led some governments and companies participating in PSA solar thermal activities to scale back or even withdraw their participation. Nonetheless, those that continued with the solar thermal programs were able to reduce costs and improve performance by amounts comparable to the decrease in oil prices. 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$/kWhe of the first solar thermal demonstrations in 1981 to less than 0.15 US$/kWhe of today's state-of-the-art solar thermal technology. In fact, in 1995 all three relevant technologies on the PSA, parabolic trough, dish/Stirling and power tower, saw the consolidation of development programs in which long-term cooperation with industry moved closer to the common goal of commercialization. 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. It is obvious that a gap exists between solar power plant and conventional base-load fossil-fired thermal power plant economies. In this respect, the European, Spanish and German contributions to the PSA constitute an investment in clean energy alternatives and strengthen the European/Mediterranean ability to react to possible energy price swings or the need to reduce fossil-fuel consumption for environmental or other reasons.

The long-term belief in the solar thermal power option and the continous support of PSA activities over the years by its partners in Europe, Spain and Germany, has been internationally justified by the recent World Bank Global Environmental Facility (GEF) Solar Initiative and revival interest in the Mediterranean and other sun belt regions of the world. Figure 1.2 illustrates the numerous solar thermal power project developments currently underway around the world and the main industrial, utility and financing players actively engaged in these projects.

If clean power is acknowledged to be a key to sustainable economic and energy growth, implementation measures have to be taken to build up the necessary network and manufacturing infrastructure to respond to future challenges. The PSA team and its partners offer industry, electrical utilities and financial institutions its many years of experience and expertise in conjunction with its unique solar power facilities to catalyze joint ventures in joint demonstration projects.



Location	Type		MW
Crete	SEGS	Trough	52
Egypt	ISCCS	Trough	100
India	SEGS	Trough	35
Iran	SEGS	Trough	100
Israel	ISCCS	Trough	85
Jordan	PHOEBUS	Tower	30
Mexico	ISCCS	Trough	135-312
Morocco	SEGS	Trough	80
Spain	SOLGAS	Tower	10
USA	SEGS	Trough	354
USA	Solar Two	Tower	10

Fig 1.2: International Development Efforts of Solar Thermal Power Projects

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1.2 - The PSA Team and its Organization

Throughout its fifteen years of operation, the PSA has continuously added to and improved the education and training of its staff, its human capital, who have become worldwide 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 65 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 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 injected in PSA's desert location in Southern Europe.

Special mention is to be given here to the contributions and achievements of the colleagues that left the PSA core team in 1995/96:

- Bernd Ebel, who built up the Technical Demonstration Center in 1994-1995.
- Wilfried Grasse, who laid the groundwork for the PSA as the Operating Agent of the IEA-SSPS project in the years 1981-85, implemented the Spanish-German PSA Cooperation Agreement (Convenio Hispano Alemán - CHA) in 1986, and brought as CHA Co-Director from 1991 until 31.12.1995 major industrial solar power projects to the PSA, especially the German TSA Consortium and the German Dish/Stirling program.
- Mathias Haeger, who was responsible for the PSA Central Receiver program from 1992 until 1995 and was TSA test manager.
- Manuel Sánchez Jiménez, who as CIEMAT's Director of the PSA and CHA Co-Director from 1991 until 31.3.1996 brought the European Human Capital and Mobility Programs, the EU-JOULE solar thermal program for RTD on parabolic troughs and dishes to the PSA, and initiated the PSA collaboration with Eastern countries.

With a warm welcome, new colleagues that joined the PSA core team in 1995 and will begin in 1996 are briefly introduced here:

- Pedro Balsa, who took over the responsibilities for the EU Human Capital and Mobility Program parabolic trough control activities. P. Balsa graduated as a mining engineer specialized in energy and fuels and did his final project in robotics and control logic. After a student grant in this area in 1994, he has continued to work in this area coordinating the work of the European researchers developing adaptive control systems at the PSA.

- Juan de Dios Guzmán is a telecommunications engineer from the University of Alcalá de Henares. He accumulated nearly a year's experience in the PSA bioclimatic program with a student grant before continuing as head of the LECE.
- Michael Geyer, who will be German Director of the PSA effective on January 1, 1996, brings long experience in research and industry in the field of solar power generation to the PSA and new perspectives on the educational role of the PSA from his last position as professor of Power Generation and Renewable Energies at the Polytechnical University of Regensburg.
- Andreas Holländer, who will be the new Head of the Engineering Department effective May 1st, 1996, enriches the PSA team with his experience in renewable, and, especially solar energy. The PSA is particularly happy to have his experience in photovoltaics as local RWE Project Manager at the PV Toledo Project. In his last position he was responsible for small hydro power project development at the RWE electric utility in Germany.
- Bernhard Milow, who takes over responsibility for solar thermal project developments and system studies effective March 1st, 1996. He graduated in energy engineering from the University of Stuttgart and contributes experience in various national and international energy projects as a researcher in the Department for System Analysis in the Centre for Solar Energy and Hydrogen Research (ZSW) in Stuttgart and in the DLR Study Group for Energy Systems.
- Martin Stegmann, who took over responsibility for PSA's meteo data base and solar heating and cooling applications, augments PSA expertise with his practical experience as a successful independent solar energy engineer specializing in solar heating and hot water systems.

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

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

- Engineering Department,
- Operation & Maintenance Department and
- Administration Department

and into project teams in seven program areas:

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

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

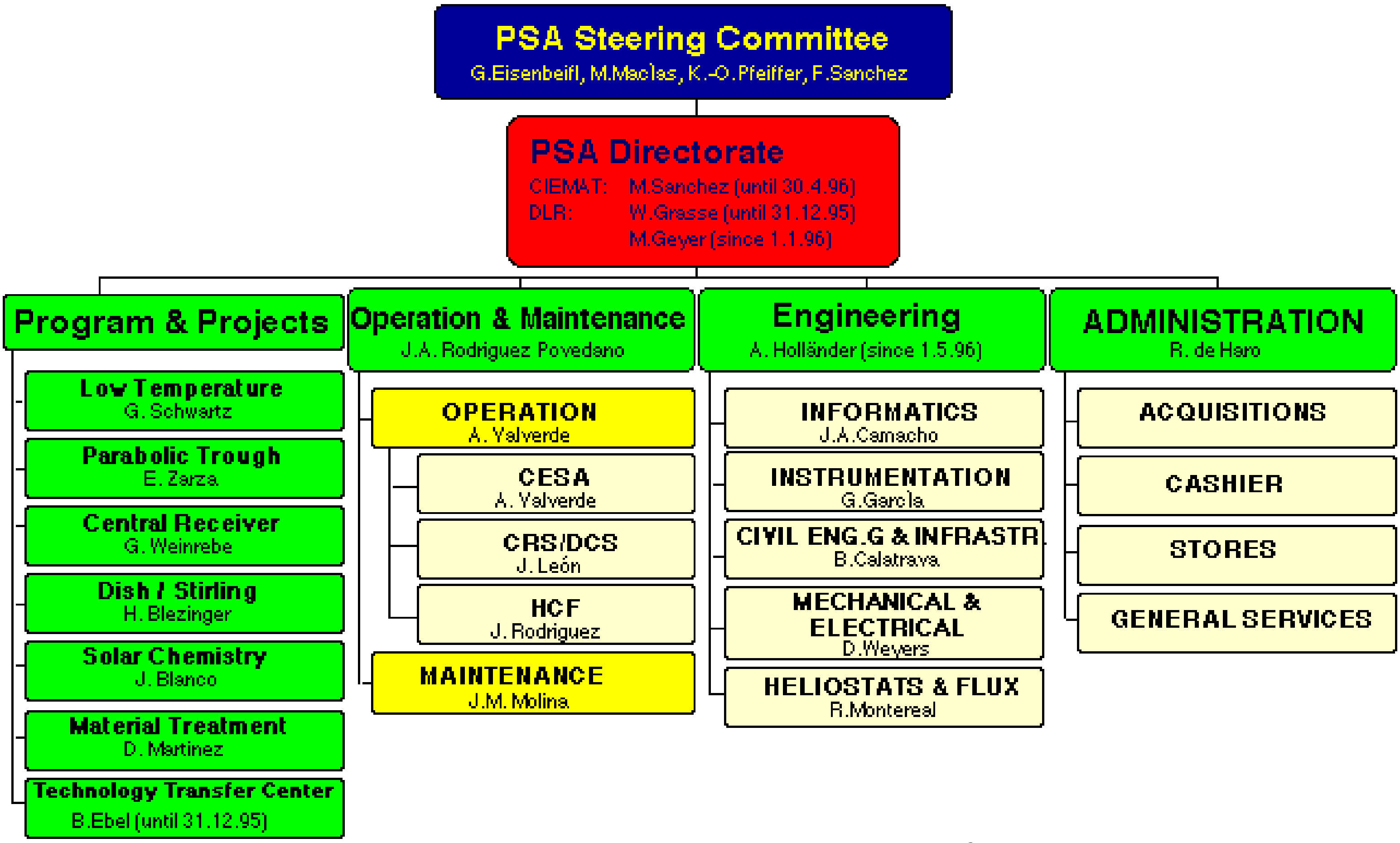

Fig 1.3: PSA Matrix Management Organization as of 31.12.95

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1.3 - The 1995 PSA Budget

The total PSA 1995 budget approved by the PSA Steering Committee amounted to 710 Million Pesetas. The two Spanish-German Agreement partners each contributed 210 million pesetas. 81.7 million Pesetas was received in contributions to projects from the European Union and 12.15 million Pesetas from industrial clients. 406.8 million pesetas of this budget were directly allocated to the projects, 16.6 million pesetas were invested in infrastructure improvements. The development of the PSA Annual Budget since 1987 is given in Figure 1.4.

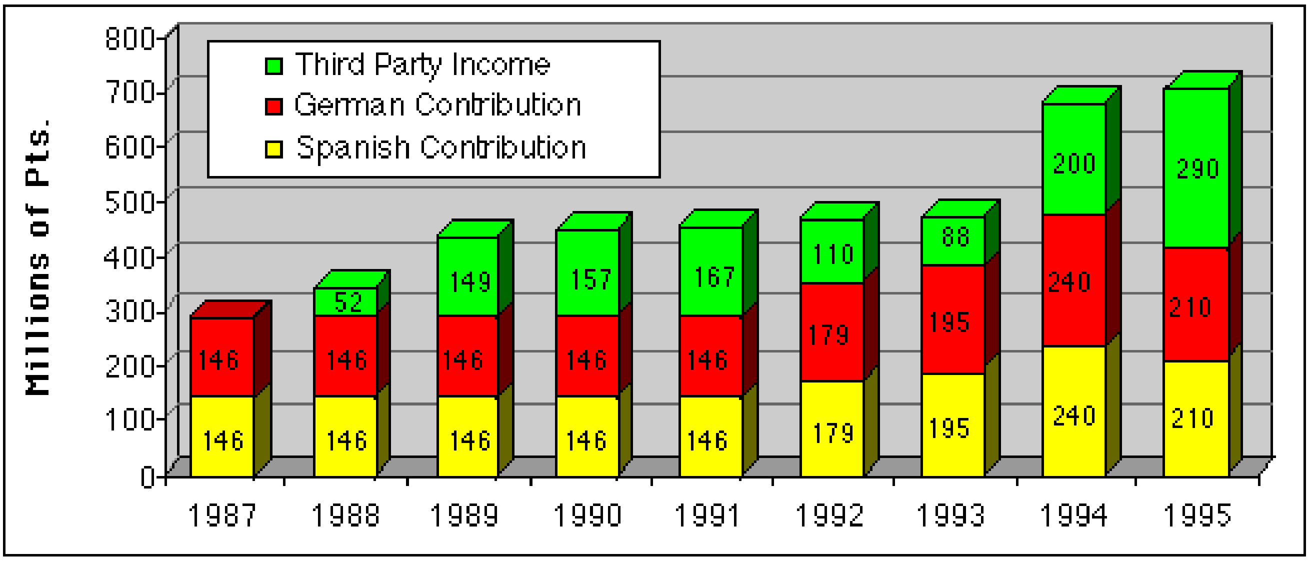

Fig 1.4: Development of the PSA Annual Budget 1987 - 1995

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1.4 - 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 on the PSA are:

- 2.7 MW_t SSPS-CRS Central Receiver Test Facility
- 9 MW_t CESA-I Central Receiver Test Facility
- High-Flux Solar Furnace
- 1.3 MW_t SSPS-DCS Parabolic Trough Test Facility
- 3 x 50 kW_t DISTAL I Parabolic Dish Test Facility

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

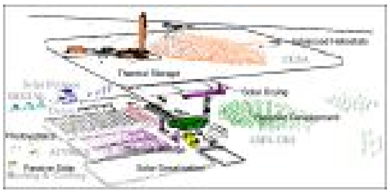

Fig. 1.5: Solar Technology Facilities at the PSA
(24 kb)

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1.4.1 - 9 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) 90%, tracking error per axis of 1.5 mrad and beam quality characterized by 3.0 mrad error width. Maximum field power is 9 MW_t. At design insolation of 950W/m^2, a peak flux of 3.3 MW/m^2 can be achieved. 99% of the power is concentrated within a 4m-diameter circumferance with 90% of the power concentrated 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 at 80 m above ground level
- 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

The tower has a 5-ton crane on top and an 250 kg-capacity elevator for personnel and equipment.

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1.4.2 - 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 52m^2 and 65 m^2 helisotats also available. Their average (clean) reflectivity is 87%, tracking accuracy 1.2 mrad error per axis and beam quality characterized by 1.5mrad error width. At design insolation of 950W/m^2 total field power is 2.7MW_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 1.8m circle.

The 20 ton-capacity structural-steel tower provides two test platforms, one on the tower top at 43m above ground level and another at an intermediate 24m level. A 600kg-capacity crane on the top of thetower and an

1000kg-capacity elevator for personnel and equipment for are available.

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1.4.3 - 1.2 MW_t SPS-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 collector absorber tubes are black chrome-coated steel and use the 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 950W/m_2 design insolation a peak thermal output of 1.3 MW_t can be reached at noon. The 114 m3 thermocline tank stores approximately 5 MWh_t thermal energy between 225°C cold and 295°C hot oil temperatures. The daily thermal energy delivered by the collector field is about 6.5MWh_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 3m^3/h of desalinated water. The performance ratio is 9 kg distillate per 2300 kJ heat input. The output salinity is 50 ppm total disolved solids.

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1.4.4 - 3x50 MW_t DISTAL I Parabolic Dish Test Facility

This facility provides three individual-tracking polar-mounted parabolic dishes. Each dish consists of a 7.5m-diameter, single-facet stretched membrane concentrator with an average reflectivity of (clean) is 94 %. At design insolation of 950W/m^2 a peak flux of 850 W/cm^2 can be achieved. 90% of the power is concentrated within a 9 cm diameter. The focal length is 4.5 m.

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1.4.5 - 60 KW$_t$ PSA High-Flux Solar Furnace

Sunlight is reflected by four 53.61m^2 heliostats with 90% average clean mirror reflectivity onto the primary concentrator, each illuminating a quarter of for 60-kW system power. The MDAC parabolic-dish concentrator, made up of 89 0.91m x 1.21m sandwich facets, is 11.01m x 10.41m. 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 7.45m and focal height of 6.09m. At the the 120mm focal spot, black-body temperature is 3150K. Sunlight concentration is controlled by a 11.44m x 11.20m louvered shutter with 30 5.60m x 0.93m 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 $8.01*10^{-5}$ and $4.94*10^{-5}$ respectively. Fastest closing time is 5 seconds. The experiments can be mounted on a 0.7m x 0.6m 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.

The infrastructure which it has developed and the technical successes it has obtained in such solar powered applications as sea-water desalination, water detoxification, and the EU-DGXII programs of "Access to Large-Scale Scientific Installations", "Human Capital and Mobility" and "Transfer and Mobility of Researchers", have enabled the PSA to further offer its services as a test center to the aerospace industry and Community research projects within a Plan for Diversification and Services.

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1.5 - PSA Milestone Achievements in 1995

- The Low Temperature Applications Area / LECE improved its infrastructure and became a facility ready for new international projects.
- The DISS project started after funding was approved by the EC DGXII and in parallel, the PSA also participated in the EC STEM and ARDISS activities and in the DLR PAREX project.
- The PSA proposal to the continuation of the HCM Program, Training and Mobility of Researchers (TMR), was approved and the contract was signed.
- The ASM150 heliostat went into operation.
- The Falling Particle Receiver tests were started in the PSA's Solar Furnace.
- The TSA was run with fully automatic heliostat control for first time.
- New flux measurement and thermography systems were installed.
- A contract to develop and build a detoxification plant for treatment of water contaminated with pesticides was signed with local municipal governments in the El Ejido area of Almería.

1.6 - Extension of the Spanish-German Cooperation Agreement until 1998

The Cooperation Agreement between CIEMAT and DLR for joint operation of the Plataforma Solar de Almería signed in January, 1987, has been renewed to the end of 1998. In this context, a 3-year Program of Work (POW) was presented to the PSA Steering Committee (SC) for the first time at its 15th Meeting in Cologne on April 28-29, 1994, where it was approved as a planning guideline in a joint analysis of the Cooperation Agreement's implementation until the end of 1996. The new POW strictly adheres to the PSA organizational and program structure as requested by the SC and clearly distinguishes between the quasi-institutional funding of the PSA and the technical programs it serves.

Prior to this meeting, the PSA and its future had been analysed on several other occasions with regard to its activities, its future and justification for extending the present Agreement, by prominent members of the European Union (DGXII), the United Nations, German and Spanish research institutions and industry, etc. A pragmatic internal project-oriented "Brainstorming" Workshop was also held in Mojácar on March 7-8, 1994, with substantial participation of all the differents branches involved in solar thermal R&D at CIEMAT and DLR.

For the 1997-98 extension of the Spanish-German PSA Cooperation Agreement, the PSA Steering Committee invited prominent members of German electrical utilities, industry and the European Union to provide the German Federal Ministry for Research and Education with an update of the 1992 PSA Program Review. After detailed review of the achievements of the PSA in 1993-95 and evaluation of the program lines envisaged for 1996-98, it was unanimously recommended that German-Spanish cooperation at the PSA be extended beyond 1996.

The present Plan of Work attempts to reflect the results of seven years of DLR/CIEMAT cooperation in R&D activities at the PSA and initiate activities for the coming years.

1.7 - Foreseen PSA Program Objectives for 1996-98

The dish, trough and tower systems, which have been the joint focus of interest of DLR and CIEMAT cooperation at the PSA over the course of the last fifteen years, have reached such maturity that PSA goals can no longer remain unchanged, but reflect a new era of solar thermal reality. If worldwide political and economic activity, as represented by international organizations such as the World Bank and the European Community, governments in the Maghreb, Egypt, Jordan and Israel, Mexico, Morocco and India, the German Bank for Reconstruction (KfW) and electrical utilities in Spain, Greece, Israel and Morocco and the U.S.A., as well as international industries, which are taking concrete steps to integrate solar thermal power plant projects into their budgets and organization, then PSA strategic goals must not keep pace, but anticipate developments. Therefore, the role of the PSA will be guided by the following long-range objectives:

- contribute to a sustainable world energy supply
- protect our climate, environment and resources
- develop a technological basis for European export industries
- as a means to carry out this long-range labor, task-sharing cooperation with research institutions, industry and electrical utilities
- further cost-reducing innovation leading to market acceptance
- become a key issue in North-South cooperation
- support industry in the identification of solar power business opportunities.

The Spanish-German Cooperation agreement at the PSA represents the unique and only well-established test and demonstration site where European industry and utilities can test, train and show their solar technologies in a desert Mediterranean environment, with modern infrastructure and communications.

For extension beyond 1996, the PSA will focus its work on the following strategic objectives:

- Intensify cooperation with Mediterranean and other electrical utilities interested in international solar project development as the future clients of the Spanish, German and participating European solar export industries.
- Bring together industrial solar equipment manufacturers and catalyze

the "on the project" formation of new solar joint ventures.

- Support solar energy project developers and financing institutions with independent engineering advice and technological know-how.
- Provide a demonstration and training platform for the solar equipment industry as a technology transfer and introductory market showcase for the region and its Mediterranean neighbours.
- Bring together solar R&D institutions and private developers with Mediterranean regional authorities,
- equipment manufacturers, vendors and end users to transfer solar technology from research labs to the market place.
- Give interested European research groups and networks access to these unique solar facilities.
- Support European industry with education and training programs.
- Intensify cooperation and join forces with the recently founded University of Almeria.

In order to reach these objectives, priority will be given the following activities on the 1996-98 horizon.

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1.8 - PSA as a Bridge to Cooperation with Mediterranean Neighbours

Located at the geographical, cultural and economic interface between North and South in the Mediterranean region with direct air and sea connections to Morocco, Almería is experiencing a growing exchange with its North African neighbours. The European Union's increasing efforts to intensify the political and economic relationships linking it with neighbouring countries South of the Mediterranean is also reviving the historic role of Andalucía as the gateway to North Africa.

In the agricultural sector, joint Spanish/Moroccan ventures are already harvesting solar energy with low cost green house technology. Developed by Belgian and Dutch entrepeneurs in Almería and surrounding area, this is one of the best examples of successful technology transfer from Middle Europe to Southern Europe and its further spread to North Africa.

The energy link between Europe and North Africa also brings Andalucía into the focus of interest. The first step Morocco with Spain has already been taken by the Red Eléctrica de Espana (REE) of Spain and L'Office National de L'Electricite (ONE) of Morocco with the engineering of the undersea electrical connection of both countries at the Strait of Gibraltar. Given the recent completion of connection between Morocco, Algeria and Tunisia, this will be the final link communicating European and North African power grids.

In April 1991, the protocol for long-term supply of natural gas over a transmediterranean pipeline connecting the Maghreb with Spain was signed by the Spanish gas company ENAGAS and the Algerian gas company SONATRACH and construction was inaugurated on May 13, 1993 by the Ministers of Energy of Spain, Morocco and Algeria. The pipeline is designed to transport 4,000 million cubic meters of natural gas per year, equivalent to an electrical power capacity of about 1 GW, from the Algerian gas field of Hassi R'Mel in the Sahara desert, 530 km south of Algiers, through Morocco to Europe. The investment cost of 2,750 MUS$ is financed by the European Investment Bank. Construction completion is scheduled for 1998.

On the other hand, Southern Europe and North Africa also suffer similar climatic hazards of desertification and diminishing water resources. Local, regional and national authorities have only just started to focus their interest on desalination technologies as an equally possible solution in both regions.

Following the accelerated economic growth of the past decade, rising living standards and a demanding tourism are now forcing the growth of a local conventional heating and cooling industry in Andalucía and North Africa, still practically undeveloped markets for domestic, municipal and industrial solar heating and cooling.
In the heart of this underdeveloped solar market, the PSA offers German, Spanish and other European manufacturers and developers an ideal, and as yet unused, strategic bridge to the rising Mediterranean solar markets with favorable connections to local authorities, consumer, industry, trade and tourism associations on one side and experienced bilingual engineers and technicians, technological infrastructure and communications on the other.

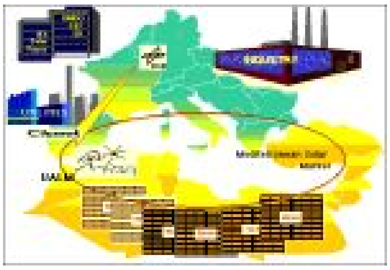

Fig. 1.8: PSA - A Bridge for European Industry and R&D Institutions to the Mediterranean
(18 kb)

In concert with other institutions in numerous research networks, the PSA extends its capacity to support the growing efforts of regional authorities, equipment manufacturers, vendors and end users to transfer solar technology from the research lab to the regional and Mediterranean marketplace through participating Spanish, German and other European developers of industry and technology. For this goal, the PSA is constantly strengthening its engineering capabilities with personnel, tools and training in accordance with the growing solar market demand in order to support industry, R&D institutions and development agencies with information on project opportunities, new European - Mediterranean solar technology ventures, and solar testing, engineering and O&M support of

- Integration of solar power with fossil energy generation
- Combination of solar power and biomass
- Solar-aided desalination and cogeneration
- Solar-aided heating and cooling of large Mediterranean building complexes
- Solar-aided agricultural applications in the Mediterranean
- Integration of solar technologies in Mediterranean industrial processes
- Solar detoxification of industrial and agricultural effluents in waste water and air
- Participation in solar exhibitions and industrial fairs
- Operation and maintenance of pilot facilities
- Solar engineering and consulting services
- Education and training

In upcoming years, the PSA will set a new focus on optimizing its services to such market needs and actively develop cooperation and technology transfer projects involving German, Spanish and Mediterranean industry.

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2.1 - Low Temperature Applications

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

Guillermo Schwartz

Juan de Dios Guzmán

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2.2 - Parabolic Trough Technologies

The activities of the Parabolic Trough Technologies Area during 1995, were grouped in five main projects. The next sections go into them in detail.

Eduardo Zarza

Pedro Balsa

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2.3 - Dish/Stirling Systems

Heinrich Blezinger

Among the three solar thermal technologies converting solar radiation into electricity, it is generally accepted that "point-focusing dish concentrators with Stirling engines" have the best system efficiencies. Overall efficiencies of 20 % to 30 % have already been achieved with various early dish/Stirling prototypes. Besides its high efficiency, the system is convincing because of its modular design, which reduces the development cost, as only one system unit has to be developed. It also makes a farm plant easily adaptable to rising energy consumption simply by adding dish/Stirling units to the plant as required. Since no cooling water is needed to operate the system, it is especially suitable for application in arid regions. The possibility of hybridization with a natural gas or biogas burner expands the range of possible applications, increases the capacity factor, lowers the capital cost per kWh and guarantees the energy supply to the consumer regardless of the availability of solar insolation.
Thus motivated, the PSA entered in 1991 in the test and development of the dish/Stirling technology in a long-term test of three systems manufactured by the German company, Schlaich Bergermann und Partner (SBP). In continuous sunrise-to-sunset operation since early 1992 as the DISTAL I project, they have demonstrated their reliability and system performance.

Fig. 2.3.1: DISTAL I parabolic dish units (49 kb)

In 1995 the activities of the PSA in the dish/Stirling area were focused mainly on three projects:

1. Continuous testing and long-term operation of DISTAL I
2. Planning of an integrated dish/Stirling test site and
3. Numerical simulation of 25 kWe dish/Stirling system performance.

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2.4 - Solar Tower Generating Systems

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Javier León

Antonio Valverde

Rafael Monterreal

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2.4.1 - Receiver Technology

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2.4.2 - Heliostat Technology Program

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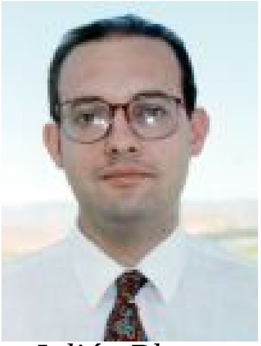
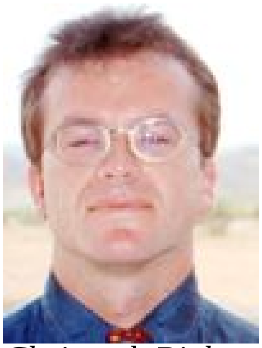


Julián Blanco

Sixto Malato



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2.6 - Materials Treatment

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Diego Martínez

2.6.1 - Introduction

José Rodríguez

PSA Materials Testing Area activities in 1995 were almost completely devoted to the EU-DGXII 'Human Capital and Mobility Program', in which thermal treatments were carried out for European Research Groups in the High Flux Concentration Facility (HFCF).

During the last quarter, there was also some activity in the CESA-1 Facility for the European Space Agency's (ESA) new 'Stamp' project test specification phase.

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2.7 - Technology Demonstration Center (TDC)

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Bernhard Milow

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2.7.1 - General

After its first year of work, in 1995 the TDC successfully continued its original tasks of testing and servicing of small autonomous solar systems, mainly as a platform for testing solar equipment.

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2.7.2 - Comparative Test of Solar Dryers

A comparative test of solar dryers was carried out by the German Synopsis company in May, 1995, by contract with DLR MD-PSA.

Fig. 2.7.1: Solar dryers (17 kb)

Drying is an old, universally applied food preservation technique. Solar drying is a challenging new technique providing better product quality with less energy consumption than conventional drying methods which may contribute significantly to an increase in the living standards of many third world countries.

The advantage of solar dryers over open-air drying is that the process can be better controlled and therefore, the resulting product quality is also better.

In 1995, six dryers and three open-air drying methods were tested. The dryers expose the produce to the sun either directly or indirectly, meaning the produce is in a drying chamber without direct solar insulation.

Three of the dryers were family-size units and tree were professional bulk-quanty systems.

The results show that the produce dried in solar dryers in general are of better quality than that dried in the open air. All of the dryers tested proved to be useful and quite easy to use. Direct dryers are more economical, but can only be used with produce not sensitive to direct sunlight. Indirect dryers should be used for sensitive products.

The results of these tests were printed as the second TDC Serial Report in August, 1995.

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2.7.3 - Comparative Test of Solar Portable Lanterns

This test of solar portable lanterns was also prepared and carried out by the German Synopsis company in April-May, 1995, by contract with DLR MD-PSA with funding by the German Ministry for Education, Science, Research and Technology (BMBF).

Fig. 2.7.2: Solar portable lantern test at the PSA (17 kb)

The use of lamps reflects the universal desire of man to illuminate his environment, his home and streets. Solar lanterns using PV modules as a power source provide better quality lighting with less energy consumption than candles, oil or gas lamps.

In many countries where a countrywide electricity supply is not economically feasible, the solar lantern technology nowadays represent a promising solution than can notably improve the living conditions of the people.

Two monoblock units and seven split units were tested. In general, all lanterns tested have reached a good level of technical maturity. But none of the cases, swiches or charge sockets were sufficiently protected against dust and water and some of the lanterns tested had only very basic protection against deep discharge.

Besides their various charge/discharge characteristics (all can be completely recharged in one day) all lanterns are reasonable products, but some are notably better than the rest.

Split units, that is those having the PV panel in a separate unit, proved to be more practical than monoblock units.

The results of this test were printed as the third TDC - Serial Report in August, 1995.

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2.7.4 - Plastic Foil Water Collectors

The 180 m^2 of plastic foil collectors installed on the roof of the Hotel Playazul in Roquetas (Almería) in 1993 to supply hot water for the hotel were monitored by TDC staff.

The collectors, developed by the University of Hohenheim (Stuttgart, Germany) under the sponsorship of the German BMBF were handed over to the hotel ownership in 1995.

This two-year-long test went on without serious problems.

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2.7.5 - Solar Cooling Unit

The Dornier Cooling Unit, which was running throughout 1995, proved to be a mature and practical technology. The system was supposed to be handed over to the TDC in 1995, but had not by the end of the year.

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2.7.6 - Window Profiles

The test rig exposing PVC window frames to the climatic conditions of Almería went into its third year of the long-duration test. Staff from the German manufacturer company occasionally visits the site for inspection.

The TDC responsibility is to ensure the ongoing of the test and to send specimen of the materials to a test lab in Barcelona.

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3.1 - CESA-1 Facility

In the CESA-1 facility, facet replacement planned for this year was completed and a new 100 kVA UPS was installed.

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3.1.1 - TSA

During the first half of the year, after having completed the technical specifications of the Advanced Heliostat Field Control, all TSA tests specifically for determination of the receiver temperature control ranges were performed. For this purpose, tests were carried out at different output temperatures.

From July to mid September, with GENESIS connected to a PC and the µVAX, the communication protocol was finished.

A first version of the University of Sevilla control program was installed and tested by gradually increasing absorber temperatures. During the last quarter of the year, tests to adjust control parameters and control temperature ranges at different output temperatures were performed under automatic control.

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3.1.2 - ASM

A 150 m^2 stretched-membrane heliostat was erected at the PSA at the end of February, 1995. After enhanced sun-tracking control had been completed, tests with the ASM heliostat alternated with TSA, since the same hardware is used to control them.

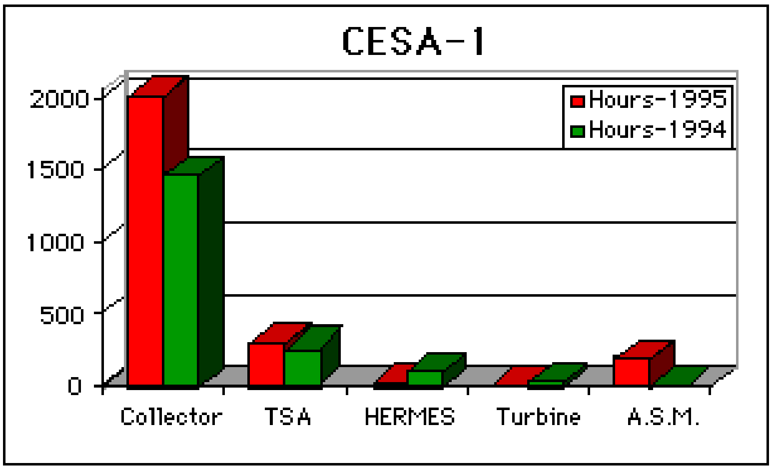

Fig. 3.1: CESA-1 comparative operation hours 1994-1995

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3.2 - SSPS Facility

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3.2.1 - Central Receiver System (CRS)

3.2.1.1 - RAS Project (Receptor Avanzado de Sales).

Various modifications and repairs to this system took place during 1995. The improvement of the strainer attachment, repair of the weldings in both inlet and outlet manifolds and replacement of heat tracing were important items for good operation.

The main problem during operation was the appearance of frozen salt in some parts of the circuit which plugged the pipes preventing normal circulation of the salt.

3.2.1.2 - Volumetric Project.

Two different absorbers were tested within this project during the year:

- The CATREC receiver was tested after changing the position of the air-flow distribution vanes and efficiency was compared to the previous vane setup.
- In the last four months of the year, the COR-REC receiver was mounted and pre-operational tests such as checking for air leakage or temperature distribution were performed. In this absorber, the flow regulator was ignored because each one of the 33 modules is calculated to allow desired amount of air to pass through them.

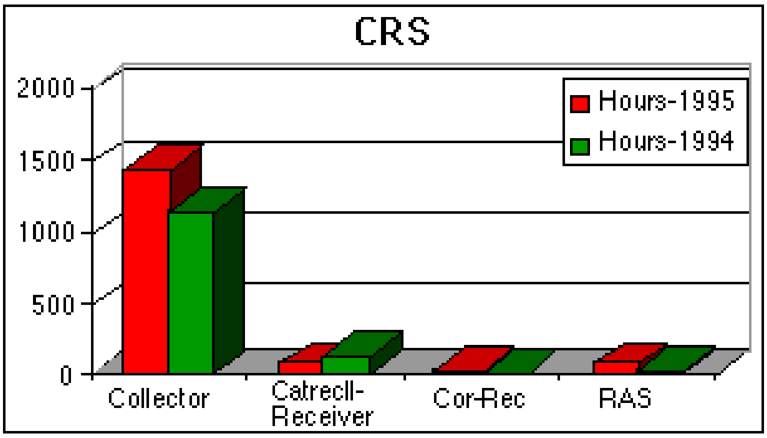

Fig. 3.2: Comparison of CRS operating hours 1994/1995

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3.2.2 - Distributed Collector System (DCS)

3.2.2.1 - ACUREX

The main goal during 1995 was to complete the Human Capital and Mobility Program test plan. This was almost completely fullfilled, but some 1995 tests have to be performed in 1996.

Tests were distributed among three organizations, the University of Manchester (UMIST), the University of Sevilla (AICIA) and the Instituto de Engenharia de Sistemas e Computadores (INESC), for all of which the oil system response was checked under different control systems.

3.2.2.2 - Desalination Plant

The plant was not operated regularly except as required for the Detoxification and TSA Projects or more general uses such as cleaning mirrors or cooling water.

3.2.2.3 - Detoxification Plant

Both the two-axis Helioman collector loop and CPCs have been used for tests within the Human Capital and Mobility (HC&M) Program with different contaminants such as acetic and dichloroacetic (DCA) acids, phenol, chlorophenol, dichlorophenol (DCP), pentachlorophenol (PCP), olive oil-food and industrial waste water.

Titanium dioxide (TiO_2) was the catalyst in all these tests.

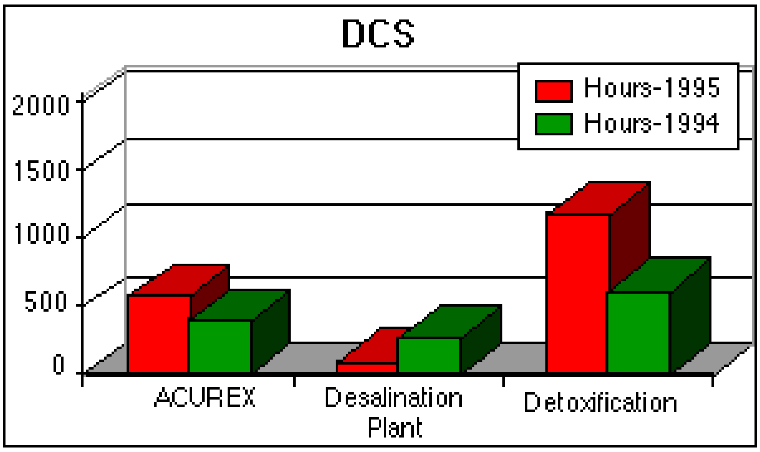

Fig. 3.3: Comparison of DCS operating hours 1994/1995

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3.3 - High Concentration Facilities (HCF)

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3.3.1 - Solar Furnace

Under the Human Capital and Mobility program, the last metal and ceramic materials thermal treatment test campaigns corresponding to were performed including:

- surface hardening of ferrous materials
- surface alloying by controlled melting
- advanced ceramic sintering
- structural modification of metals with TiN ceramic coating

Secondary concentrators were also evaluated.

Temperature measurements were taken with the *AVIO* infrared system.

The High-Resolution *THETA* flux measurement system, including CCD camera, a lambertian target with a *HI-CAL* radiometer and the Theta System software, was calibrated.

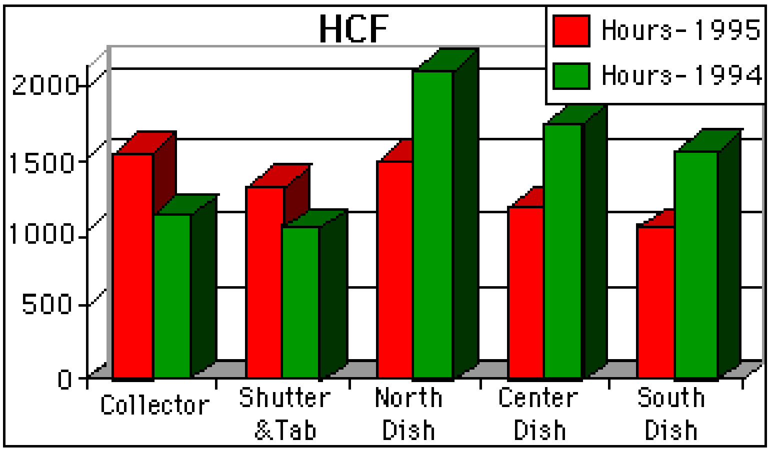

Fig. 3.4: Comparison of HCF operating hours 1994/1995

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3.3.2 - DISTAL

In 1995, 5-day-a-week sunrise-to-sunset operation was carried out in this project and more than 19,000 hours were acummulated by the three dishes.

One new receiver was tested, proving better performance and operation characteristics. Tracking control was improved.

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7.2.1 - Direct Radiation

Fig. 7.1 shows the monthly and hourly average values of direct radiation. It is easy to see, that the year started with an excellent January and ended in a relativly cloudy December. An average peak over **900 W/m^2** was only reached in July at high noon. The diagram confirms the experience that, especially in autumn and winter, days begin clear and end with an accumulation of clouds.

1995 offered 3039 hours of sunshine with radiation over 175 W/m^2.

Fig. 7.2 shows the accumulated hours of varying intensities of direct radiation. It also very clearly shows the local weather situation, which was generally very sunny, but exceptionally cloudy at the end of 1995.

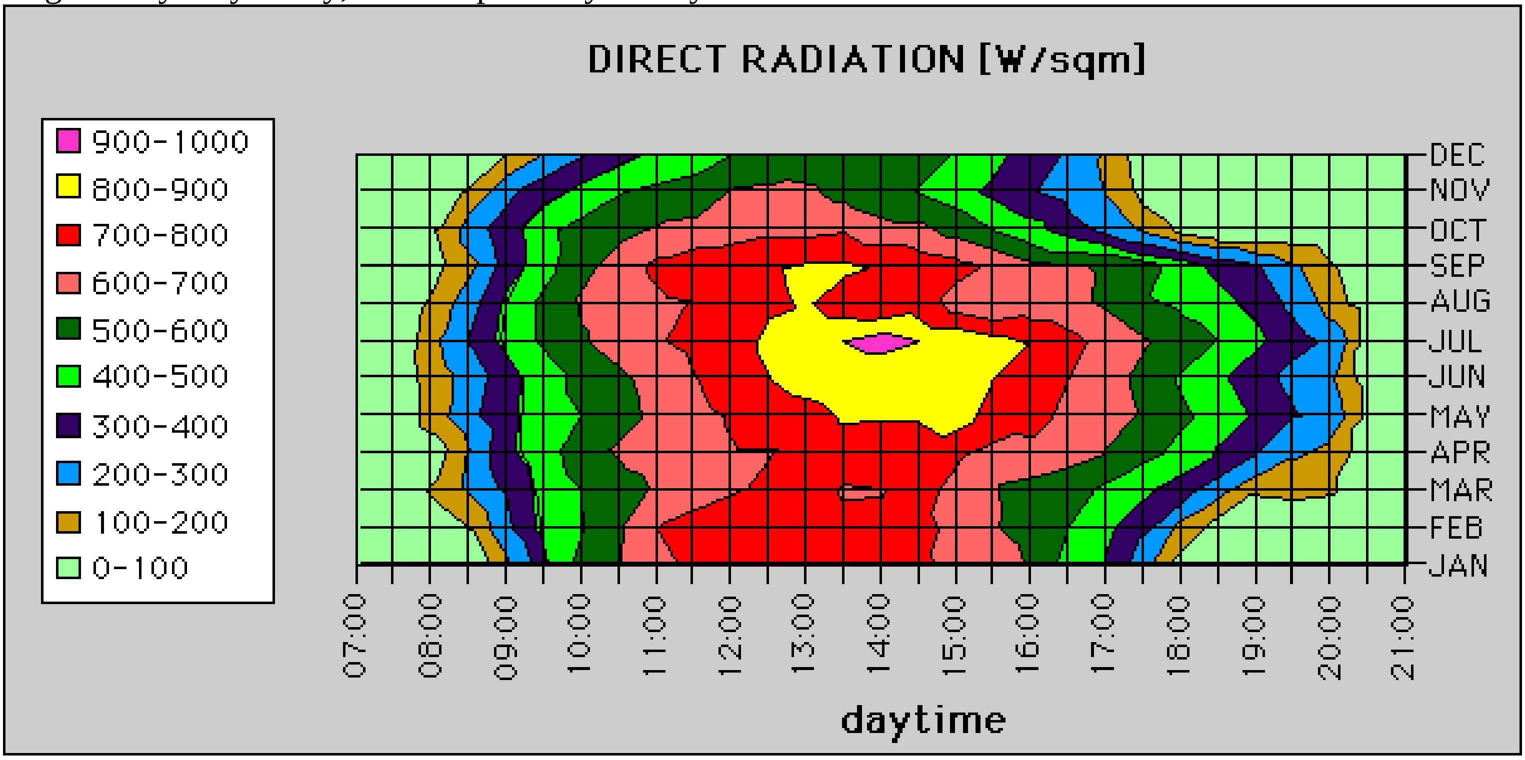

Fig. 7.1: Direct radiation

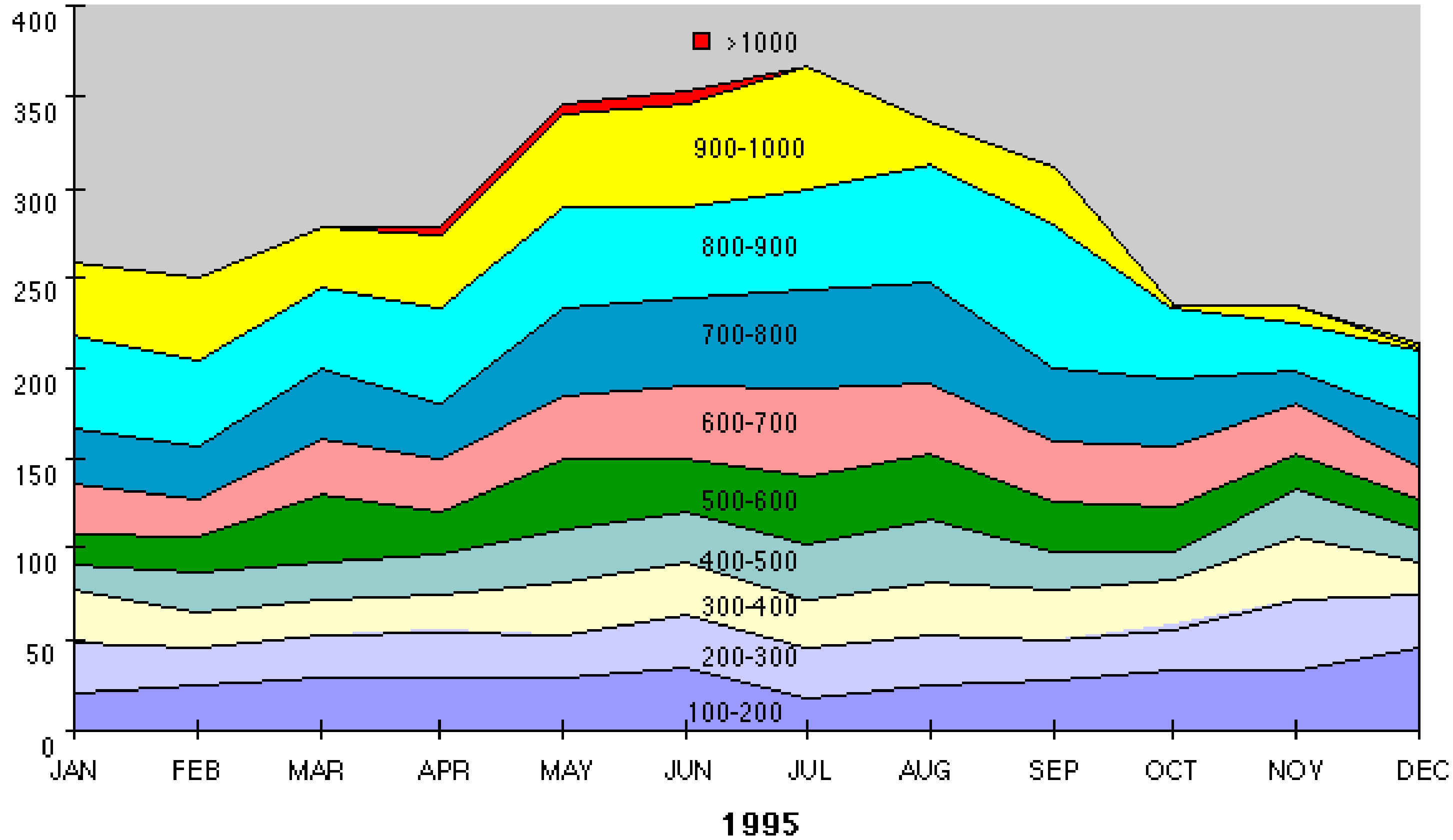

Fig. 7.2: Accumulated hours of direct radiation

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7.2.2 - Temperatures

The diagram in Figure 7.3 giving the monthly and daily temperature distribution shows how inertia of the heated earth and atmosphere is dependent on the solar radiation.

The coldest time of day is between 6 and 8 o'clock a.m., hottest temperatures are reached between 2 and 4 o'clock p.m.

As in the radiation diagram, this figure shows that the year started with a clear, sunny January with big differences between day and night, and ended with relativly cloudy, low-pressure weather with smaller diurnal differences during the day. Fig. 7.4 indicates monthly maximums, minimums and average temperatures. The maximum was 40°C in July and the minimum -2°C in January.

Fig. 7.5 shows the average and extreme temperatures during the last eleven years. The average temperature for 1995 was about 18.7 °C.

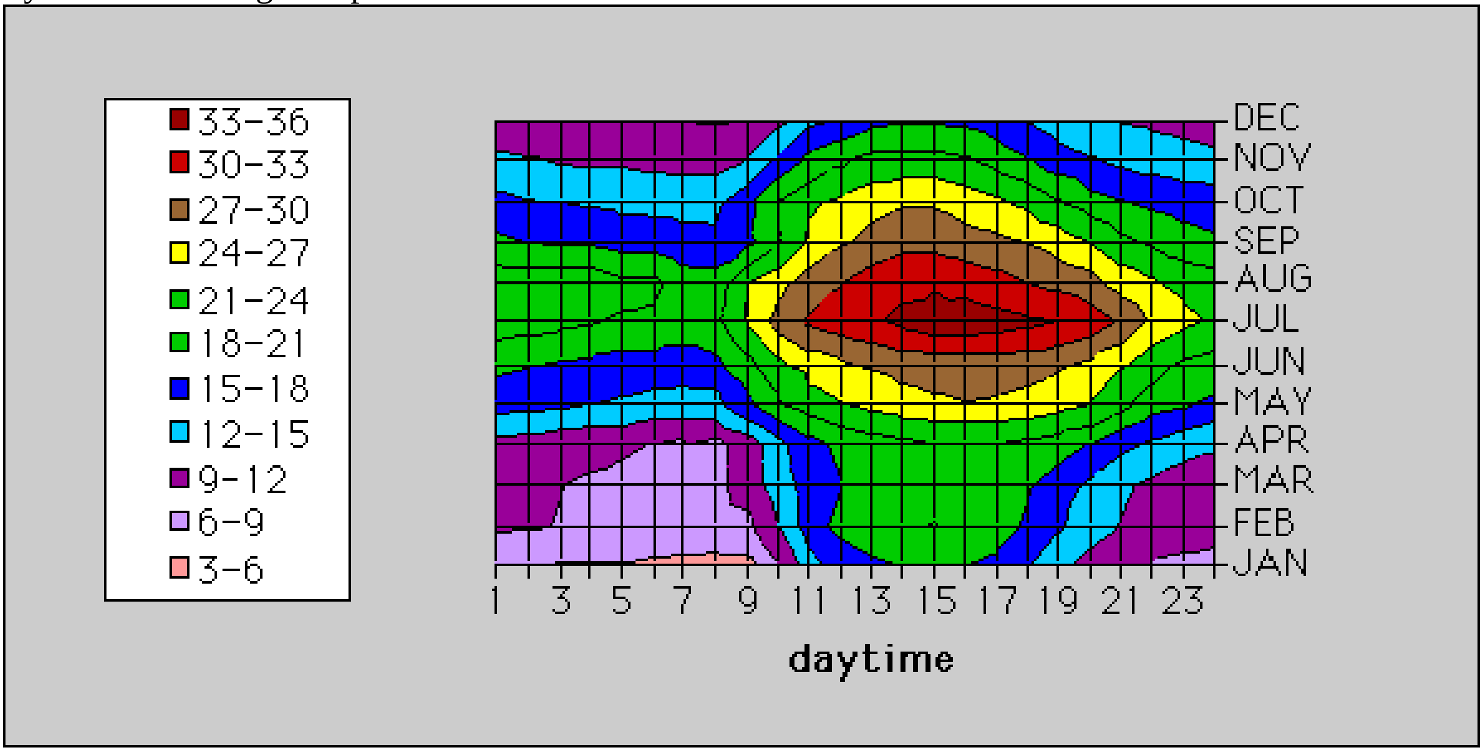

Fig. 7.3: Monthly and hourly average ambient temperature in °C

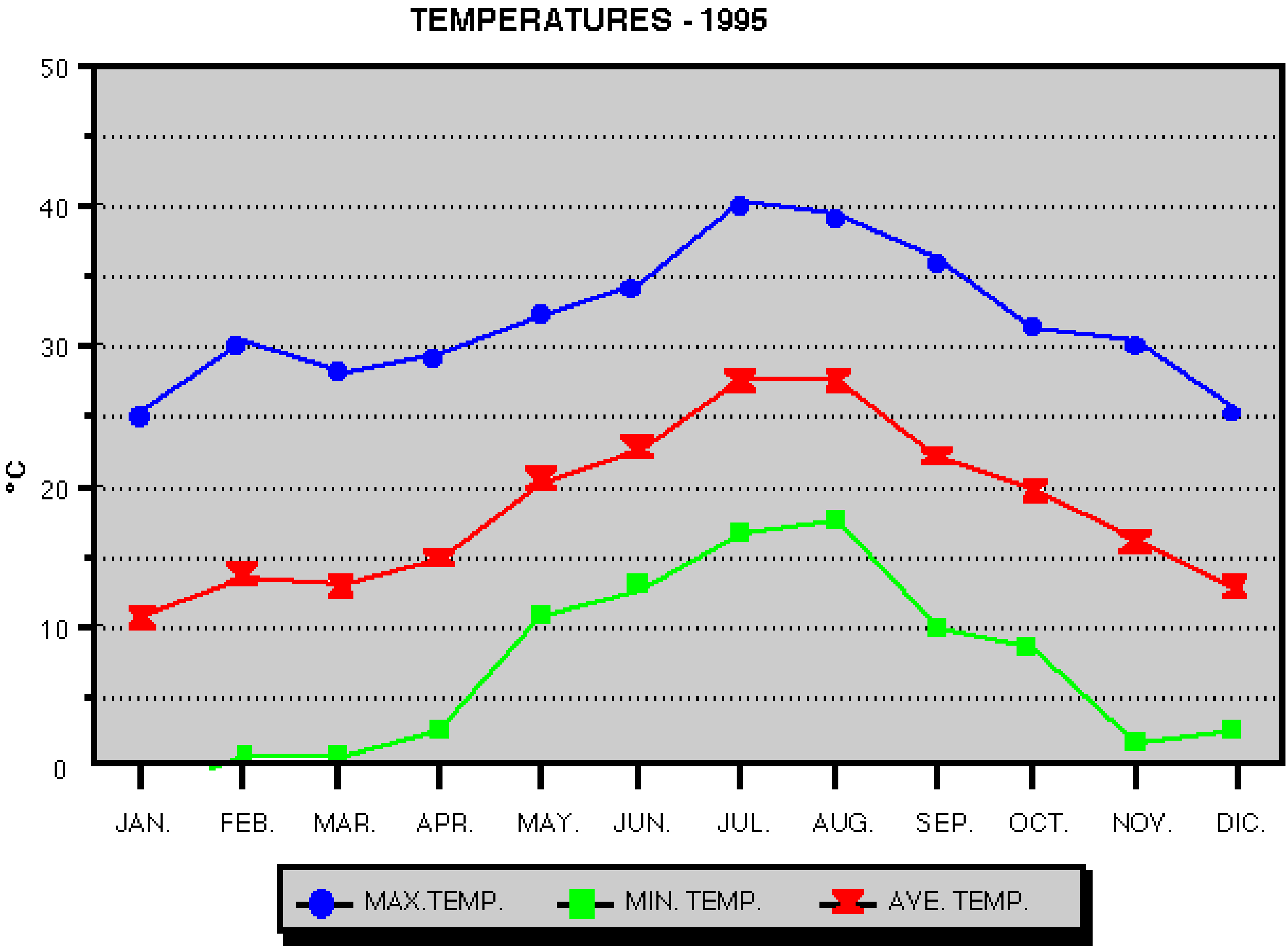

Fig. 7.4: Extreme temperatures 1995

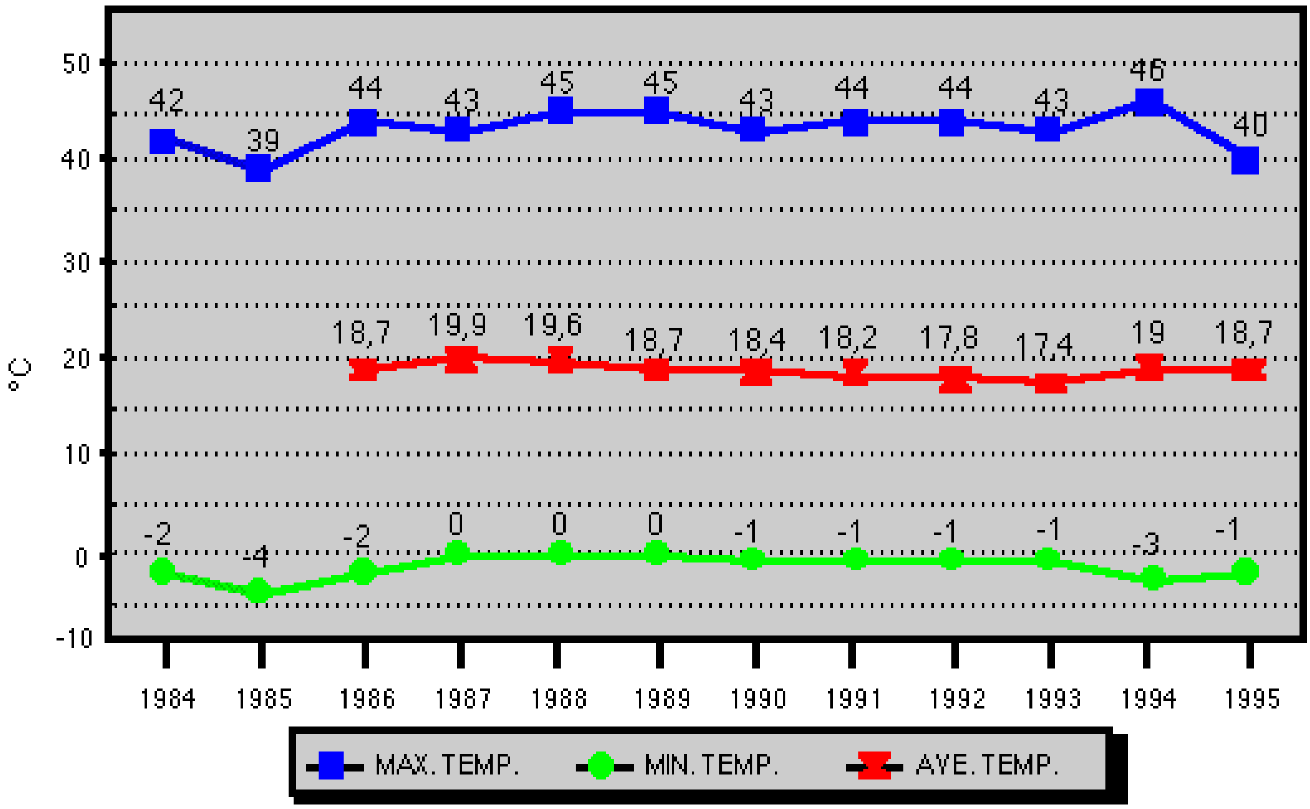

Fig. 7.5: Historical pattern since 1984

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7.2.3 - Wind

Fig. 7.6 gives the monthly and hourly average wind speeds, clearly showing that the windy season is generally from March to July and that the wind rises mainly after midday and calms in the early evening.

Figures 7.7 and 7.8 represent the wind frequency and the average wind speed by direction. Prevailing winds blow out of the East and North-East (Levante), but are not as strong as the west and south-westerly winds (Poniente).

The average wind-speed in 1995 was about 2.7 m/s.

Fig. 7.9 indicates 5-minute averages and maximum peaks of the windiest day in 1995, which was February 28th. The West wind on this day had an average speed of 8.5 m/s and peak of about 26.3 m/s (95 km/h) at ten meters off the ground.

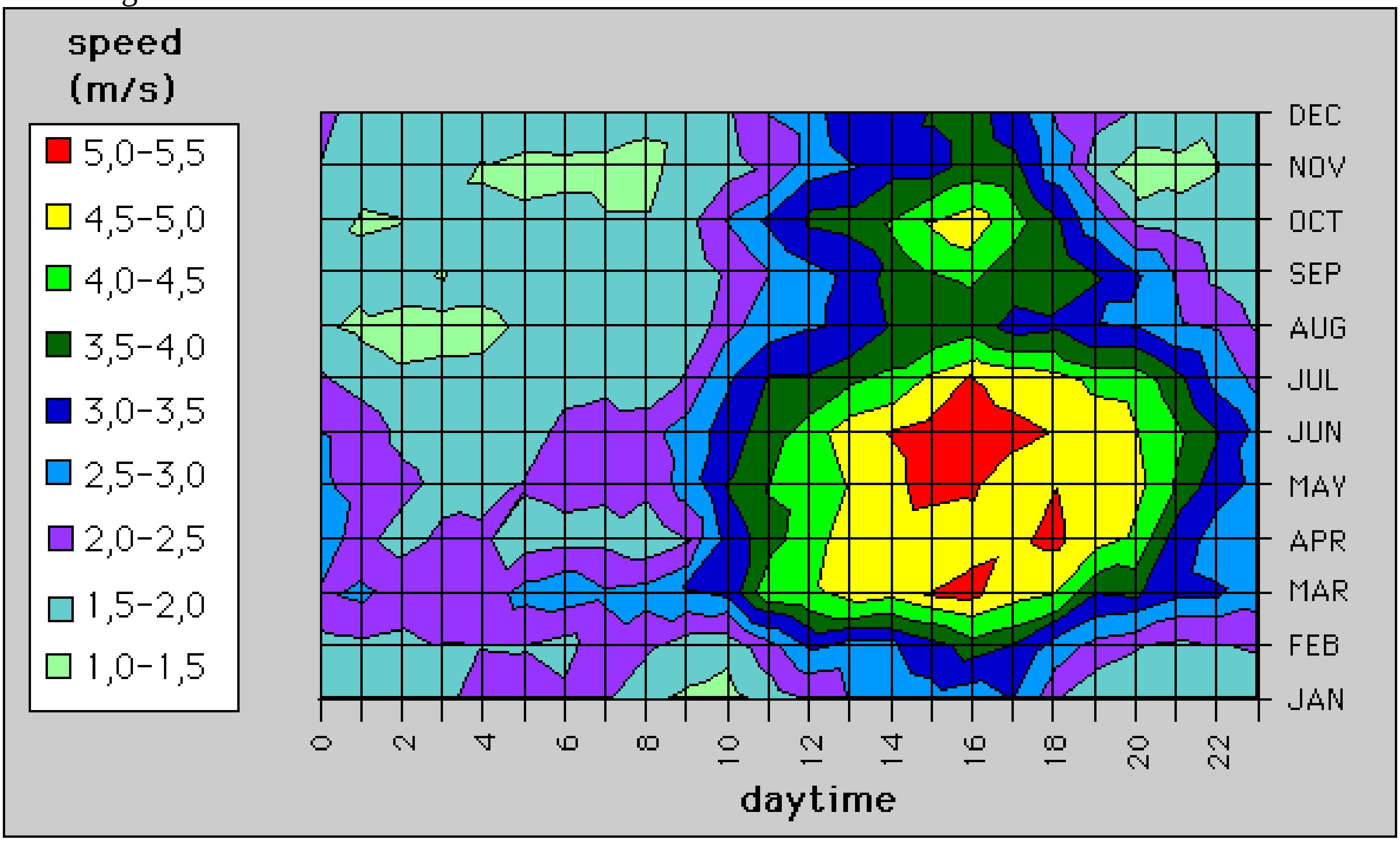

Fig. 7.6: Monthly and hourly average wind speeds at 10 m

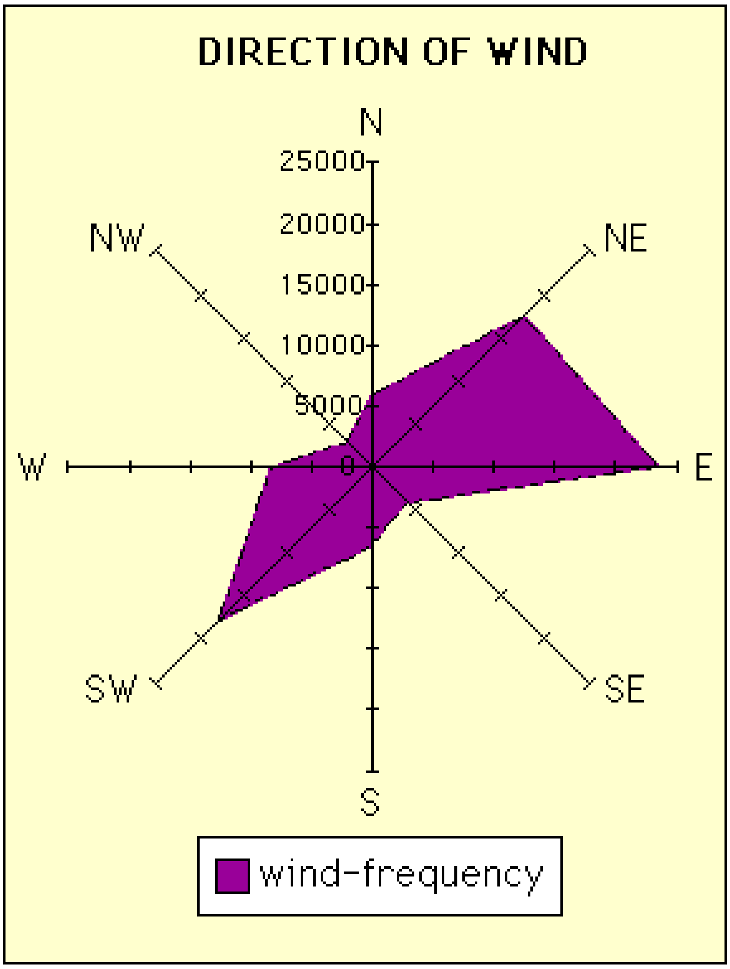

Fig. 7.7: Wind frequency

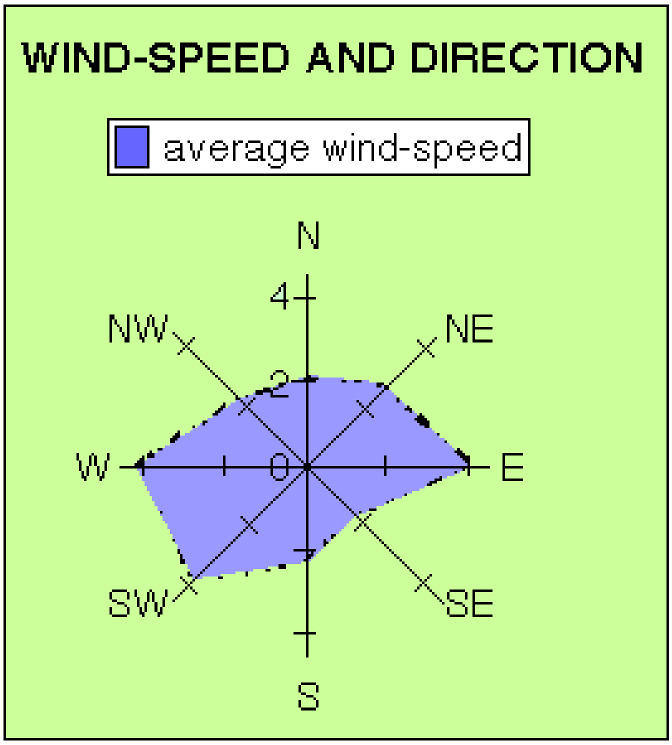

Fig. 7.8 Wind speed

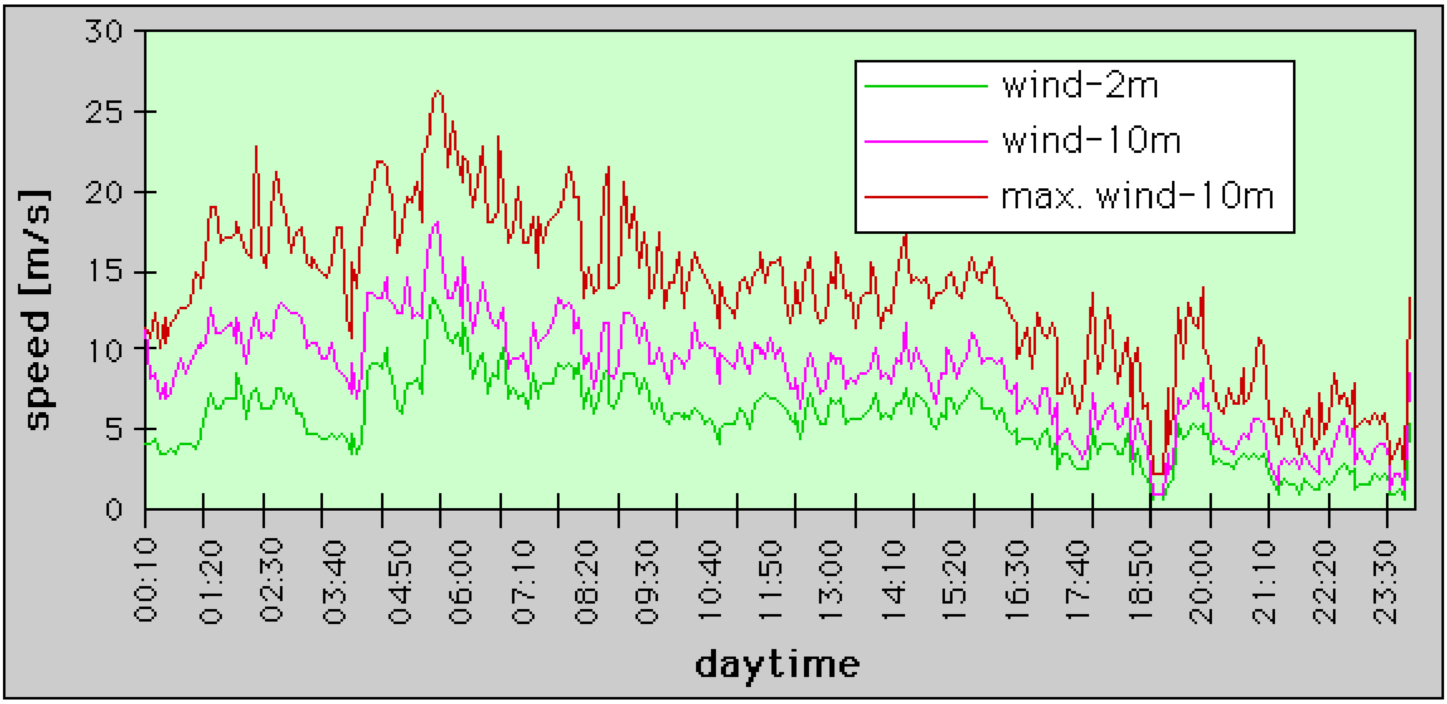

Fig. 7.9: The windiest day in 1995 (February 28th)

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7.2.4 - Rain

This very poor chapter once more demonstrates that the PSA is in a desert.
Fig. 7.10 shows the precipitation and the number of rainy days since 1983.
The total precipitation of 137 l/m^2 is a negative record for the last ten years.

Fig. 7.11 presents the monthly distribution of rain for last year. In three days 88 l/m^2, about 64 % of the total precipitation, fell.

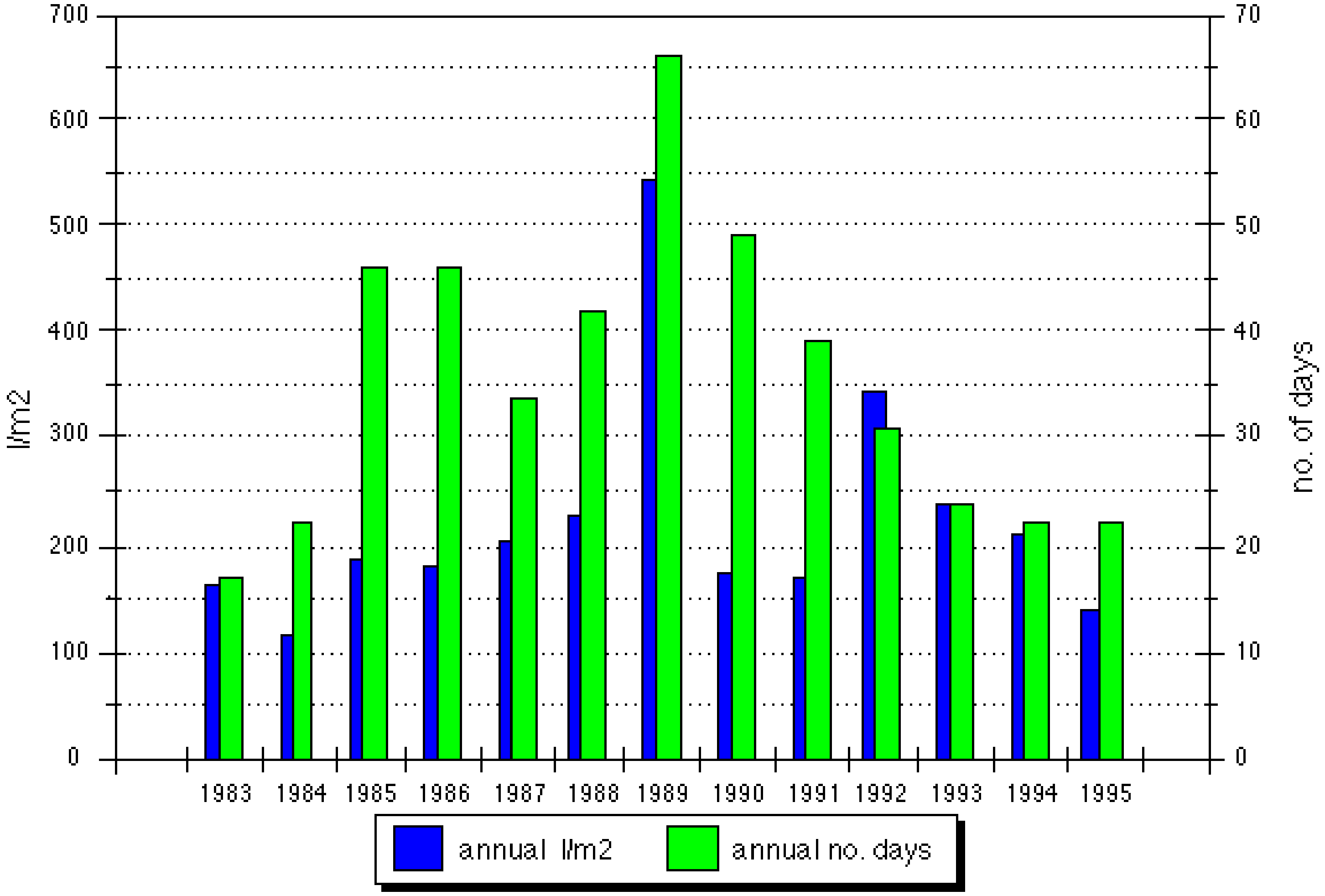

Fig. 7.10: Historical pattern since 1983

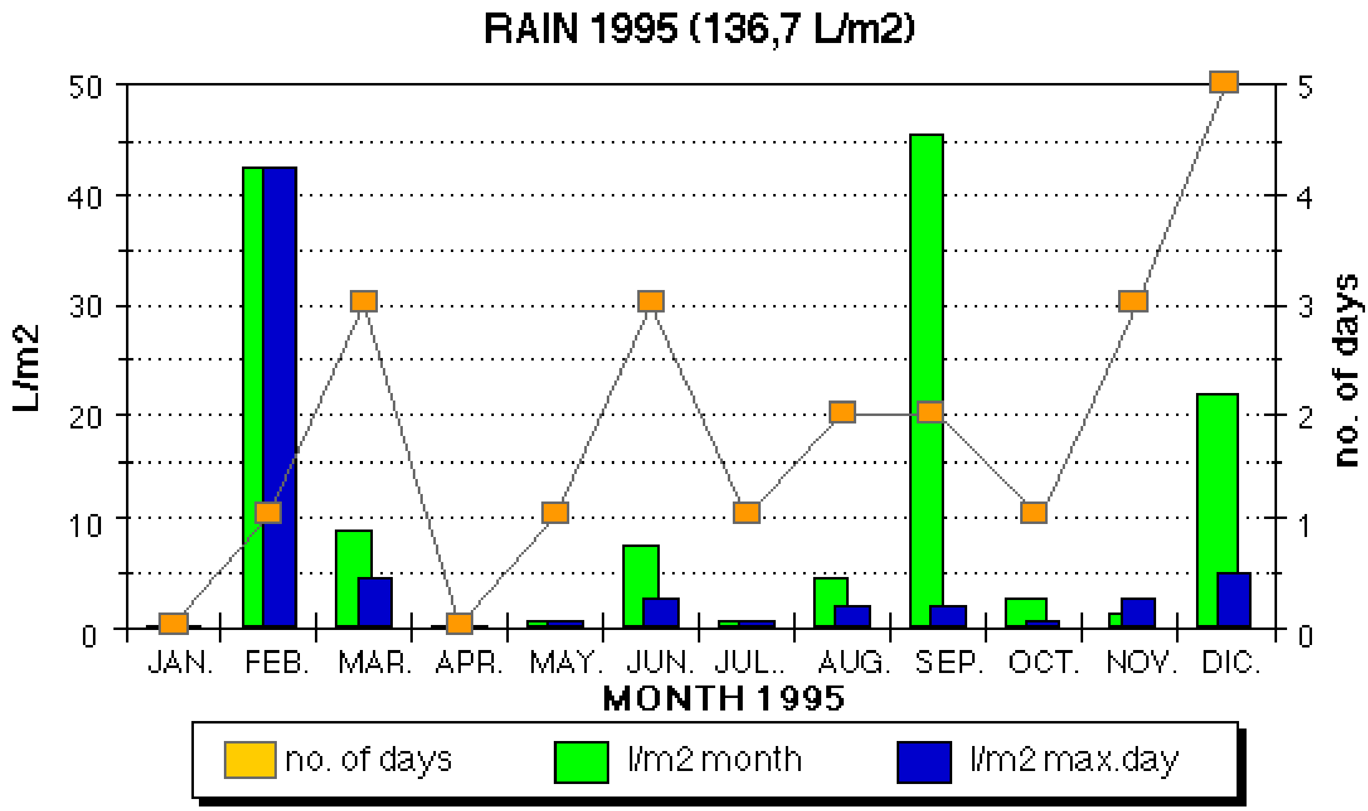

Fig. 7.11: Monthly precipitation

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Adaptive Control System Development

Test Engineer:	P. Balsa
Participants:	Univ. Manchester, Institute of Science and Technology (UMIST) (UK) Dept. Ing. Electrónica, de SAistemas y Automática, Univ. Seville (E). INESC, Lisboa (P)
Duration:	**From:** April, 1990 **To:** March, 1996
Funding:	CEC
Source:	DGXII: Human Capital and Mobility Program

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.2	2.0	0.3	1
1996	0.1	0.4	0.1	0.3

Objectives:

The objective is to provide European research groups with the experimental facilities need to:

- Perform an in-depth study of the difficulties involved in improving control design schemes for parabolic-trough solar collector fields, opening a wider field of application for them.
- Test and validate their theoretical approaches concerning new advanced control systems, improving the control response speed and performance.

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. Though several types of control had been implemented and tested in such solar systems over the last few years, their performance was not very good under some working conditions. Good control performance 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 would open a wider field of application for these systems.

The PSA's DCS facilities (parabolic-trough collector fields, DCS thermal energy storage systems, computer systems, etc.) 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.

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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: February, 1997

Funding: 1 MECU

Source: DG-XII

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.2	0.5	0.3	0.4
1996	0.2	0.27	0.1	0.2

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-93 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 driven electricity production system.

And the expected achievements are:

- The basis, from experimental research on the thermodynamics of direct solar steam generation in pipes, 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.

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DISS-Phase I - Direct Solar Steam in Parabolic Troughs

Project Leader: E. Zarza

Participants: CIEMAT
DLR
ENDESA
INABENSA
FLAGSOL
ZSW
Siemens
Unión Fenosa
Iberdrola
UMIST

Duration: **From:** January 1996
To: December 1997

Funding: 6.13 MECU

Source: DG-XII

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	--	--	1.0	1.5
1996	0.3	0.3	1.2	3.5

Objectives:

The objective of DISS is to develop a new generation of Solar Thermal Power Plants using parabolic-trough collectors to produce high pressure steam in the absorber tubes, thus eliminating the oil currently used as a heat transfer medium between the solar field and the conventional power block. DISS is an R+TD project including 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, thus increasing the competitiveness and efficiency of this type of solar power plant.

Description:

The nine SEGS plants currently in operation supplying 354 MWe peak power to the California grid using the technology developed by the LUZ International company since the early 80ís are a demonstration of the state-of-the-art of solar thermal power plants. LUZ achieved continuous increase in efficiency while reducing costs. Unfortunately, LUZ's 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 capable of reducing the cost of electricity generation by 30%. These improvements were grouped into three categories:

1. Solar Collector improvements
2. Replacement of the oil with the new process of 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 (liquid 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

Direct steam generation also has a certain number of technical problems that require real-scale experimentation and evaluation in order to settle some cost issues. To find the solutions to these problems, the laboratory facilities currently available (HIPRESS, Siemens-KWU, Solel) are not sufficient. A specific test facility with proper dimensions (real scale) is needed, 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.

Since the DISS objectives cover not only the development of the new process (direct solar steam generation) but also all those potential improvements identified by LUZ in the past, parallel activities on System Integration and Collectors Improvements will be performed simultaneously with the design, implementation and operation of the PSA test facility.

Status:

The DISS test facility to be implemented at the PSA was designed in 1994. Project planning including work packages and financial structure was prepared early in 1995. The conceptual design proposed in 1994 was revised in November-December, 1995.

Two LS4A1 collectors used by LUZ in the past to investigate the two-phase flow under solar conditions have been acquired by PSA from Solel. These collectors are intended for use in the PSA DSG test facility.

Electric utilities, industries and institutions were contacted and motivated by the PSA to submit a project proposal to the Joule-II program in 1995 to cover the first phase of DISS, with a budget of 6.13 million ECU. This proposal was approved by the Commission in July, 1995, and the contract was signed in December, 1995. The official commencement date of DISS-Phase I was January 1st, 1996.

Plans for 1996:

Due to the complexity and importance of the objectives of this project, a six-year period is required to perform all the planned activities. This six-year period has been divided into three two-year periods, thus covering from 1996 through 2001. This division makes project financing easier and also allows the achievement of intermediate goals, thus reducing technical risks and uncertainties.

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DISTAL - Dish Stirling Almería

Test Engineer: H. Blezinger

Participants: CIEMAT/DLR

Schlaich Bergerman und Partner (SBP)

SOLO

Duration: **From:** December 1991
To: December 1998

Funding: 21 million Pts. (1995)
11 million Pts. (1996)

Source: CIEMAT/DLR
BMFT
SBP
EC DGXX Joule II
EC DGXII HCM

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.2	1.4	0.1	0.9
1996	0.2	1.1	0.0	0.8

Objectives:

- To prove and demonstrate ready-for market designs with 20,000 hrs. of routine operation
- To test advanced system components/receiver
- To evaluate operation and maintenance requirements of sunrise-to-sunset operation
- To provide a PSA testbed for further development of the dish/Stirling technology

Description:

Three dish/Stirling systems built by SBP were put into continuous operation in May, 1992. Each system consists of a 7.5 m diameter single-faceted metal-membrane concentrator and 9 kWe Stirling engine (V160 SOLO?USAB) as the energy conversion unit. As the dish/Stirling system's high performance has already been proven, remote-power market prospects look good.

The goal of the DISTAL project is therefore not only to optimize system performance, but above all, to demonstrate system reliability and availability in continuous operation.

Status:

- Continuous sunrise-sunset operation of the SBP dishes
- Implementation of new tracking and engine control systems
- Test of new receiver designs
- Mirror cleaning techniques

Plans for 1996:

Encouraged by the positive test results, several clients showed their interest in testing components and complete systems on the PSA. Therefore, it is planned to improve the DISTAL test facility in order to be able to satisfy the requirements for the testing of one fixed-focus system developed by HTC planned for the middle of 1996 and three 9 kWe systems designed by SBP which will be erected by April of 1996.

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El Ejido Solar Detox Project

Test Engineer:	J. Blanco
Participants (Consortium):	CIEMAT-PSA Asociación Empresarial para la Protección de las Plantas (AEPLA), Madrid Ibacplast S.A., Almería Ecosystem S.A., Barcelona Diputación Provincial de Almería. Council of Adra, Almera. 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:	8.4 million Pts. (in 1996)

Objectives:

Feasibility study of a solar detoxification plant to the treatment of wastewater from industrial washing of herbicide plastic 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 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 extensive use of chemicals and pesticides, and their removal from water is a pressing ecological problem. Such persistent organic chemical contaminants include pesticides, solvents, detergents and a variety of industrial chemicals which, due to a combination of chemical stability and resistance to biodegradation, together with sufficient water solubility, penetration deep into the soil reaching groundwater.

The Spanish province of Almería is a perfect example of such important economic growth during the last 15-20 years, chiefly due to large numbers of greenhouses, for which it has an excellent climate and, unfortunately, 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 Almera alone, around 1.5 million of these containers per year), which are usually burnt or buried. In the recent a parallel rise in

Source: Consortium

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	--	--	--	--
1996	0.2	0.2	1	0.4

environmental consciousness is concerned with their recycling, however the recycling includes washing the shredded plastic containers, contaminating water in relatively small amounts, but with highly toxic and persistent compounds at a concentration 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 for this problem, which has no clear alternative solution since the biological purification of water polluted by organic micropollutants is quite inefficient at low levels of the substrate. 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 (OHo) 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 paint manufacture. 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:

The consortium contract was signed at the end of

1995 and first test runs are scheduled for the first six months of 1996.

At the PSA detox facility, an intensive test program is being carried out to, firstly, demonstrate the feasibility of the process with the pesticides most used in the county, and secondly, to outline the main characteristics (dimension, rates, etc) and economic figures of the plant. The project consists of three phases, the first of which is feasibility demonstration; the second, the installation of a small on-site pilot plant, and the third, full plant installation and operation.

This solar photocatalysis project is the first to make the jump from laboratory to industrial scale by developing an effective industrial toxic waste destruction system using solar radiation and, if El Ejido, the main center of Almería's greenhouse production, becomes the first place in Europe to include solar photocatalytic detoxification in a waste treatment plant, will establish a significant milestone in solar research.

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Falling Particle Receiver

Test Engineer:	G. Weinrebe
Participants:	DLR/EN-TT (Design, fabrication, assembly, evaluation) PSA (solar furnace infrastructure preparation, operation)
Duration:	**From:** December 95 **To:** April 96
Funding / Source:	DLR/EN-TT (SOLEP program) CIEMAT/DLR: 1.25 Mio Pts. (Basic Budget)

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.2	0.5	0.1	0.2
1996	0.03	0.1	0.2	0.14

Objectives:

Based on the results of previous research, a DLR Stuttgart study in 1989/90 concluded that the best layout for a directly absorbing particle receiver is a circulating fluidized bed (CFB) in which the irradiation enters from the side. For experimental research, the "TERZ" test facility was constructed. Chemically inert silicon carbide (SiC, average particle diameter 60 µm) particles were used. The irradiation into he riser of the CFB was provided by the DLR Stuttgart Fixed-Focus Concentrator (solar power 4 - 10 kW). As expected, only moderate temperatures of up to 200 °C could be reached, because the CFB requires larger dimensions for thermodynamic reasons. Measurements and additional calculations showed that it is thermodynamically advantageous for the irradiation to enter the downcomer rather than the riser. An additional advantage of such a configuration is that one of the main problems of all particle receivers, the protection of the window from hot particles, is easier to solve. With this background, the current falling particle receiver was designed and constructed in 1993-95.

Description:

The solar irradiated experiments start with low solar fluxes, and then increase step-by-step up to about 50 kW. After the demonstration of operability, the behavior of the receiver with constant and variable irradiation is determined. The most important receiver parameters are the circulating particle mass flow and the power input and output. Further experients will determine the influence of the solar flux distributon and investigate the protection of the window. Solar power will be measured with an indirect flux measurement system.

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Heliostat Technology Program

Project Leader:	G. Weinrebe
Test Engineers:	G. Weinrebe, R. Monterreal
Participants:	CIEMAT/DLR L.&C. Steinmüller (D) Schlaich Bergermann und Partner (D) Fichtner Development Engineering (D) JUPASA (E) Pujol Muntala (E) University of Almería (E)
Duration:	**From:** beginning of 1995 **To:** end of 1996
Funding:	4.660 Mio Pts.
Source:	CIEMAT DLR

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1995	1.1	0.2	0.4	0.2	1.0
1996	0.3	0.6	2.1	1.4	--

Objectives:

After a delay of almost seven years, major efforts are again being undertaken by industry and research institutions to take solar tower technology development from the existing research pilot plant stage to the commercial application stage. Project activities such as TSA (2.5 MWth) / PHOEBUS (30 MWel), SOLAR TWO (10 MWel) / SOLAR 100 (100 MWel), SOLGAS (20 MWth) and the DSW solar tower plant (50 MWth) demonstrate the great industrial interest in this technology.

One of the most important, and at the same time most cost intensive, solar components is the heliostat field (90% of the total solar capital cost / 30% of the total project cost). It has already been demonstrated that only large-size heliostats of at least 100 m^2 will satisfy the cost related and technical requirements of solar tower plants of the next generation.

So far only a few prototype, large-area heliostats have been built and tested in the U.S.A.:

- ATS 150 m^2 (mirror facets)
- SAIC 98 m^2 (two stretched membrane modules, polymer films)
- SPECO 200 m^2 (mirror facets)

The PSA together with industry has initiated a Heliostat Technology Program, in order to provide new solutions for this topic.

Description:

Within the framework of the program, two different large-area heliostat concepts, complying with the PHOEBUS 1B specifications (beam quality of 2.9 mrad etc.) have been built and tested at a distance of 477 m north of the CESA tower.

Parallel activities aim at advanced canting methods, improved low-cost local heliostat controllers and heliostat radio control.

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LECE
Laboratorio de Ensayos energéticos para Componentes de la Edificación

Test Engineer: G. Schwartz

Participants: CIEMAT
DLR
EU DG-XII
IEA
Univ. Politéc. de Madrid
Cristalería Española

Duration: **From:** 1994
To: 1997

Funding:

Source: CIEMAT
DLR
EC
Industry

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.	Techn.
1995	0.2	--	0.2	1.0	1.0
1996	0.4	--	0.1	2.0	--

Objectives:

- Testing of passive solar construction materials and techniques using real-scale outdoor test cells to assess the reliability of these elements for savings in homes and non-residential 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 building materials suitable for energy optimisation 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 cell environment response to be assigned exclusively to the test component. The test sequence and data treatment follow a carefully designed procedure to increase accuracy and obtain the maximum information. The LECE participated in the EU PASSYS II Program in 1992 and 1993. Presently, it also participates in CIEMAT initiatives for third parties, such as the Junta de Andalucía, UPM, or the Building Material Manufactures Association.

Status:

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

Plans for 1996:

In 1996 two main projects under the JOULE program will be undertaken. The ROOFSOL project, for passive cooling techniques, and the PV-Hybrid project, which studies the implementation of PV-panels in building faades. Also following recent developments, the LTS (light transmittance system), will be built, calibrated and used for the IEA project.

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Materials Testing Project

Test Engineer: D. Martínez

Participants: Centro Nacional de Investigaciones Metalúrgicas (CENIM) (E)

Trinity College of the University of Dublin (IR)

Katholieke Universiteit, Leuven (B)

'Demokritos' National Centre for Scientific Research (G)

Institute for High Temperatures of the Russian Academy of Sciences (IVTAN) (RUS)

Duration: **From:** April 1990
To: March 1996

Funding:

Source: CEC DGXII Human Capital & Mobility Program

CIEMAT/DLR Agreement

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.2	0.5	0.6	0.7
1996	0.3	0.5	0.5	1.8

Objectives:

In general, the two main lines of thermal treatment of materials are:

- Treatments with mass industrial application, using renewable energies and processes 'friendly to the environment', saving energy and avoiding the production of noxious wastes. In general, the quality of the product obtained, which is more homogeneous and has better physical properties, is also better with the "solar option". An example of this is the transformation hardening of steels.
- Thermal shock testing of materials that are going to be used for applications such as the aerospace or nuclear energy industries which have very strict requirements. In many cases solar energy is the only procedure which can simulate the real working conditions. This is the case of the tests carried out on the ESA (European Space Agency) "HERMES" space shuttle pieces.
- A third line of application supporting the above two, is the development and implementation of new testing devices and techniques to broaden the range of 'solar thermal' possibilities.

Some particular cases illustrating these general objectives may be found in the projectís current activities:

- Surface modification of steels by melting of pre-applied layers.
- Surface modification of steels by gas/solid reaction
- Photothermal oxidation of TiN-based coatings to create dedicated surface oxides

- Heat treatment of ferrous metals for improved friction and wear
- Sintering of advanced ceramics
- Thermally induced alloying of composite coatings to create super-alloy coatings.
- Development and evaluation of materials for applications in concentrated solar energy, such as secondary concentrators, reactors, etc..

Description of the Facility:

The main tool of this project is the so-called High Flux Concentration Facility (HFCF) or Solar Furnace.

It consists basically of a 98.51 m^2 parabolic mirror, which collects and concentrates the sunlight directed at it by 4 flat-faceted 53.61 m^2 heliostats.

This light is concentrated at the focal point of the paraboloide, producing energy densities of up to 3 MW/m^2 by condensing the 60 KW of energy in a 20 cm. diameter circle.

The amount of energy can be regulated from 0% to 100% almost instantantly by a computer-controlled shutter.

Available auxiliary equipment includes:

- Test Table movable in three axes
- Data Acquisition System
- Vacuum Chamber
- Infrared Camera for Temperature Measurement
- Tilted Mirror
- Rotating Device

Status and Plans for 1996:

At present, and until the end of 1998, the HFCF will be involved in the new European Union Program for 'Access to Large-Scale Facilities' called 'Training & Mobility for Researchers'. Through this program, seven research groups, selected every year by an expert panel, are invited to stay at PSA to perform their proposed materials research test campaigns.

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PAREX

Test Engineer:	P. Balsa (on site)
Participants:	CIEMAT DLR
Duration:	**From:** 1995 **To:** 1996
Funding:	t.b.d.
Source:	DLR CIEMAT

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	--	--	0.4	--
1996	0.02	0.1	0.1	0.1

Objectives:

Development and testing of advanced parabolic trough receivers to:

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

for potential in 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 thereof. The experiments will be used to validate the design assumptions and to serve as a basis for further development and optimization.

Tests planned will be performed at the PSA facilities.

The facility uses Santotherm-55 oil as a working fluid with a maximum temperature of 300 °C. The ARDISS facility is composed of a modified Helioman -3/32 connected to an oil cooler and an oil heater.

Materials and subcontracts related to PAREX will be paid by DLR (MD-ET, in cooperation with EN-TT). PSA support will be required for the installation of new receivers and performance of the test programme.

Plans for 1996:

First tests in 1996 will be performed with the ARDISS test facility implemented in 1995.

Since up-scaling of promising concepts to a commercial size collector (LS-3) is desirable, the 400 °C-HTF oil loop with half LS-3 collector to be implemented at the PSA in 1996 will be used to perform the second test campaign.

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PVPSA
Photovoltaic Testing on the PSA

Test Engineer:	H. Blezinger
Participants:	CIEMAT/DLR ISET, Kassel
Duration:	**From:** May 1991 **To:** December 1996
Funding:	3.0 million Pts.
Source:	EC DGXII-HCM PSA

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.1	0.2	0.3	0.1
1996	0.0	0.0	0.0	0.1

Objectives:

DS/PV:

Operation of a 2-axis tracking PV generator over at least one year in order to generate a database for the comparison of equivalent state-of-the-art PV and SBP dish/Stirling systems in the following respects:

- Comparison of systems with the same collector area
- Investment and estimated financial and energy amortizement
- Operation and maintenance costs
- Reliability
- System efficiencies under different weather conditions
- Energy production over at least one year

Telemetric PV:

Operation of an autonomous PV-powered telemetric meteo station for ISET over at least one year in order to:

- Test PV modules in different orientations
- Test the telemetric system
- Collect weather data and transmit them via satellite to Germany
- Comparison with an identical system mounted at ISET in Kassel
- Comparison with tracked PV and dish/Stirling systems

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Secondary Concentrator

Test Engineer:	D. Martínez
Participants:	Danish Technological Institute (D) Instituto Nacional de Engenharia e Tecnologia Industrial (INETI) (P) CIEMAT/DLR
Duration:	**From:** January 1994 **To:** March 1996
Funding / Source:	CEC-DGXII 'Human Capital & Mobility Program' CIEMAT/DLR Agreement

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.1	0.2	0.1	0.3
1996	--	--	--	--

Objectives:

The secondary concentrator (SC) has been used since the early years of modern solar energy research. It basically consists of a hollow 3-dimensional body with a highly reflective inner surface and high-precision geometry.

In contrast to a primary concentrator, such as a heliostat or a parabolic trough, the SC does receive the direct sunlight, but intercepts the concentrated beam between the field of primary concentrators and the receiver surface.

The SC inlet area is several times larger than the outlet, so that by geometry only, it should theoretically produce an increase in the energy densities proportional to the reduction in surface area.

In practice, however, this is not exactly so, due to losses along the beam path, such as reflection, dissipation from heating of the SC body, beam redirection outwards, etc.

This makes research in the following topics necessary:

- Energy efficiency
- Materials to be used in fabrication
- Quality and lifetime of inner reflective layer
- Optimum geometry
- Characteristics of the outlet fluxmap: maximum peak, uniformity

The PSA SC project was initiated in 1994 and is being carried out with two European Research centers, DTI of Denmark and INETI of Portugal.

The 'test bench' is the PSA-HFCF for several reasons, among them, the availability in this facility of appropriate sensors for the measurement of energy flux and temperature, and the small size of the primary focus (about 20 cm.) which requires the fabrication of small-sized prototypes, thus reducing the cost of research.

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Solar Water Detoxification Project

Test Engineer:	J. Blanco
Participants:	Universita di Torino, Dept. di Chimica Analitica, Italy Univ. de Barcelona, Facultad de Química, Dpto. Ing. Química, Spain INETI (Instituto Nacional de Engenharia e Tecnologia Industrial), Portugal ISFH (Institut fr Solarenergiefoschung GmbH), Hannover, Germany Technical univ. of Vienna, Institute of Physical Chemistry, Wien, Austria URA an CNRS, Ecole Centrale de Lyon, France
Duration:	**From:** 1990 **To:** 1998
Funding:	11 million Pts. (in 1995)
Source:	UE DGXII / PSA

Man Power/Year:

Year	Tech.	Oper.	Eng./ Maint.
1995	3	0.5	1
1996	2	0.5	0.2

Objectives:

1. Determination and quantification of process parameters for system and hardware component optimization.
2. Study and modeling of the chemical reactions.
3. Development of the technology necessary for commercial application.

Description:

The long experience of CIEMAT in solar thermal systems at the Plataforma Solar de Almera has combined in the Detoxification Loop with the knowledge of some of the most important European scientists in the field of photocatalytic detoxification, who have been working for many years to develop and set up effective systems using concentrated solar radiation for the destruction of toxic compounds in industrial waste. The feasibility of the photochemical reaction has been fully demonstrated in the laboratory. The main objective of the PSA Detoxification Loop, erected as an experimental facility for European Community users, has been to uspcale from the laboratory to pre-industrial-size experiments, an absolutely necessary step towards real applications, which now seem viable in the near future due to their technical and economical attractiveness in sunny locations.

The PSA Solar Photocatalytic Water Detoxification Loop consists of 12 two-axes solar-tracking Helimans collectors, originally designed to concentrate and transform solar radiation into thermal energy and modified for solar chemical applications. The collector aperture plane is always perpendicular to the solar rays, which are reflected by parabolic mirrors and concentrated onto the focus where the contaminated water to be detoxified flows through a borosilicate glass tube (absorber reactor).

The reactor is 56 mm inner dia. by 216 m long. The 12 modules are connected in series by polyethylene pipes in such a way that any one of them may be eliminated or modified with a by-pass valve on each, and placed in two rows of 6 modules each, The nominal aperture area of each module is 32 m^2, implying a total effective loop aperture area of 384 m^2. An aluminized thin plastic film selected as the reflective element provides a practically first-surface aluminum mirror. The aluminized side of the plastic film is fluid to the original glass mirror which is used as a support structure to give the collector the appropriate parabolic curve. Total collector optical efficiency is 58%, the fraction of solar UV radiation over the collector aperture area available inside the absorber. Total loop capacity is 838 liters and flow rate can be altered and controlled between 500 and 3000 l/h.

Initially, it has been thought that these parabolic-trough collectors were the most suitable for this type of applications and in fact the first experimental plants in the world were built with this technology . However, a recent demonstrated improvement in the efficiency of the process due to the additional gain of diffuse radiation and a substantial reduction in the global cost of the system using static collectors, has led at present for the use of non-concentrating static systems.

CPC's (compound parabolic-trough collector) are a very attractive type of non-concentrating collectors, due to the special curvature of the reflecting surface, able to concentrate diffuse as well as direct radiation. According to this, during last year, a second detoxification loop using this type of collectors has been installed in the PSA's facility, each one with a 2.5m^2 surface and south orientated with a tilt angle similar to the latitude of the site (37°) to obtain the maximum yearly efficiency. The optical efficiency in the ultraviolet band is 65%.

The test substance, in the normal test procedure, is previously weighed and dissolved in the laboratory at a high concentration and later added to the tanks in the loop; a similar procedure is followed for the catalyst (TiO_2 Degussa P-25 P-25 anatase). The suspension is then stirred until the whole system, reactor included, is homogeneous normally by recirculating the suspension from the supply tank back trough the loop.

Once the suspension is considered to be homogenous and all parameters set (flow, pressure, oxygen input sequence, etc.) have been reached, the outlet is switched to a different tank and the solar tracking command is given. This point is considered test startup. Residence time, or time each unit of the test liquid volume is exposed in the absorber, is computer controlled. Several process parameters are continually measured simultaneously, by on-line instrumentation, transmitted to the Data Acquisition System and sent to the computer which controls the process, continually renewing the readings of the various parameters (physical as well as chemical and weather), and recording data.

Samples are taken periodically and the concentration of the reactive released by the HPLC-UV Hewlett-Packard 1050 is monitored; total organic carbon (TOC) existing in the suspension is also analyzed with a Heraeus-Foss Electric TOC-2001 Analyzer.

Status:

Activities during 1995 have been mainly related with the EU-DGXII Human Capital and Mobility Program under which different European Research Groups have used PSA Detox installations to carry out their specific test programs. This program, initially expected to conclude on 31.12.95, was extended until 31.03.96.

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'STAMP' Project

Test Engineer:	D. Martínez
Main Contractor:	Dassault Aviation
Duration:	**From:** January 1, 1995 **To:** December 31, 1996
Funding:	4 Mpts.
Source:	Dassault Aviation

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	--	--	--	0.1
1996	0.15	0.1	0.4	0.2

Objectives:

The project basically consists of applying thermal shock on a reduced-scale model of the E.S.A. Mars Penetrator.

Description:

The sample has the following parts:

- An spherical, ablative cap
- A 'CSiC' shell surrounding the cap and,
- A rear structure made of aluminium and titanium

General dimensions are:

- Diameter: 700 mm.
- Width: 200 mm.

Thermal Cycle: Only one thermal cycle to be per formed to consist of:

- Solar Thermal Shock from 0 KW/m^2 up to 600 KW/m^2 in 25 s
- 5 s at constant energy level
- Cooling down in 20 s.

The test will be performed at the 60 m-high test room in the CESA-1 tower using the heliostat control system to generate the time-flux profile. To adapt the sample to the existing facility, an interface between the probe and the 'HERMES'-Nosecap Test Jig must be developed and fabricated. In addition, this interface must protect the test room against the incoming rays during exposure, for which a water-cooled barrier must be designed and installed.

The tasks under the PSA responsibility are:

- Design and manufacture of the above mentioned interface.

- Performance of necessary simulations
- Setup of the test assembly, including instrumentation of the test article with thermocouples.
- Test performance, observing ESA quality assurance regulations
- Removal of the test article and transport back to France

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STEM
Solar Thermal Electricity in the Mediterranean

Test Engineer: E. Zarza

Participants: CIEMAT
DLR
European Union
Iberdrola
INTECSA
Pilkington
Siemens
Solel
ULP
UMIST
ZSW

Duration: **From:** January 1995
To: June 1996

Funding: 119.7 Mpts.

Source: DG-XII
Partners

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	--	--	--	--
1996	--	--	--	0.15

Objectives:

STEM is being developed under the European Union APAS'94 Program. The project objectives are:

- Develop the concept design for a commercial scale 100-200 MWe Integrated Solar Combined Cycle (ISCC) demonstration plant integrating a solar field with Direct Steam Generation (DSG). Such a design will be compared to a state-of-the-art reference system with oil cooled collectors. The benefits of a bottoming sea-water desalination system will also be investigated. A specific reference site in Southern Spain as well as in Morocco will be chosen for these comparisons.
- Prepare large-scale testing of the process and of those research concepts which promise to be the most competitive, including performance, investment and/or O&M costs. The concept design for a DSG test loop at the PSA will be included in the study as the first step toward the full-size demonstration of a DSG plant in the 100 MWe range.

Demonstration of the existing technology and further cost-performance improvements are expected, namely:

- Quantification of the cost and performance advantages of integrating DSG into 100-200 MWe commercial combined cycle plants.

- Concept design of such a hybrid solar/fossil combined cycle plant with DSG.
- Identification of the next steps in collector design development and system optimization.

Concept engineering for a DSG/ HTF test loop at PSA.

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TDC
Technology Demonstration Center

Test Engineer:	B. Ebel
Participants:	IST HTC ECSCR/Synopsis University of Hohenheim Dornier REHAU G. Kunkel
Duration:	**From:** 1994 **To:** 1996
Funding:	--
Source:	PSA Basic Buget BMBF Industry

Man Power/Year:

Year	Main.	Oper.	Eng.	Project Relat.
1995	0.1	--	0.1	2.0
1996	--	--	--	1

Objectives:

The overall objective of the TDC is to promote solar technology of small autonomous solar systems.

Description:

The following measures are taken to achieve the above objectives:

- testing and servicing of small solar systems
- offer industry the possibility to demonstrate and promote their products
- offer users the possibility to see the products in operation and learn about their functioning
- offer the possibility of gaining practical experience in solar technology

Tasks carried out during 1995:

The following activities:

- testing and servicing of small solar systems
- comparative testing of solar lamps and solar dryers

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The PSA on the World Wide Web

The Plataforma Solar de Almería has built this Web Site, which you are visiting this very moment, hoping it will be both useful and informative. Right now this service includes general and historical information about the Plataforma Solar, many of the ongoing projects, this Annual Technical Report '95, meteorological data, PSA staff and more.

As you can see, the PSA Web Site is undergoing a major revamp. In the near future it will hold information about all current projects, the next Annual Technical Reports and even real-time information about ongoing experiments (for researchers).

You can get in touch with the PSA Web Team through the link at the bottom of every page. As you should know by now, "we are always open to your suggestions."

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1.7.1 - Solar Thermal Power Demonstration and Development Requirements

Reflecting the requirements of equipment manufacturers and electrical utilities, the improvement in the parabolic-trough technology and development of direct steam generating collectors will be devoted primary attention and most of the PSA resources, in such projects as DISS, PAREX, ARDISS and IMAGENES. This development and qualification of the next-generation technology is a fine complement to parallel ongoing efforts to build solar plant projects with current technology by preserving the technological lead of the participants. With the inauguration of the first full rows for solar direct steam generation at the PSA, the participants aim to demonstrate their ability of supplying and operating solar fields in upcoming projects

In the field of central receiver technology, the PSA on its own will focus on the improvement of automatic closed-loop heliostat control and communications, where advances in digital electronics have made control of radiation patterns and temperature much less dependent on the human operator than in current central receivers, including Solar Two.

Further development and testing of central receiver equipment will depend on market interest and success of the industry and electrical utilities involved. The SOLGAS group, in which the Andalusian utility SEVILLANA participates, has announced that they will contract the PSA for engineering support, testing of heliostats and other new SOLGAS equipment. The PHOEBUS and TSA consortium relies on the preservation of their existing system installations at the PSA for equipment testing, demonstration and operator training for a future first PHOEBUS plant contract. DLR Cologne has planned further open-cycle volumetric receiver tests.

Of equal industrial importance is the dish/Stirling program, in which German industry has proven its technological leadership with the DISTAL I project. In DISTAL II, participating German industry will take the final step toward marketing by testing and demonstrating the first three of a pre-series of one hundred dish/Stirling units in which Mediterranean and other electrical utility companies have already expressed their interest in purchasing as an alternative to Diesel and PV generators after successful qualification at the PSA. The PSA, having identified the specific interest of development organizations and end users in the hybridization of such dish/Stirling systems, an inherent advantage over their PV competitors, will initiate development and testing of combinations and interfacing of fossil/solar in Stirling engines. A first project in this field, HYPIRE, has been granted funding by the European Union with the objective of developing such sustainable, CO_2-neutral electricity generation systems for remote areas or grid stabilization.

Future solar power equipment and system tests will focus on the integration of solar power into fossil-energy generation systems and their combination with biomass firing. The PSA will also offer its support of regional and Mediterranean solar thermal power and process heat demonstration projects. Its 7 years experience in solar thermal desalination is an example of a basis for such cooperation.

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1.7.2 - Research Challenges in Solar Chemistry and Materials Testing

Responding to the increasing demand for access to its facilities for non-electrical applications of concentrated solar energy technologies, the PSA has opened its doors to research groups interested in educating their personnel in these new applications. The broad range of these facilities enables testing in such different areas as detoxification of industrial effluents, production of fine chemicals and thermal treatment of advanced materials. PSA will continue to improve them and extend the services offered to interested third parties, as it has done in the past with the detoxification loop, the solar furnace, data acquisition systems and the chemical laboratory.

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1.7.3 - Cooperation with Industry and Electrical Utilities

On the verge of marketing its various technologies, the PSA will intensify cooperation with industry and electrical utilities in the field of solar power generation and solar technology transfer. The DISS and DISTAL II projects, for example have been organized and structured with the clear objective of capturing the interest of industry and utilities and stimulating follow-up ventures. Schedules have been timed such that PSA activities complement and strengthen ongoing industrial project development.

Similar cooperation will be built up in the low temperature area, where the PSA will seek to initiate kick-off projects that involve solar technology developers, interested manufacturers and Mediterranean end users. The positive experience and response to PSA mediation and support in a project uniting a German developer of collectors and a local Spanish hotel chain as the end user have demonstrated that the market needs such PSA services. To this end, the PSA will offer electrical utilities and independent power producers interested in the implementation of solar thermal power systems its facilities, O&M and training capabilities. It also offers them its independent engineering experience in solar power for radiation analyses, feasibility studies, review of specifications, bid evaluation, acceptance testing, performance monitoring and other related support. Such cooperation has been established with ENDESA, SEVILLANA, UNION FENOSA and IBERDROLA in the European STEM, DISS and SOLGAS projects. The first consulting contracts of this kind have been received by the PSA from the German Development Bank (KfW) and GTZ.

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1.7.4 - Education, Training and Scientific Cooperations

Since 1990, the PSA has been selected by the European Commission's DGXII together with 10 other large European installations for a research subsidy program called "Access to Large-Scale Scientific Installations" (LIP), in order to subsidize the operating and other costs originating in the use of PSA facilities by groups of Community scientists who would otherwise not have access to them. From 1990 to 1995, the LIP contribution to PSA represented an average of 15% of its total budget, allowing the PSA to provide access to twenty-four users from ten member states. For the 1996-98 period, fifty researchers of fifteen European member countries have applied for 256 weeks of access to the various PSA facilities within the European Commission DGXII's Training and Mobility of Researchers (TMR) program. The PSA will continue to ensure the scientific quality Users require in the most important PSA vehicle for scientific cooperation with European partners by allocating appropriate budget and personnel. Special emphasis will be placed on its support of European industry and research groups in research networks.

For the 1996-98 period, the PSA will seek funding of educational, training and R&D projects for students and guest scientists from Mediterranean, Middle South America and Third World sunbelt countries, none of them represented as yet at the PSA. For the tutoring of academic thesis work, the PSA will join forces, share laboratories and facilities and exchange teaching personnel with the recently founded University of Almería (UAL), for which CIEMAT and DLR have agreements with the UAL.

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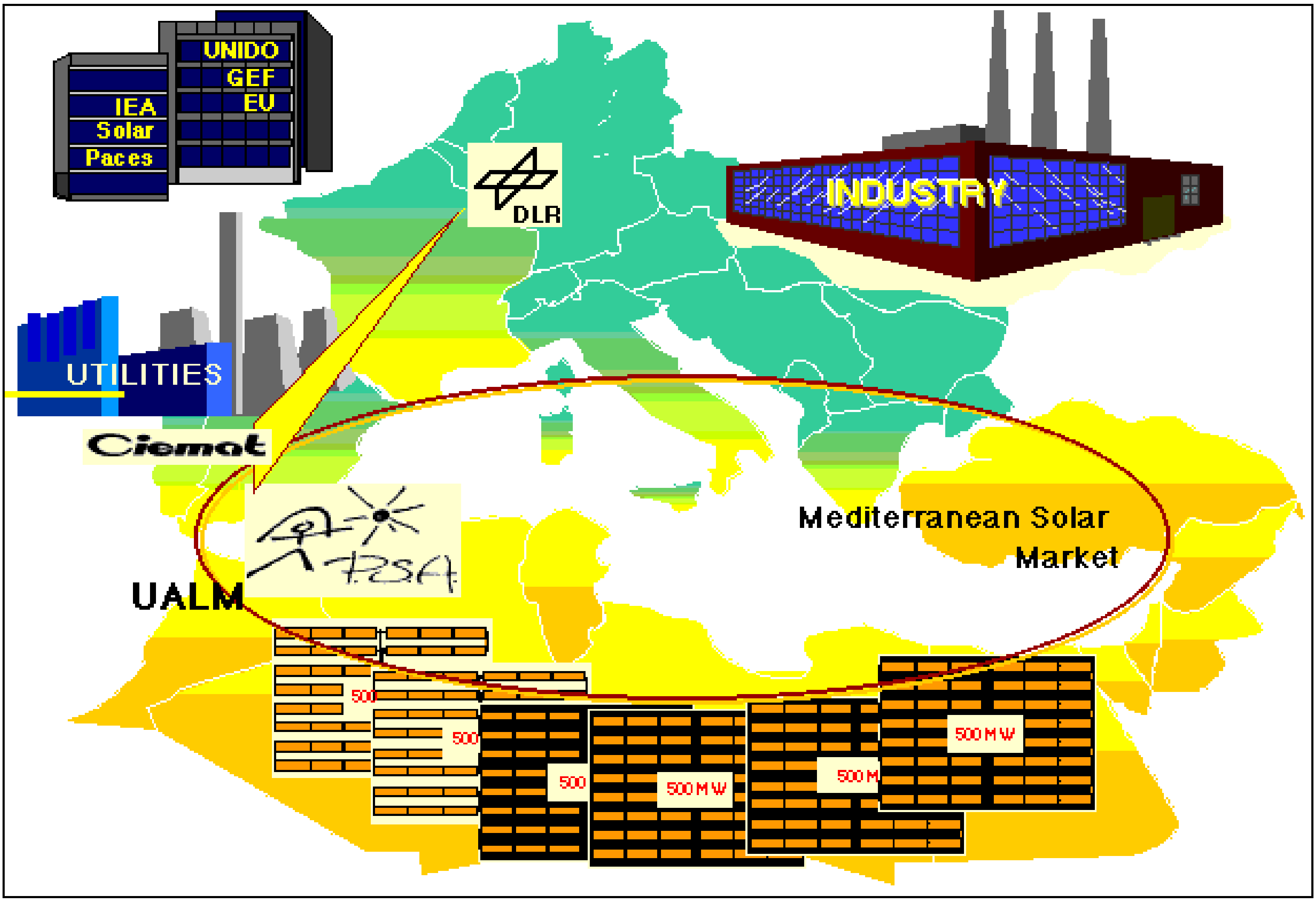
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2.1.1 - The LECE

The LECE (**L**aboratorio de Ensayos **E**nergéticos para **C**omponentes de la **E**dificación) on the south side of the PSA, forms part of the European PASSYS 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 outdoor conditions (See Fig. 2.1.1). The LECE carries out the experiments as part of a continuous action of the CIEMAT solar energy building R&D section.

Fig. 2.1.1: The LECE laboratory
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2.1.2 - The Test Cells

The test cells, which are well insulated by 40-cm-thick polystyrene walls, are approximately the same size as a standard room, the opposite wall to the service room or the roof are interchangeable with a test specimen. Once the test component is installed, the test sequence, which produces different power and temperature conditions in the interior of the test cell, is started up.

Through the continuous measurement of the various parameters, some of the thermal properties of the component, such as the overall thermal loss coefficient (UA), solar gain factor (gA), or system time response (tau) can be determined.

These properties allow the reliability of these elements for energy savings in residential and non-residential buildings to be assessed.

The existing laboratory equipment is:

- 4 test cells.
- 1 light transmittance sensor for translucid panes.
- 2 data acquisition systems with a total of 350 channels
- 120 surface-temperature measuring points (approx. 40/cell)
- 40 internal air-temperature measurement points (10/cell)
- 2 systems for measurement of air-tightness in components and buildings (tracer gas and pressurization methods)
- 4 heat flux sensors
- 4 hot-wire low-wind-speed anemometers
- 2 automatic cooling systems
- 4 automatic heating systems
- 1 meteo station
- 6 light meters
- 1 Pseudo Adiabatic Shell (PAS), installed in one of the cells.

Fig. 2.1.2: Interior of a LECE test cell
(19 kb)

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2.1.3 - New Infrastructure at the LECE

One of the main tasks at the LECE, after its development under different European programs had ended, was to finish the infrastructure needed for it to become a laboratory meeting standards. The LECE facility was greatly improved during 1995. The changes range from improvements in existing instruments to completely new measuring capabilities.

To start with, the laboratory has been implemented with a small new workshop so that some of the construction and assembling tasks can be performed by the LECE personnel themselves. This gives the lab the ability to resolve the small technical problems that come up in all projects and speed up the completion of the projects.

As a second improvement, the facility's data acquisition system has been transformed into a more user-friendly tool so that any researcher can use the system straight away without too much delay. They are also now connected by local net to the main computer of the Plataforma Solar. This makes standardized automatic routing of the information possible, allowing authorized persons direct access to the information whenever they want. This is quite important in projects where analysis and control are shared by people from outside the Plataforma, as in the ROOFSOL project, where easy access means that the corrections to the control parameters can be made much faster, saving precious time for the project.

New capabilities have been given the LECE with the following new features:
The PASSYS Mediterranean Cell has been upgraded with the installation of a rotating platform, providing new richness for experiments, since orientation with respect to the Sun can easily be changed.

Fig. 2.1.3: PASSYS and CESPA Mediterranean test cells
(44 kb)

A new instrument in the lab is the solar outdoor Light Transmittance Sensor (LTS), shown in Figure 2.1.4. This device contributes to the laboratory's capability to calculate the energy and light transmittance of non-homogeneous translucid construction components. At the moment the LTS sensor is a pyranometer, so the only measurable variable is total solar transmittance. Nevertheless, it can be used with a portable spectrometer, which would enable calculation of spectral transmisivity.

Construction of a calorimeter to calculate the Total Solar Energy Transmittance (TSET) through translucid non-homogeneous construction components is also being studied. Such a device would complete the laboratory capabilities needed to test the energy behavior of any kind of building component. The results of the feasibility study will be ready in the autumn of 1996.

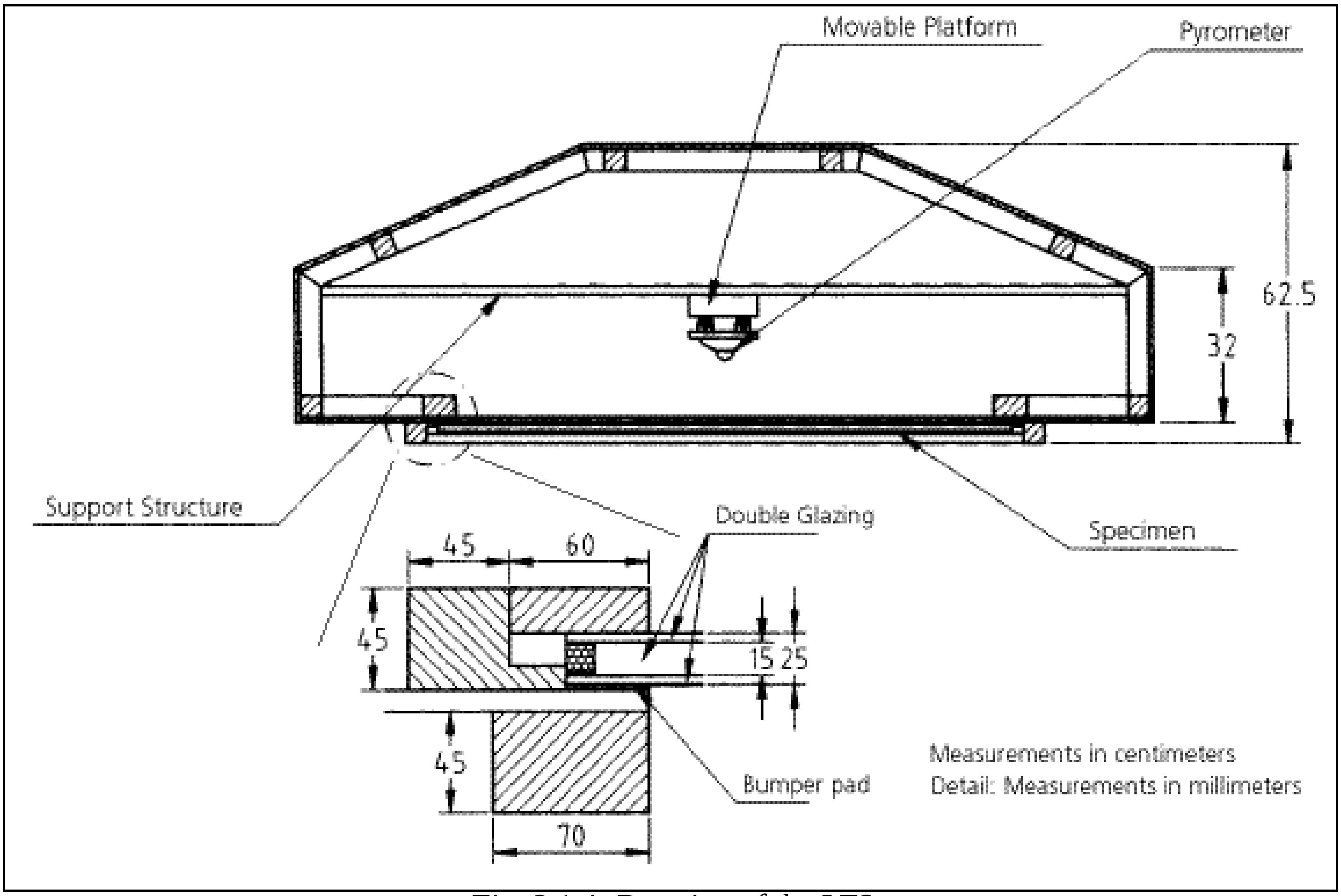

Fig. 2.1.4: Drawing of the LTS

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2.1.4 - Tests and Achievements During 1995

Several tests were performed this year:

- A PAS U-value identification test was carried out.
- Participation in IEA Task 18 for the study of advanced glazing and associated materials for solar and building applications
- At the same time, one of the CESPA cells was test-calibrated. Afterwards, a simple wall with an air cavity and a double-glazed window was designed and built for that cell as part of a project in collaboration with the Polytechnic University of Madrid. The tests on that wall have already started and will last most of 1996.
- Also on the PASSYS II cell after the PAS tests, two more tests were performed. One was with a polystyrene panel on a calibration wall mostly made of polystyrene and plywood, and the other substituted the polystyrene panel with a double-glazed low-emittance-coated window pane. Both tests are part of the same identification process. The heat flux exchange results of the polystyrene pane are "substracted" from the results of the double-glazed window in order to identify the desired parameters.
- Two European projects ended this year, PASCOOL and COMPASS, in which the Department of Solar Energy in Buildings was an active member. The LECE participated in the testing of the components and all the associated papers presented.
- This year, the LECE produced the laboratory technical procedures as part of the necessary documentation for ENAC (the Spanish accreditating institution) accreditation.

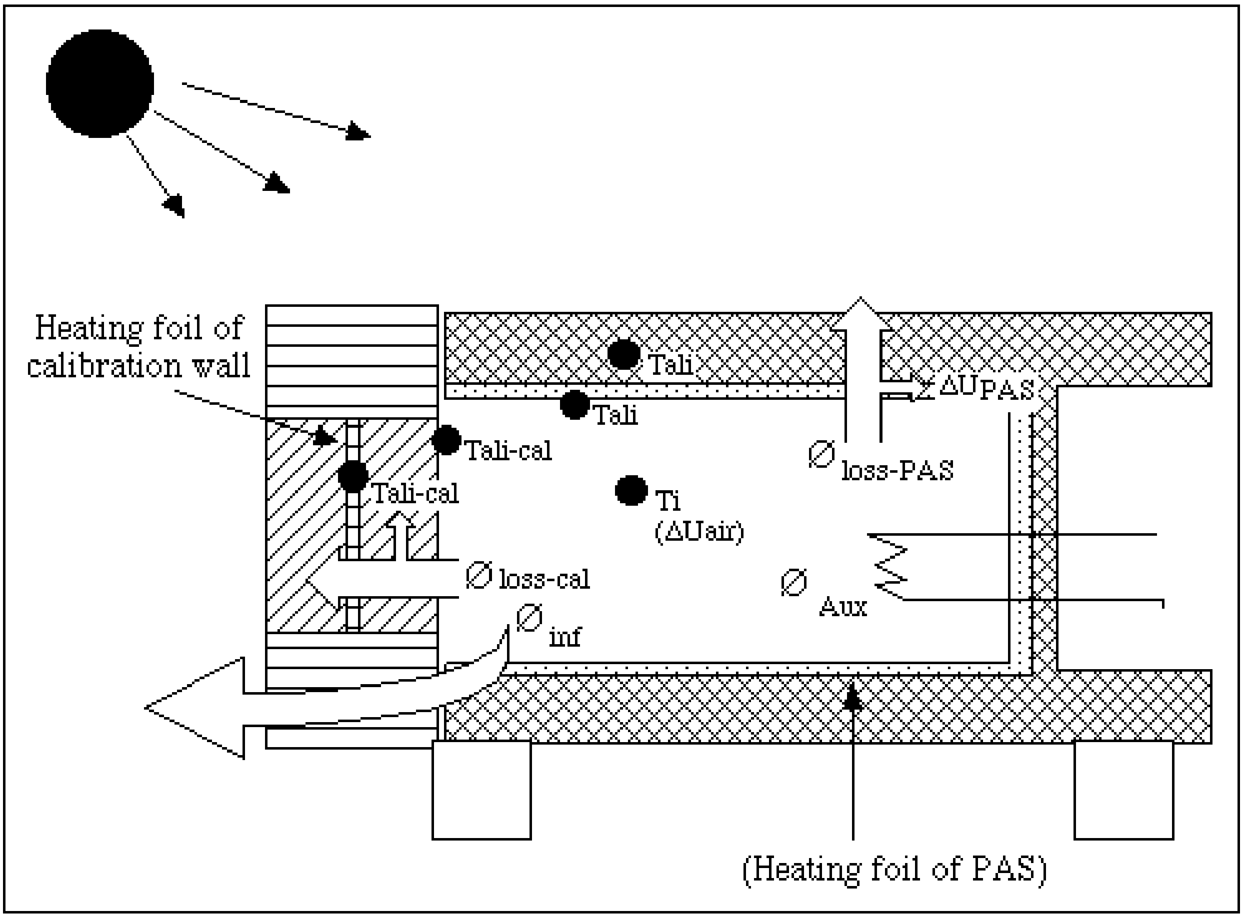

Fig. 2.1.5: Heat Flux in a PASSYS test cell

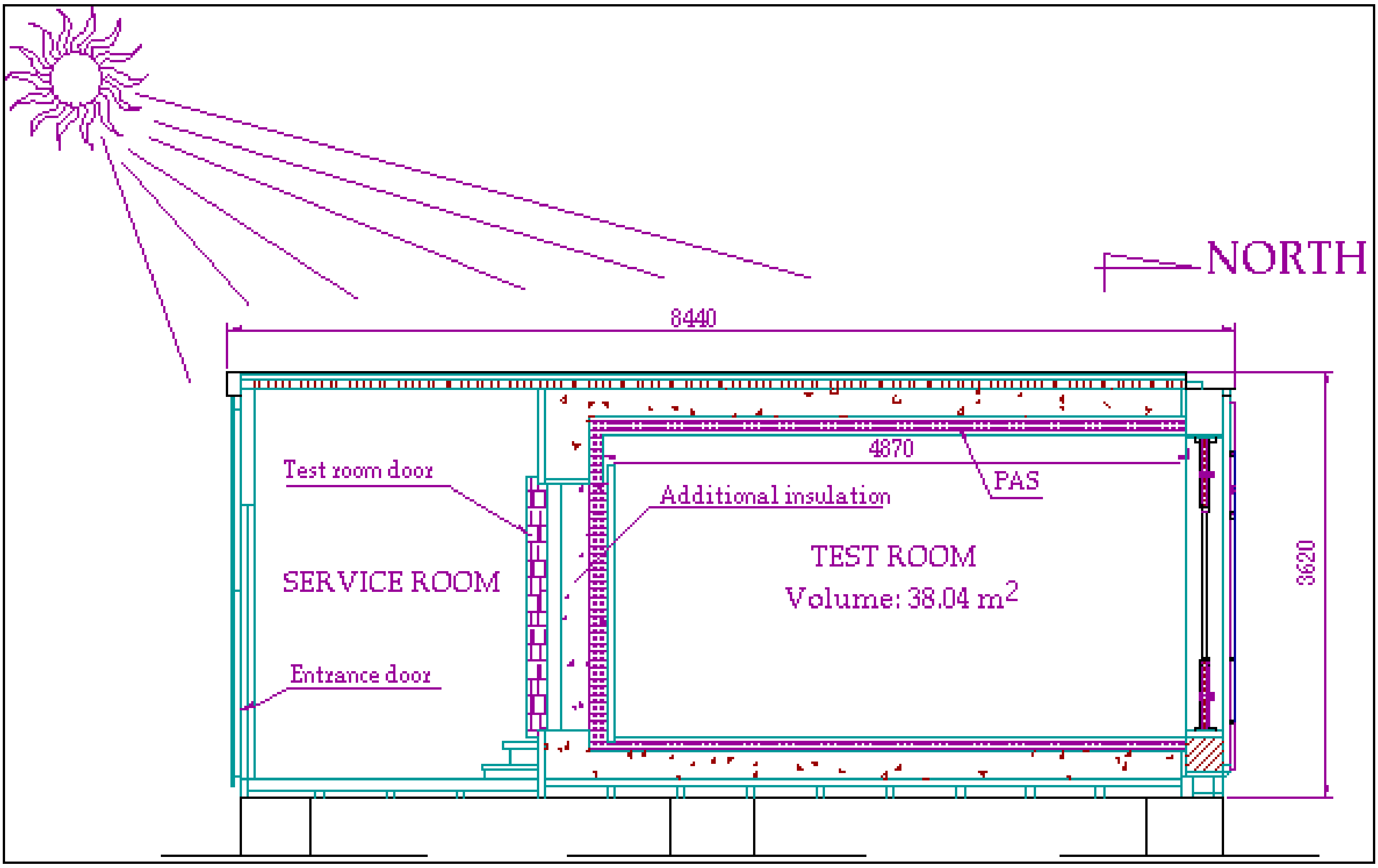

Fig. 2.1.6: The double glaze window test

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2.1.5 - New and Ongoing Projects

- The joint project with the Polytechnic University of Madrid continues its progress and is due to be finished by the end of 1996.
- The IEA Task 18 project, in which the U-value of two selected windows is being calculated, is still ongoing. A double-glazed window with low emittance coefficient has already been tested. The second window, double glazing with interior venetian blinds, will be tested in 1996.
- Within this framework and as a use of the new laboratory capabilities, light transmittance tests will be performed on those two innovative windows with the recently installed LTS.
- In 1995, one of the CIEMAT Solar Energy in Buildings Section proposals accepted in the EU Joule Program was ROOFSOL. The project consists of testing roofs used for cooling through the use of semi-passive techniques. Five roofs will be tested, two at the Plataforma Solar.

  The typologies of roof solutions have been selected using the following criteria:

  1. Prevention and/or protection from heat gains,
  2. modulation of heat gains and
  3. heat dissipation to environmental heat sinks (atmosphere, sky, ground and water).
- At the Plataforma Solar, one of the roofs will probably be of rocks with a water sprinkler system. One of the important parameters to be optimized during the experiment will be the control of the amount of water needed for the day's weather. The other roof has yet to be chosen.
- Another Joule project in which the Plataforma will participate will be the so called PV-Hybrid. In this project a scaled PV building façade will be thermally tested and optimized in the PASSYS cells.
- The Laboratory is part of the infrastructure included in the 1995 Joule proposal called the Training and Mobility of Researchers program (TMR). This proposal has been accepted and will start at the beginning of 1996. This program will open the LECE facility to other researchers so they can perform their tests and also acquire new experience in our laboratory.

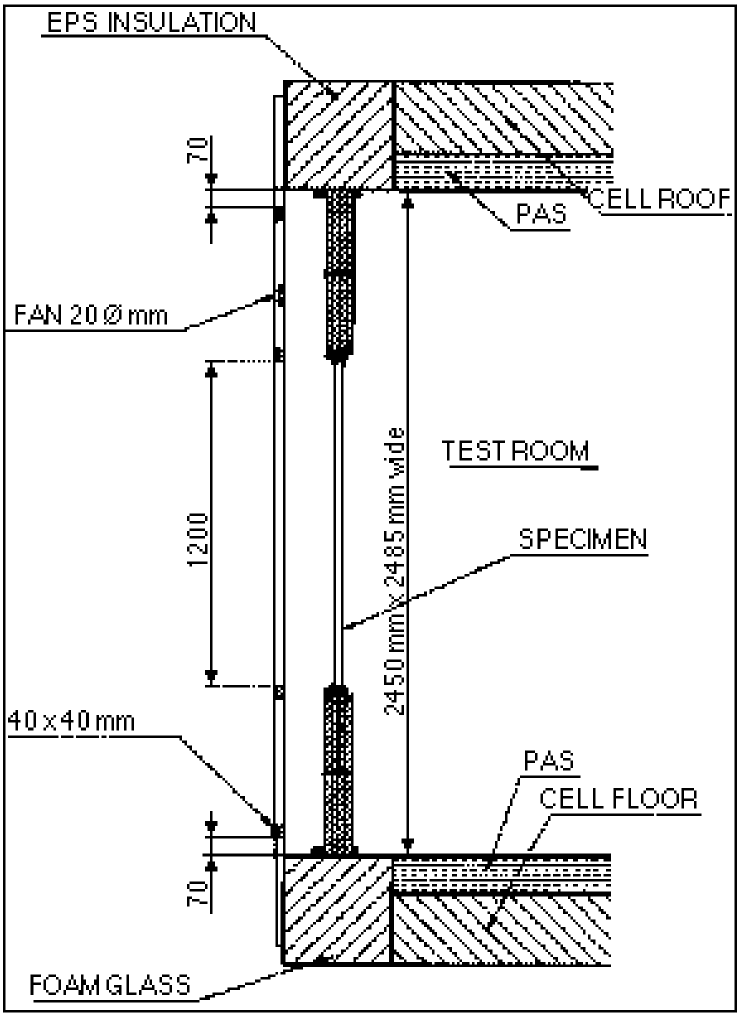

Fig. 2.1.7: Detail of the wall component tested

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2.2.1 - Direct Solar Steam (DISS)

DISS is an R+TD project for developing a new generation of solar thermal power plants with improved parabolic-trough collectors and Direct Steam Generation (DSG) in the absorber tubes in order to eliminate the oil which normally acts as a heat transfer medium between the solar field and the conventional power block, thereby increasing system efficiency and competitiveness.

State-of-the-art parabolic-trough collector solar thermal power plants are marked by the nine SEGS plants currently in operation in California. These plants, with over 2.5 million square meters of parabolic-trough collectors, have a peak power of 354 MWe, and produce more than 85% of solar-generated electricity.

The SEGS plant technology, developed by the LUZ International company in the 1980's, was continuously improved by LUZ, increasing efficiency and reducing electricity generation costs until becoming competitive with conventional power plants. Unfortunately, this effort was not enough to withstand reductions in conventional fuel costs and tax subsidies, and the company collapsed after the implementation of the ninth SEGS plant in the early 1990's.

Nevertheless, before its demise, LUZ had identified a number of improvements in the solar collectors, the thermal process and integration of the solar system into the conventional power block, that could reduce the levelized electricity generation cost by 30%.

In 1989, LUZ had already started an R+TD program to develop and implement all these improvements, but, unfortunately, this program was aborted by its collapse and the encouraging theoretical results claimed by LUZ could not be verified by experiment. Continuation and completion of this R+TD program is the main motive of the project DISS.

In all the SEGS plants, the heat transfer fluid (HTF) between the solar field and the power block connected to the external grid is a synthetic oil. A major item within the process improvements planned is the replacement of the synthetic oil heat carrier medium by Direct Steam Generation (DSG) in the solar field absorber tubes. In the DSG process, water is preheated, evaporated and converted into superheated steam as it is circulated through the absorber pipes of long rows of solar collectors. The DSG process has many technical and economic advantages that make it of great interest (e.g., no danger of pollution or fire due to the oil, reduction in the size of the solar field due to a higher process efficiency, the reduction in O+M-related costs, etc). Nevertheless, from a technical stand point, the critical DSG process is very difficult to carry out because of the two-phase flow (liquid water+steam) in the collector absorber tubes, and some uncertainties must be clarified before a commercial plant making use of this technology can be implementated. Some of these are:

- Control of the solar field
- Process stability
- Availability of suitable DSG materials and components (swivel joints, valves, piping....)

Four flow patterns are possible in a pipe with two-phase flow, depending on the surface velocities of the liquid and steam phases: Bubbly, Intermittent, Stratified and Annular. Figure 2.2.1 shows these four flow patterns. In bubbly and intermittent flow, the inside of the metal pipe is well wetted, thus avoiding dangerous temperature gradients between the top and bottom of the pipe cross section and the heat transfer coefficient is good all the way around the pipe.

In the stratified region, water stays in the lower part of the pipe and there is steam above the surface of the water. As a result, the heat transfer coefficient around the pipe is not homogeneous and strong temperature gradients are produced, causing dangerous thermal stress which could destroy the absorber pipe.

Where flow is annular, though there is partial stratification of the water at the bottom of the pipe, a thin film of water also keeps the top wet enough to ensure good heat transfer all the way around the pipe and avoid the dangerous thermal gradients.

Any two-phase flow pattern causing a strong temperature gradients in the collector absorber pipes has to be avoided in the DSG process. Fortunately, there are three ways to do this: the once-through process, the injection process and the recirculation process.

In the once-through process, high temperature gradients are avoided by tilting the collectors. It has been verified by experiment that in the two-phase flow pattern map there is a much smaller region of stratification in a tilted pipe than in a horizontal one. In the once-through process all the feed water is preheated, evaporated and converted into superheated steam as it circulates from the inlet to the outlet of long rows of parabolic-trough collectors. The main advantage of the once-through process is its simplicity, while its main technical difficulty is control of the superheated steam parameters under solar radiation transients.

In the injection process, the collectors are horizontal and the water is injected little by little along the collector row. The main advantage of this process is that it is easily controlled. On the other hand, it makes the system more complex and increases its cost.

In the third option, the so-called recirculation process, a water-steam separator is placed at the end of the evaporating section of the solar field. The feedwater flow at the inlet is much greater than the steam flow to be produced and only a part of it is converted into steam as it circulates trough the collectors in the evaporating section. The steam is separated from the water by the separator and the remaining water is recirculated back to the system inlet by a pump. The excess water in the evaporating section guarantees good wetting of the evaporator tube, avoiding the high temperature gradients. The main advantage of this system is its good control, but the need for a recirculation pump and the excess water that has to be recirculated greatly increase the system parasitic load.

The DISS project has been planned in three consecutive two-year phases (See Figure 2.2.2), during which not only the current technical DSG-process difficulties will be studied, but two other tasks will be also developed, "DSG Applied Research" and "Collector Improvements", to complete the R+TD program.

During the first and second phases, a real-size test facility, essential for the study of the DSG process under real working conditions, will be designed and erected at the PSA in order to find out which of the three options is the best. Though some laboratory facilities currently available have been and still are very useful for part of this R+TD program, they can not provide the answers to many other important technical problems, such as steady-state in a single-row, single-row operation and control under transients, parallel row operation and control under non-uniform solar radiation, bowing of the absorber tubes under real conditions, etc.

Figure 2.2.3 shows a schematic diagram of the DSG test facility planned for the PSA. The pre-design is for two parallel rows of 20 parabolic-trough collectors each, and a Balance of Plant (BOP) in which the superheated steam produced by the solar field is condensed and reconverted into feed-water that is again pumped to the inlet of the solar field in a closed-loop operation with the consequent savings in water and energy.

Each row is divided into evaporating and superheating sections. The evaporating section is made up of 15 collectors, while the superheating section has only five collectors. Separators may be connected to the rows by valves after the 15th collector. The last five collectors are equipped with water injectors for study of the injection process.

The first phase of DISS, to start officially in January, 1996, covers the design of the test facility and the first stage of its implementation (erection of a single row of collectors and BOP). It will be completed during the second stage, when the second row of collectors is to be erected.

Summary of Activities in 1995

Since all the 1995 activities have been been aimed at starting up the project, it has become the year of the launching. A proposal for the first phase of DISS submitted to the EU Joule'95 Program in March, 1995, was approved by the Commission in July. The contract was signed in December, 1995, thus obtaining 2 million ECUs in EU financial support.

A varied, efficient working group from research institutions, industries and electrical utilities has been organized for the project, thus covering all the sectors involved in the future commercialization of this technology. All the partners have had long experience in large R+TD projects and their qualifications in the sector are well known and internationally acknowledged. So far, they are:

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

During the first phase, the SOLEL (Israel), INITEC (Spanish Engineering Company), and UFISA (Spanish Engineering Company) companies and the University of Manchester Electrical Engineering and Electronics Group (UMIST) will also participate as subcontractors for the detailed design of the test facility and the solar field control system.

In July, 1995, a revision of the 1994 PSA test facility pre-design was initiated in order to include the recent result obtained by DLR and SIEMENS in the German GUDE project experiments and the innovative information acquired by ZSW at the HIPRESS facility.

Late in 1995, a small test stand was designed for evaluating the performance of high pressure/temperature steam pipe swivel joints at the PSA. This test stand will be manufactured and used in 1996 to check whether swivel joints can be used to connect the DSG system collectors, which would allow lighter structures and mechanisms.

The project organization chart was also defined in 1995 and of the DISS Project Committee Task Leaders and representatives were designated. Figure 2.2.4 shows the DISS project organization chart.

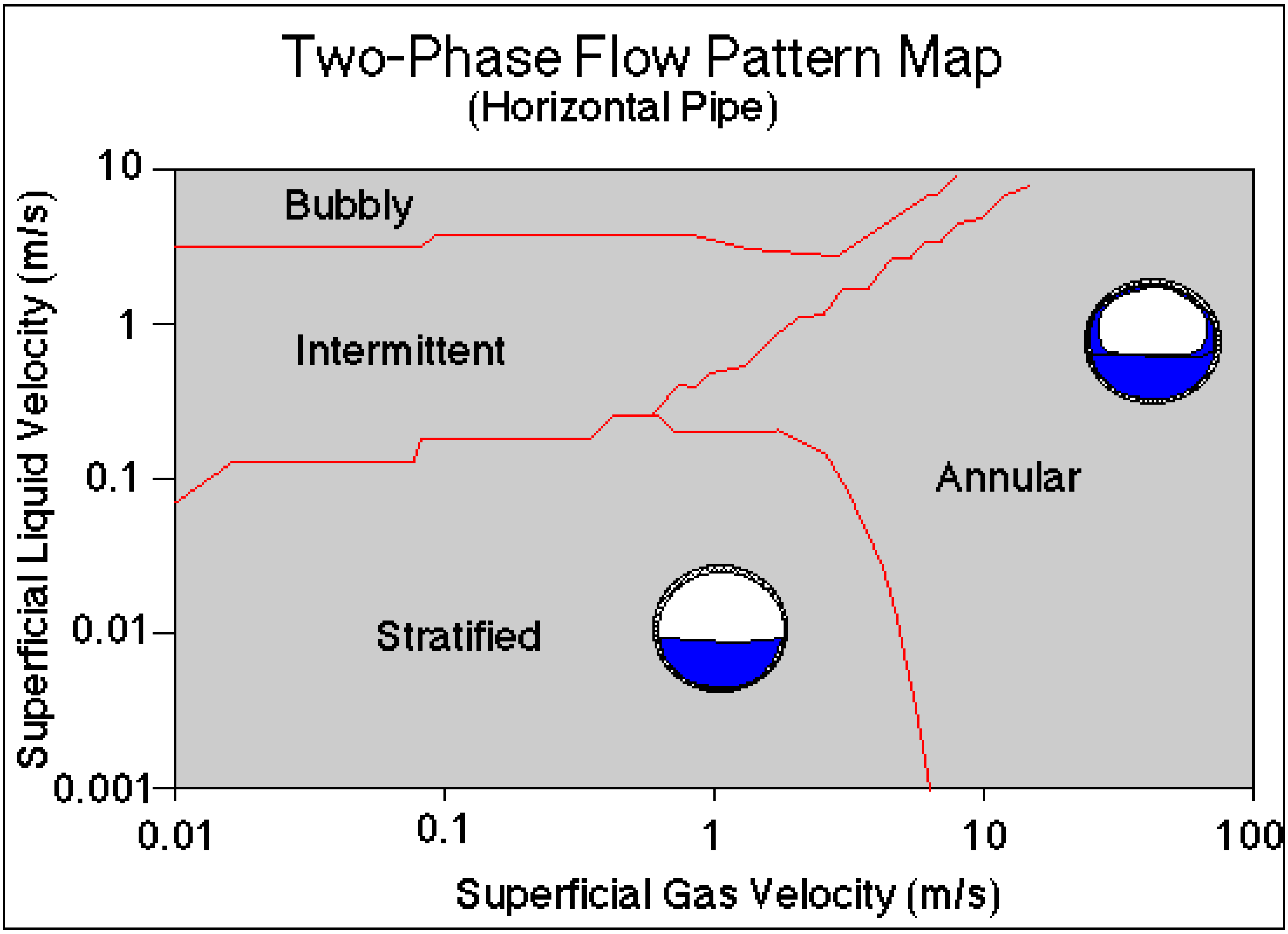

Fig. 2.2.1: Two-phase flow pattern map in a horizontal pipe

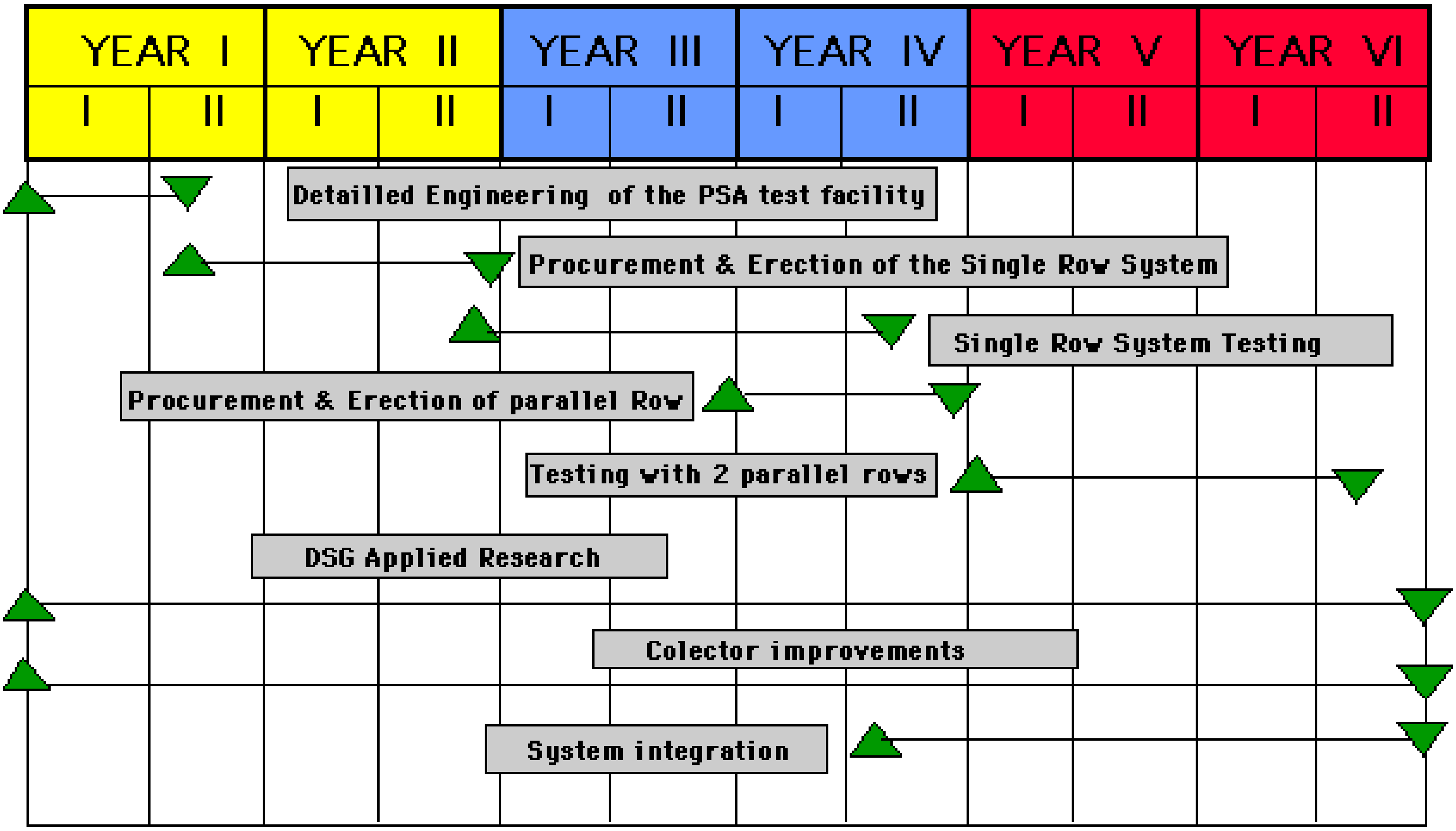

Fig. 2.2.2: Overall DISS project planning

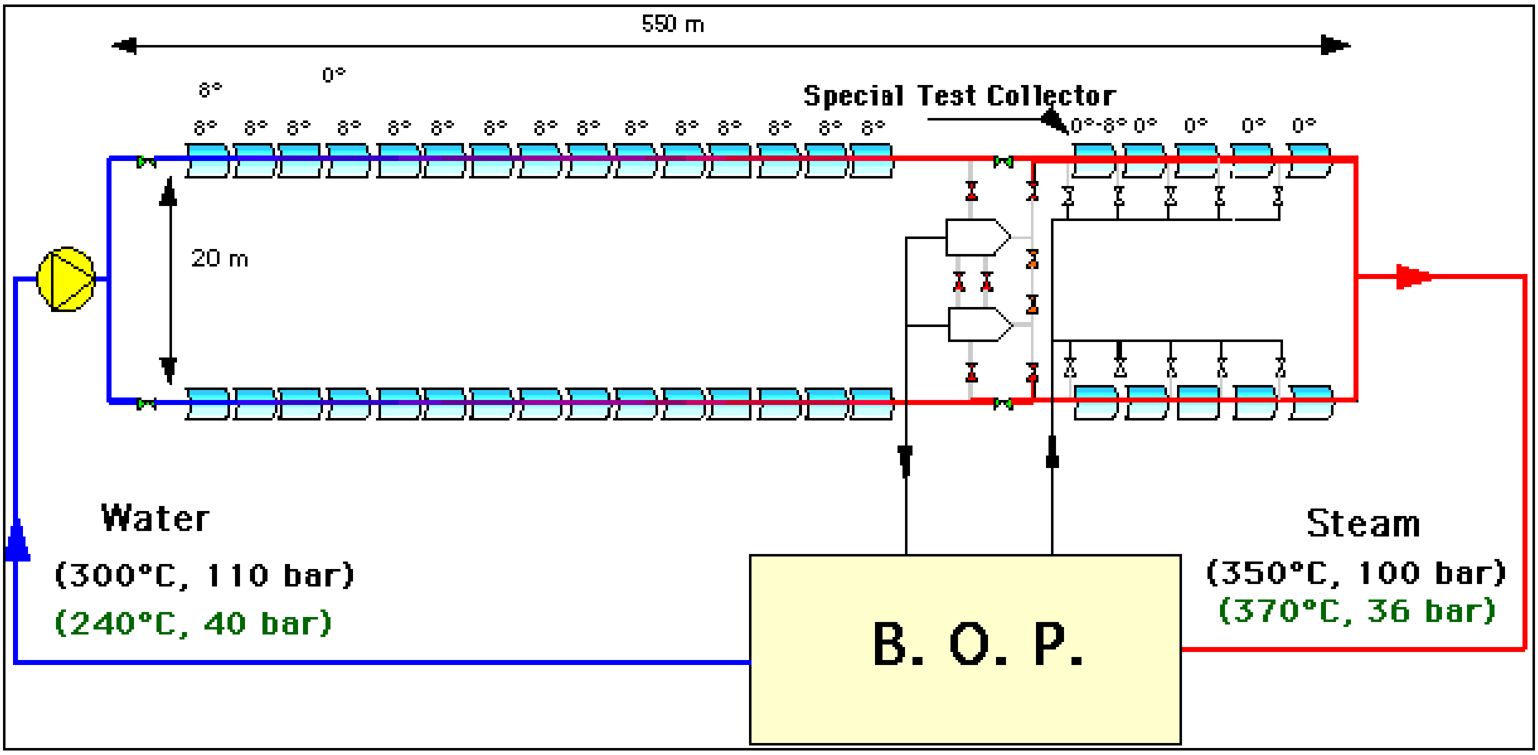

Fig. 2.2.3: Diagram of the test facility proposed for DSG experiments at the PSA

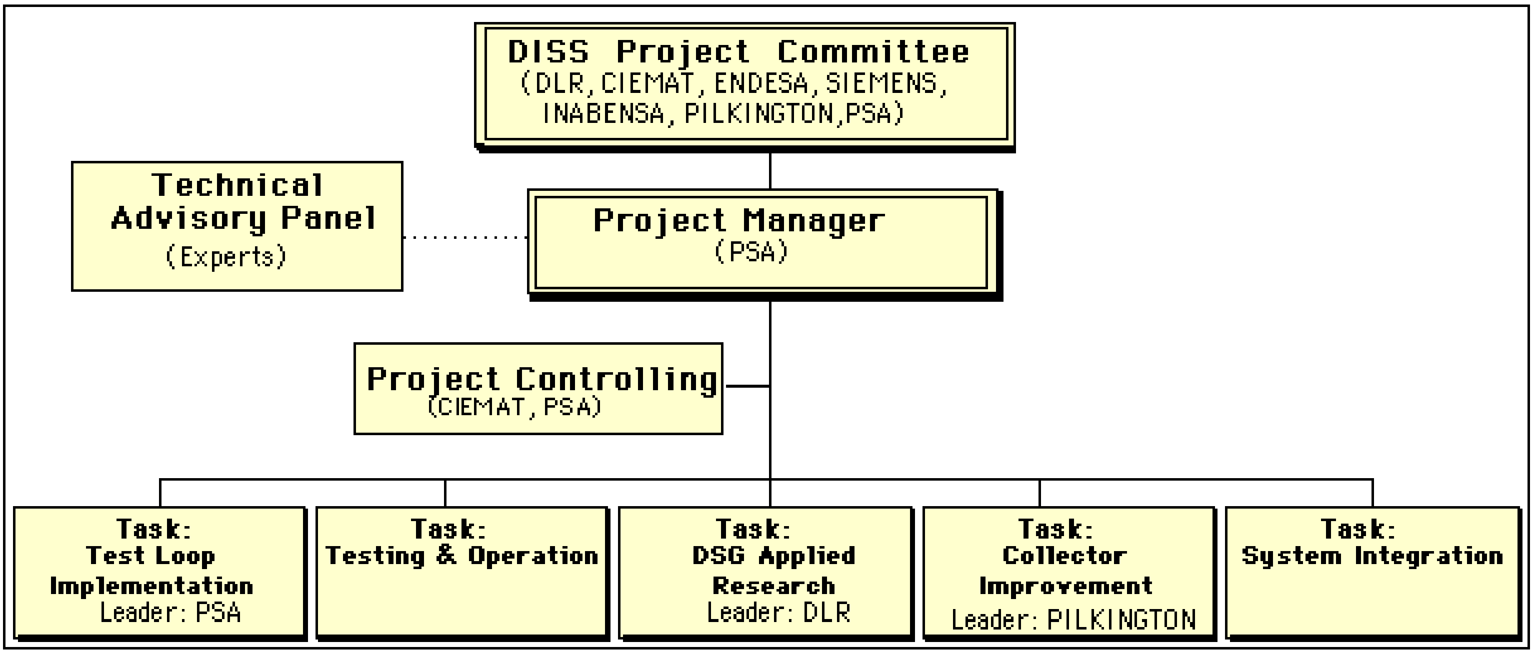

Fig. 2.2.4: DISS Project Organization Chart

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2.2.2 - Project STEM

The STEM (**S**olar **T**hermal **E**lectricity in the **M**editerranean) project is a feasibility study which assesses the improvements in performance and cost reduction potential of Direct Steam Generation (DISS) with large parabolic trough collector fields when integrated into 100-200 MW combined cycle thermal power plants in the Mediterranean area. This project is being carried out with European Union financial support within the framework of the APAS'94 Program. It is due to end in June, 1996.

The STEM project has two objectives:

- Development of the conceptual design for a commercial-scale 100-200 MWe Integrated Solar Combined Cycle (ISCC) demonstration plant with Direct Steam Generation in the solar field. This design will be compared to a state-of-the-art reference system with oil-cooled collectors. The advantages of a bottoming sea-water desalination system will also be investigated. A specific reference site in Southern Spain or Morocco will be chosen for these comparisons.
- Preparation for large-scale testing of the DSG (Direct Steam Generation) process and those research concepts which promise to be the most competitive with regard to their performance, investment and/or O&M costs. The concept design of a DSG test loop at the PSA is considered the first step toward full-size 100 MWe-range DSG plant demonstration and will be reviewed within the study.

Preparation of existing technology demonstration and the next step in improving cost/performance are expected, namely:

- Quantify benefits to cost and performance of integrating Direct Steam Generation in 100-200 MWe commercial combined cycle plants.
- Conceptual design of such a hybrid solar/fossil combined cycle plant with Direct Steam Generation.
- Identify the next steps in technological development of collector design and system optimization.
- Elaborate conceptual engineering for DSG and HTF test loops at the Plataforma Solar de Almería (PSA).

STEM project participants are:

- Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), a dependency of the Spanish Ministry of Industry and Energy.

- Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V. (DLR), German public research institution
- IBERDROLA, Spanish electric utility
- INTECSA, Spanish engineering company.
- Pilkington Solar International GmbH, German industry
- SIEMENS-KWU, German industry
- Unión Eléctrica Fenosa (UEF), Spanish electric utility
- University of Las Palmas (ULP), Spanish University
- University of Manchester (UMIST), English University
- Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), German research centre.

Summary of activities in 1995

PSA participation in STEM during 1995 has been devoted to completing the conceptual designs of the DSG and HTF test loops to be implemented at the PSA during the DISS project. The 1994 DSG facility concept design to be implemented at the PSA was revised during the last six months of 1995.

The PSA team has completely prepared the concept design and planned the erection of the HTF test loop, consisting of half an LS-3 collector, an expansion oil tank, an oil cooler and an oil heater, to be used for evaluation of parabolic-trough collector improvements and new absorber pipe designs under real working conditions.In November, 1995, the PSA coordinated a working group of STEM participant experts that performed thermal and stress studies and optical analyses to determine the optimum test facility design parameters (e.g., flowrate, inlet/outlet temperatures, tilt angle, etc.) for the DSG test loop.

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2.2.3 - Project ARDISS

The objective of the ARDISS (**A**dvanced **R**eceiver for **DI**rect **S**olar **S**team) project is to analyze the constraints of Direct Solar Steam Generation with parabolic-trough collectors and develop an advanced receiver fulfilling the requirements of this process.

ARDISS is being carried out with the financial support of the JOULE-93 program. The project coordinator is CIEMAT's Institute of Renewable Energies (Madrid) and the PSA only provides technical and test support. The other participants in the project are ZSW (Germany), CONPHOEBUS (Italy) and INETI (Portugal).

The main objectives are:

- Design, construction and testing of the concentrator/receiver.
- Theoretical and experimental analysis of Direct Steam Generation.
- Simulation of the solar-driven electricity generation system.

And the expected achievements are:

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

Summary of Activities in 1995

PSA personnel have contributed to the design of a test facility for the new absorber prototypes to be developed in ARDISS. The detailed design was finished in March, 1995, while system implementation was concluded in December, 1995. The PSA Engineering Department prepared the technical specifications. Figure 2.2.5 shows the schematic diagram of the PSA ARDISS test loop. An old MAN-3/32 collector was used to support the two solar concentrators (parabola width = 262 cm, parabola length= 450 cm) for mounting and testing the absorber pipe prototypes.

The test loop consists of an oil cooler, an oil heater and the solar concentrator where the absorber pipes are to be installed. All the components are provided with high precision instrumentation. The oil circuit, which uses Santotherm-55 as a working fluid at a maximum temperature of 300°C, is connected to the PSA thermocline storage tank. Figure 2.2.6 is a picture of the test facility.

Fig. 2.2.6: Picture of the ARDISS test loop
(49 kb)

In 1995, some spare parts from a MAN-3/32 collector were sent by the PSA to the of CIEMAT workshop in Madrid for manufacture of a second parabolic trough concentrator which will be mounted on the MAN-3/32 collector in 1996.

The PSA main roles in ARDISS are the implementation of this test facility for new absorber prototypes and their testing under real solar conditions.

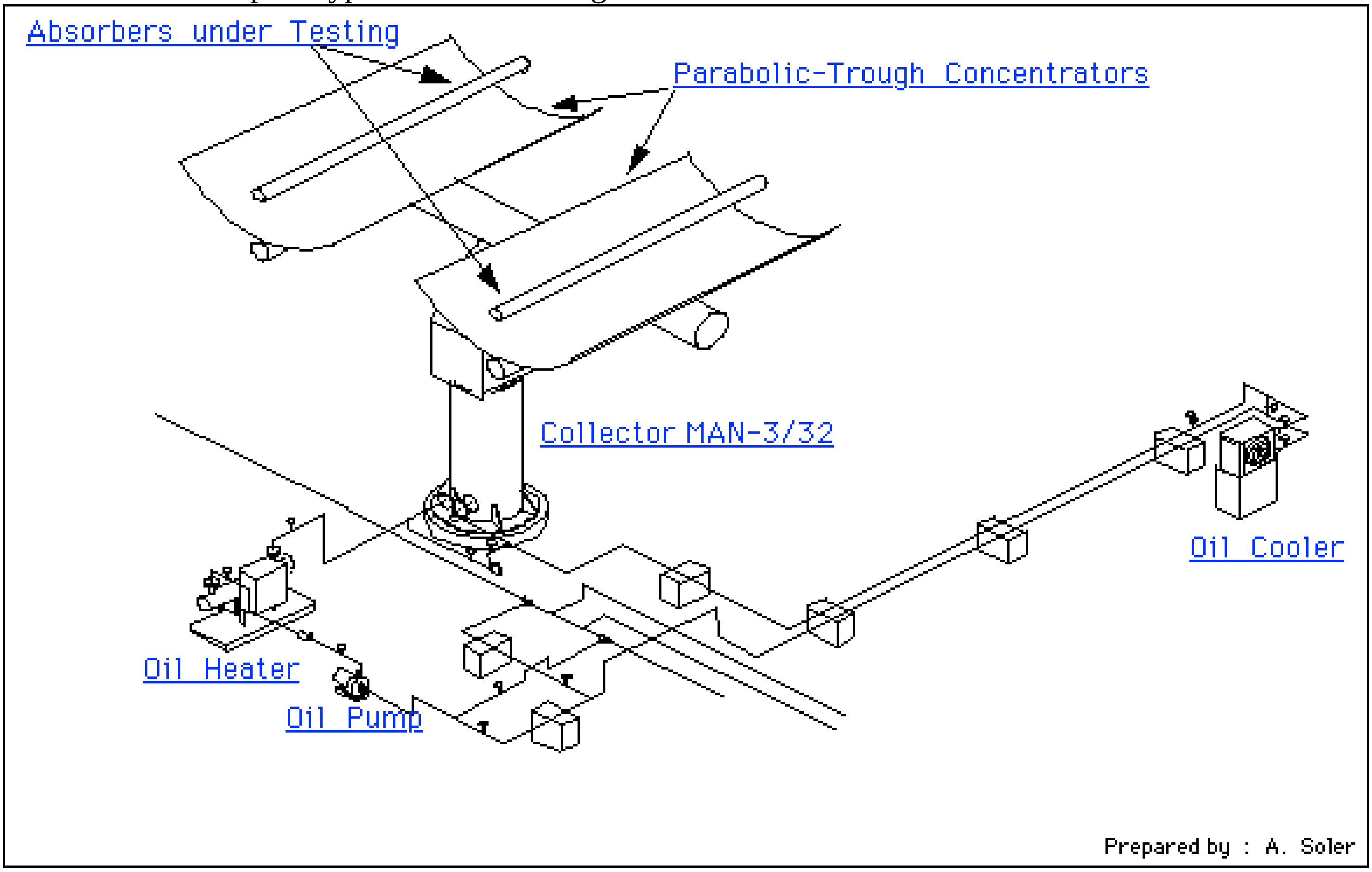

Fig. 2.2.5: Schematic diagram of the ARDISS test loop

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2.2.4 - PAREX

PAREX, a German project managed by DLR, is aimed at developing and testing advanced parabolic-trough receivers to:

- reduce losses at increased working temperatures,
- reduce thermomechanical loads due to cyclic and uneven heating.

These advanced receivers are intended for potential application in parabolic-trough collectors with either thermal oil or direct steam generation. PSA participation in PAREX is limited to test support for the DLR receiver prototypes. In 1995, a first PAREX receiver was manufactured at the PSA and components for future prototypes were received. Since PAREX prototypes will be tested using the ARDISS test loop, the PSA contribution to PAREX in 1995 has been mostly within ARDISS (i.e. implementation of the test loop).

The first PAREX prototype will be evaluated early in 1996. 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.

2.2.5 - Control System Developments

The second year of the European Union DGXII Human Capital and Mobility (HC&M) Control Project has been distinguished by three main features: an increase in field availability, a large number of controllers prepared by the different groups for testing, and dissemination of the results, not only within the European Community, but also in South America and Australia where various institutions have expressed their interest in the work carried out here. The work being done under this project will continue in 1996 under the DGXII Training and Mobility of Researchers Program.

Operating time has increased from 15 weeks the first year to 29 this year, demonstrating the effort made by the PSA operation and maintenance department. Considering that the field was shut down for almost two months due to an important failure in the storage tank fire-extinguishing system. The outage time was used to good advantage by updating instrumentation, replacing the control computer with a better one and making some small hardware repairs (e.g., painting the collector support structures and replacement of some of the flexible joints). A periodic test of the fire-extinguishing system has also been included in the general maintenance plan to avoid such inconvenience in the future.

The number of different controllers tested has also gone up. The Instituto Nacional de Engenharia e Tecnologia Industrial (INESC) in Lisbon, Portugal, has tested three MUSMAR configurations, including a cascade configuration suitable for the control of many control loops. This institution also used the program to provide industrial environment background for two PhD students. The group leader visited Almería twice and the PhD students spent almost two months testing their programs. The INESC group also carried out joint activities in solar control with Firenze University at the PSA. One member of this group is concluding his PhD thesis. In Fig. 2.2.7 a control test with MUSMAR connected in cascade with a PID controller carried out last June 23, 1995 may be seen.

The University of Seville (Spain) sent seven different algorithms to the PSA for testing: Fuzzy Logic, Incremental Fuzzy PI, Gain Scheduling GPC, Robust Adaptive GPC with Unstained Debounds, Non Linear GPC, Frequency Based Adaptive Internal Model Controller and Optimal Controller LQG\LTR. Their approach is to implement new theoretical achievements in an industrial environment. One of the main goals reached was a reduction in required computing time with sophisticated algorithms which make it more suitable for industrial applications. The Head of the Department and some of the teaching staff have made many short visits to the PSA. A young researcher also spent two months at our installation. One member of this group presented his PhD thesis based on the work carried out at the PSA.

The University of Manchester Institute of Science and Technology (UMIST) in Manchester, United Kingdom, has tested two controllers: Parallel Resonance Compensator and On-Line Identification Package. The latter attempts to obtain a self-tuning procedure able to obtain good control parameters with only one test. A member of this group obtained his PhD this year with the results of the work carried out within HC&M and Access to Large Installations programs. An MSc Thesis prepared by a Spanish student at UMIST was also presented.

Two User's meetings took place in Almería during 1995, in April and November. During these events, the on-going program was reviewed and the new Training and Mobility of Researchers Program was presented. A solar control network of seven relevant institutions submitted to the European Union for funding was not approved.

As result of the publication of the work done in this field by Users and PSA in technical journals and conferences, institutions from South America, Australia and Eastern Europe have expressed their interest. Due to the great number of papers concerning solar control, most of which originate at institutions related to the PSA, a separate session of the 1997 European Control Conference is foreseen.

These activities will continue within Training and Mobility of Researchers framework from 1996 to 1999.

Other Control Related Activities:

As result of the activities carried out within the Human Capital and Mobility Control Project a TMR Research Network for Advanced Control of Solar Energy Systems (NACSES) with a team of seven research groups from six European countries was submitted to the Commission. Although this proposal did not obtain financial support in the first stage, there is still a possibility depending on the availability of funding, due to its high technical quality.

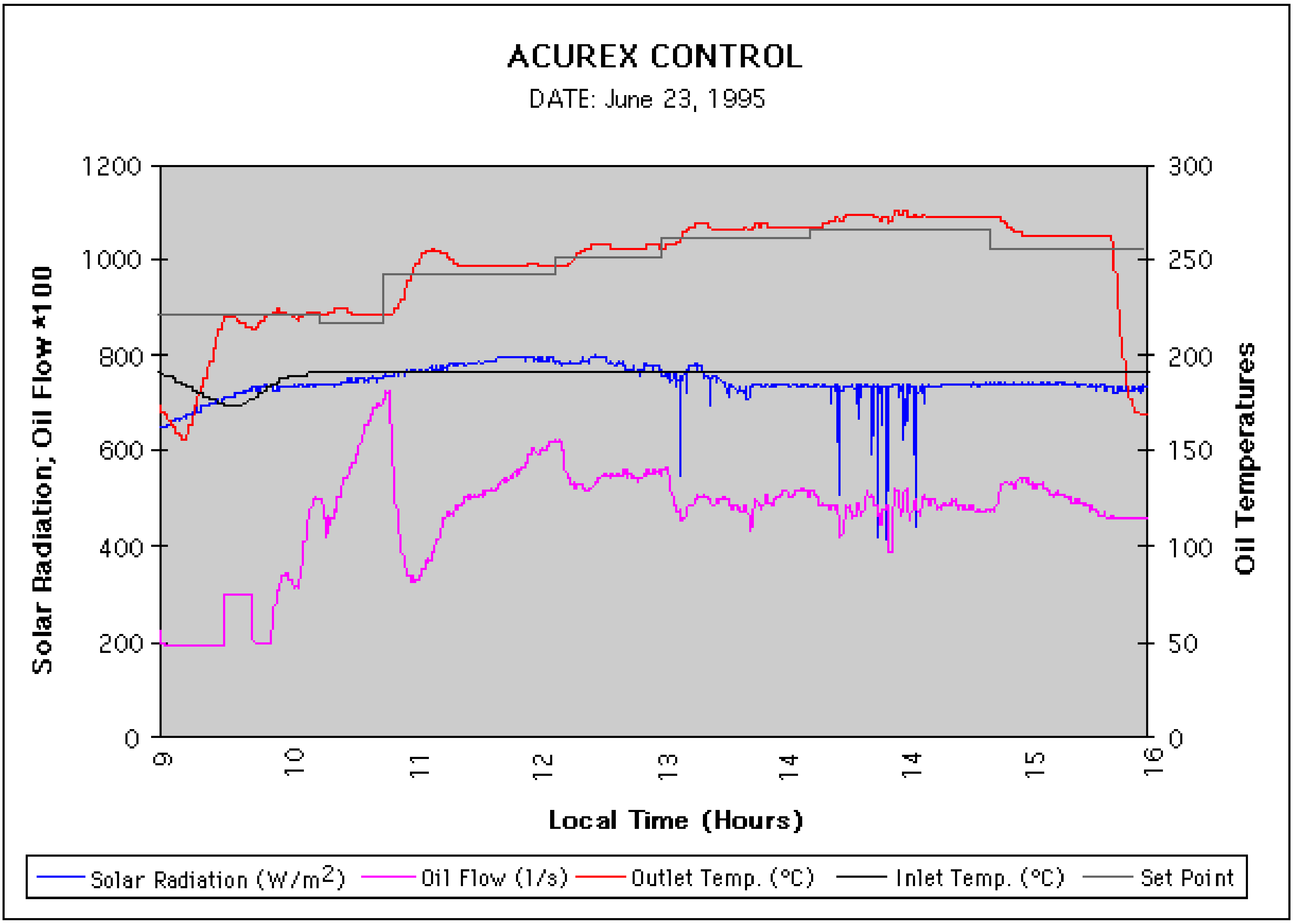

Fig. 2.2.7: Cascade PID-MUSMAR Control Test

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2.2.6 - Other Activities in 1995

In addition to the five projects scheduled within the Parabolic-Trough Technologies Area in 1995, other activities have been performed in this Area of Work in 1995.

Within the framework of Solar-PACES Subtask 3.2, a Test Facility Brochure has been prepared. This brochure includes data on all the parabolic-trough test facilities currently available in the world and was put together with information from other solar research and test facilities. The complete Test Facility Brochure will be edited as a Solar-publication in 1996.

Late in 1995, the European Union launched the MED-Techno Program, a preparatory action in the field of industrial applications of renewable energies with high potential for the Mediterranean area, with a call for draft proposals from all those interested in the developing renewable energy projects with participation of Mediterranean countries. In view of the experience and know-how gained by the PSA during its Solar Thermal Desalination project from 1987 to 1993, a draft proposal was submitted to the E.U in 1995 for a pre-feasibility study for a demonstration solar thermal sea-water desalination plant in the Mediterranean area.

This proposal was prepared by the PSA with the collaboration of an international team from industry and research institutions involved in desalination technology and Mediterranean market. Proposal selection by the Commission for the MED-Techno program is expected in 1996.

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2.3.1 - DISTAL I

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2.3.1.1 - System Description

The SBP dish/Stirling system (Fig. 2.3.2) consists of a 7.5 m-diameter, single-facet stretched-metal membrane concentrator with a Stirling-engine receiver at its focal point. The receiver, a tube-type heat exchanger, converts the concentrated solar radiation into thermal energy, which then powers the Stirling engine. A generator connected to the Stirling motor produces 3-phase 380 V electrical energy, which can be directly supplied to the electric grid.

The concentrator consists of a 7.5 m-diameter, 1.2 m-high outer ring. Two 0.23 mm-thick stainless-steel membranes are placed at the top and bottom of the ring. The front membrane is freely deformed by a hydropneumatic load. There is no need for a countermould to attain the high-precision parabolic geometry. After the shaping procedure, in which the membranes are plastically deformed, 0.9 mm-thick glass mirrors are glued onto the front membrane. A slight under pressure has to be guaranteed during operation to maintain and stabilize the shape of this reflecting surface.

In operation, the concentrator tracks the sun on two axes. A cheap and reliable tracking system with low-power consumption (< 1 %) is achieved by polar mounting with large lever arms. Its main feature is that the two rotating movements are separated into a constant-speed axis and a seasonal axis which only needs to be adjusted once a day. The maximum deviation of the focus as a result of the changing inclination over the course of the day and the refraction and fluctuation of the earth's rotation, is less than 15 mm, an acceptable tolerance. The large lever arms lead to a minimization of torque and force, so that small cheap standard drives can be used.

The V-160 Stirling engine developed by United Stirling AB, Sweden, was licensed to SBP and is now manufactured by SOLO Kleinmotoren GmbH, Germany. It is a 90° V-type single-acting Stirling engine with 160 cm^3 displacement in an alpha-configuration and rated power output of 9 kW at 1500 rpm.

Among the main components of the energy conversion unit, which are the receiver, the Stirling engine and the generator, the receiver is, on the one hand, highly stressed by high temperatures and pressures and on the other hand significantly influences the overall efficiency. As in 1994, one main action item was the development of the receiver technology. A new tubular receiver (See Fig. 2.3.3) was designed and tested. Due to its reduced dead volume and an improved design with better overall system performance, efficiency and availability was obtained.

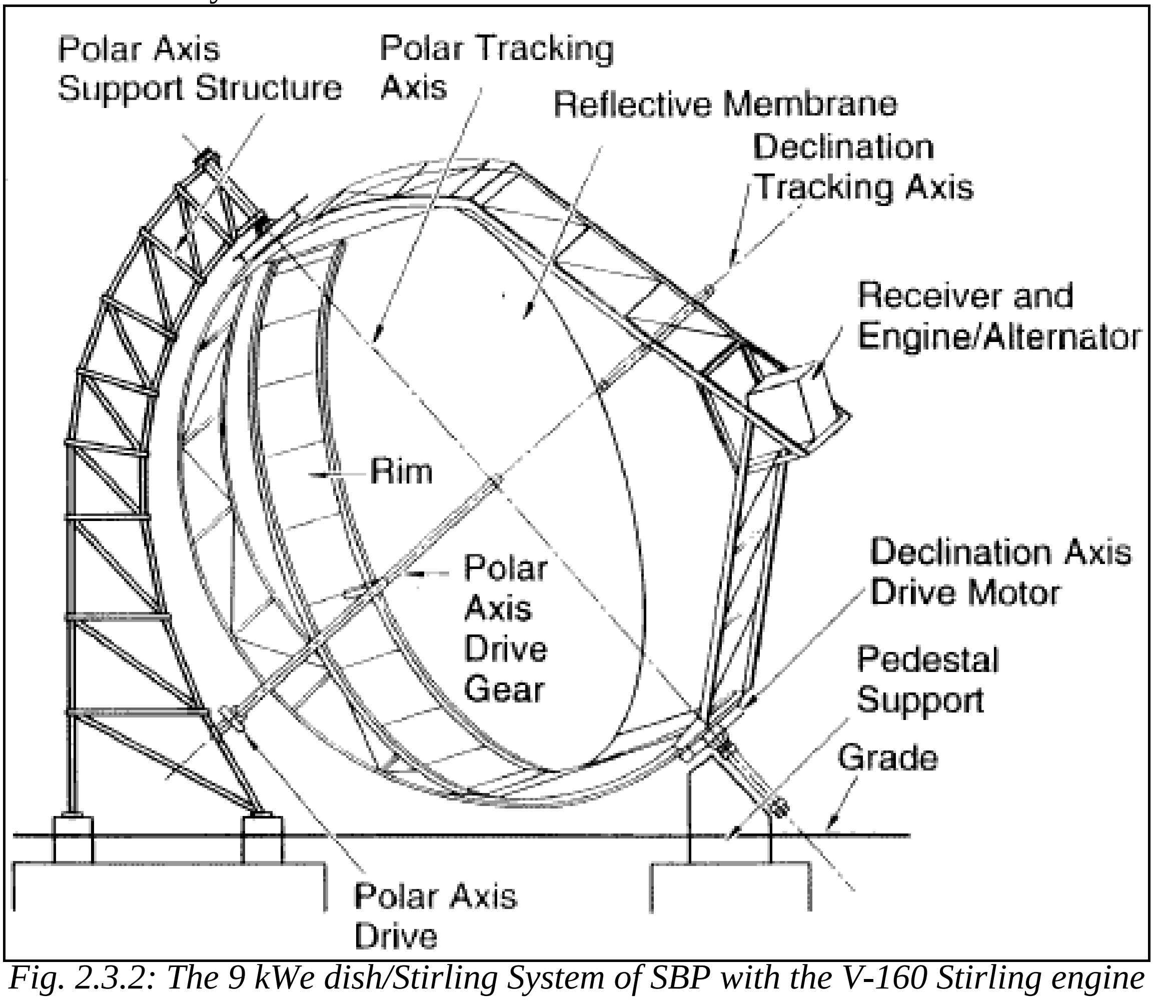

Fig. 2.3.2: The 9 kWe dish/Stirling System of SBP with the V-160 Stirling engine

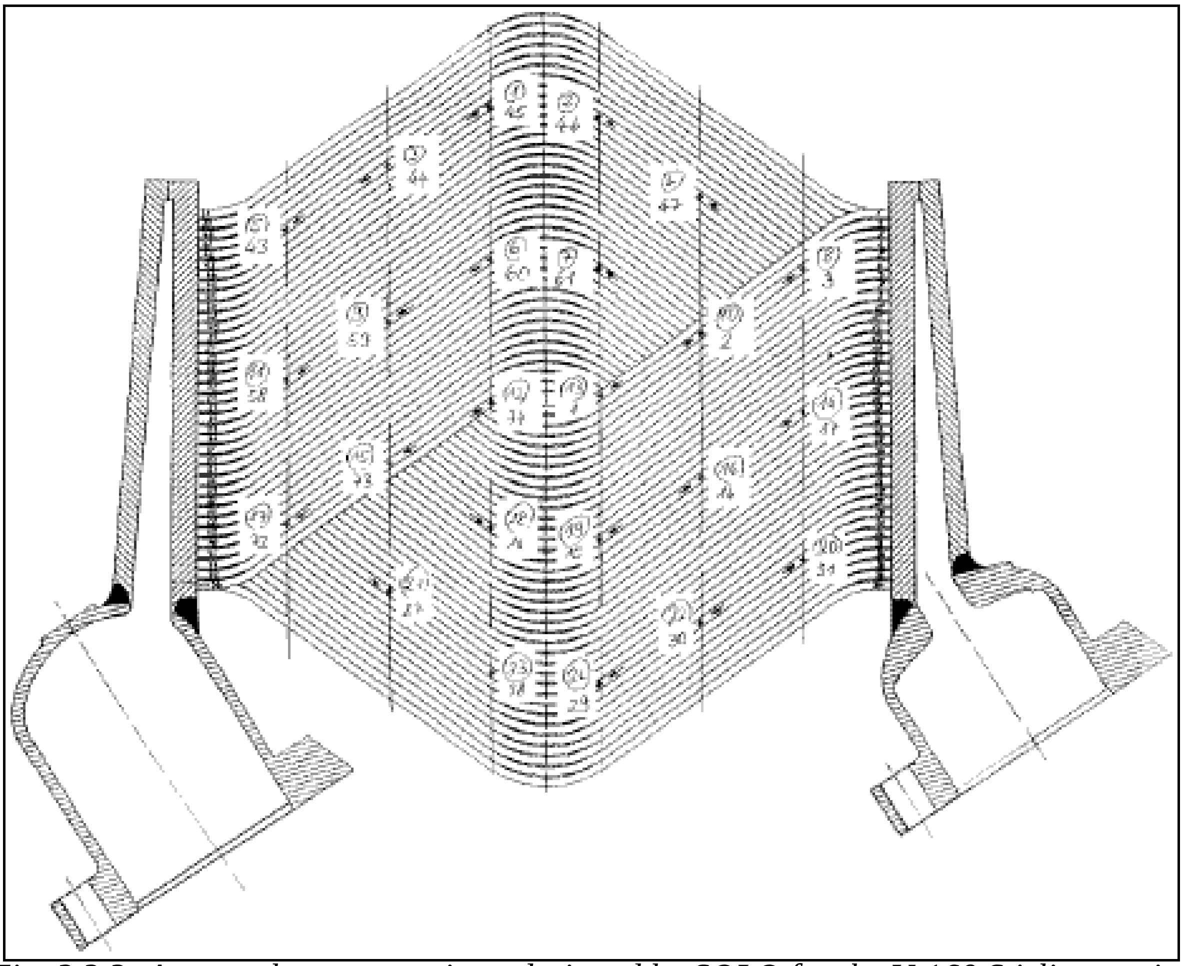

Fig. 2.3.3: A new tube-type receiver, designed by SOLO for the V-160 Stirling engine

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2.3.1.2 - Operating Experience

Net energy output is reached at approximately 15 to 20 minutes after sunrise, at an insolation of about 300 W/m^2. On days with unsteady weather conditions, where most other solar thermal power plants are not able to operate under these conditions, the systems are still able to operate efficiently due to their fast system response.

In Fig. 2.3.4, overall efficiency and gross and net power are shown in relation to the direct normal insolation. The rated power output of 9 kWe is reached at 1000 W/m^2 insolation with a gross efficiency of 19.4 %. The parasitic power consumption (fan, water pump and driving units) totals approximately 0.45 kW which leads to a net efficiency of 19 %.

In December, 1995, the goal of operating 20.000 on-sun running-hours was reached. The monthly operating hours since project startup are shown in Fig. 2.3.5.

The relation between hours of solar radiation with more than 300 W/m^2 and operating hours shows a mean system availability of about 70 % for the three units during 44 months of operation. This also includes all the outage time caused by modification work necessary for the test configuration and system improvements. Maintenance was required due to different kinds of failures. Most of them were caused by minor problems, like defective electrical connections.

The experience gained in DISTAL I will be applied to the improved design of three dish/Stirling pre-series prototypes which will be installed at the PSA by April, 1996.

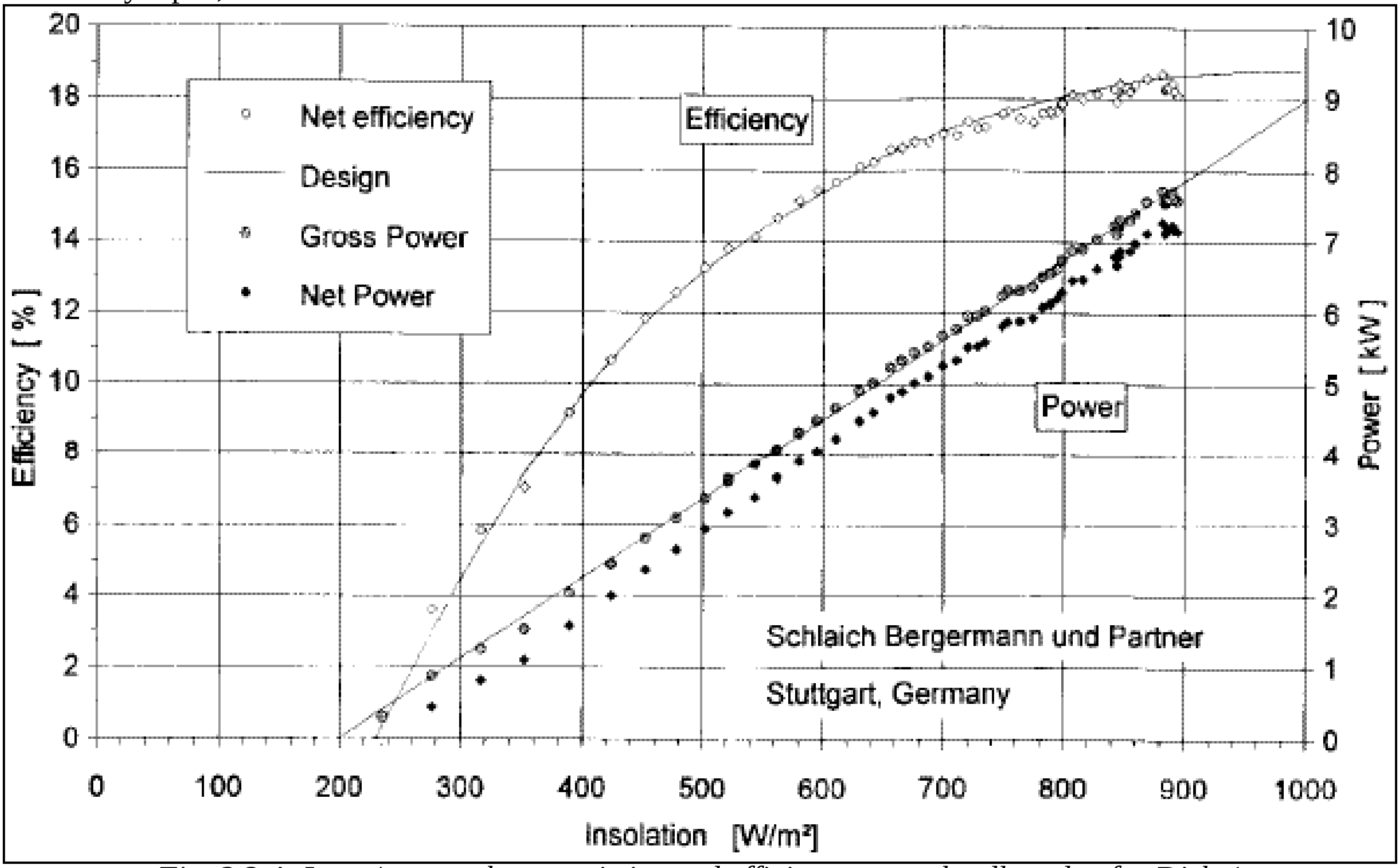

Fig. 2.3.4: Input/output characteristics and efficiency on a cloudless day for Dish-1

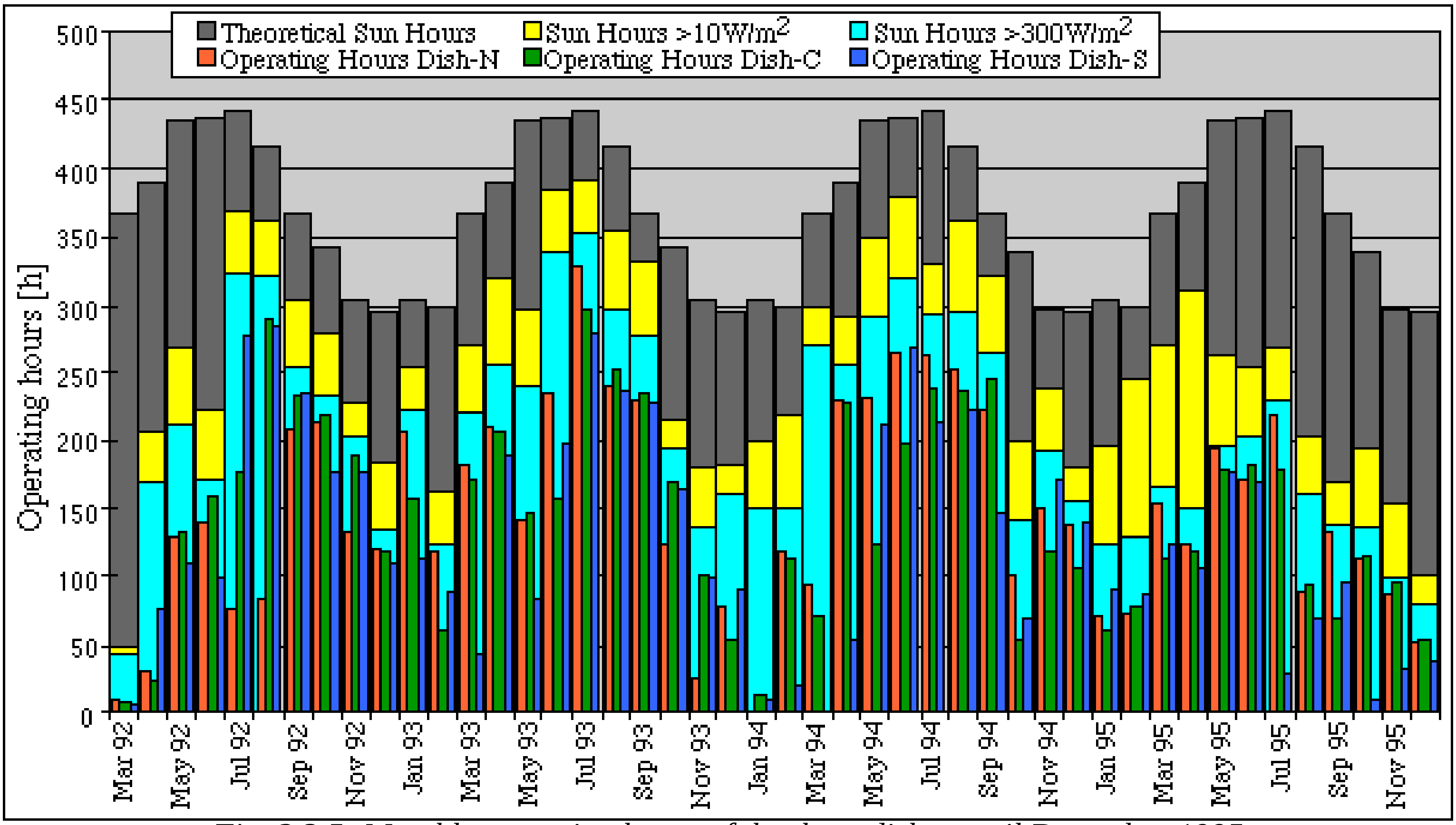

Fig. 2.3.5: Monthly operating hours of the three dishes until December 1995

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2.3.2 - Planning of an Integrated Dish/ Stirling Test Site

The Plataforma Solar de Almería plans to increase its activity in the field of decentralized solar thermal power stations for electricity generation, in particular in the area of parabolic dish systems with Stirling engines or gas turbines. In order to meet the requirements of American, Spanish, German and Russian industry dealing with this technology and its components and in order to be able to offer the equipment and infrastructure corresponding to a world-wide test center working in this field, a parabolic dish test site will be built and equipped with the required specific machinery and installations.

The first step of its implementation was the study issued in 1995, in which the requirements of infrastructure, measuring equipment, data acquisition, control and safety devices, etc., were planned in detail.

Essential for this integrated test site is the need to combine the existing facility (DISTAL I) cost-effectively with the new complex, using the already installed components and avoiding limitations for new clients, systems and their requirements. The planning took into consideration the integration of several dish/Stirling systems and a PV test site scheduled for 1996, where a comparison test between dish/Stirling and photovoltaic systems will be carried out. The purpose of the planning activities was to specify in detail the necessary devices and steps to be taken for erection of this test site and to elaborate detailed planning documentation, considering basic conditions and aspects of its realization. A central operating room has been designed for use by individual clients to operate their systems, with the logical requisite that the data produced remain confidential. General comparisons of the individual systems should be viable, comparing energy output, efficiency and other global system characteristics under the same basic external conditions, measured with the same precision usual in solar technology.

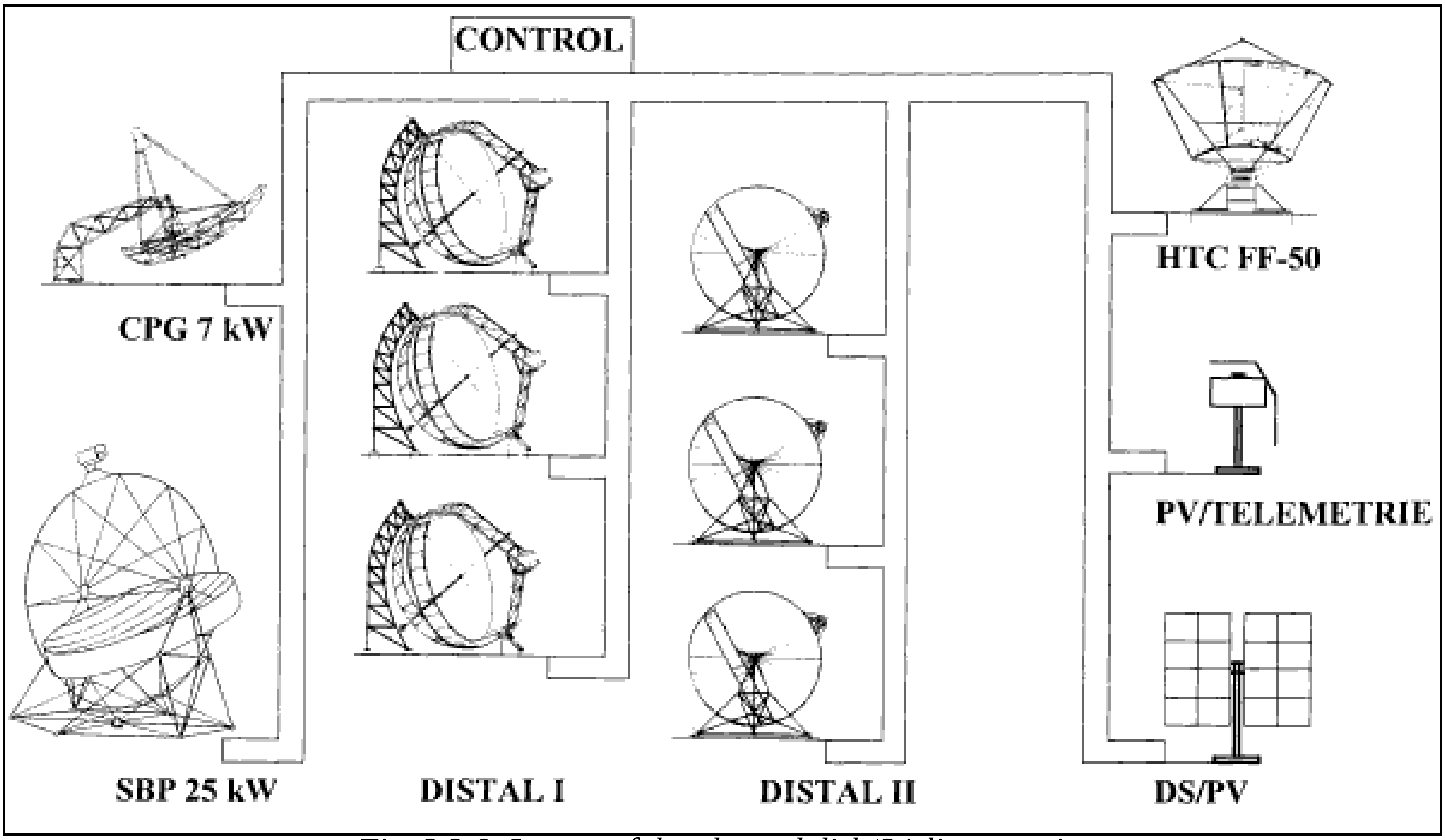

Fig. 2.3.6: Layout of the planned dish/Stirling test site

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2.3.3 - Numerical Simulation of the System Performance of a 25 kWe Dish/Stirling System

In the DISTAL I project at the Plataforma Solar de Almería, three dish/Stirling-systems are operated in a long-term test. These dishes have a rated power output of 9 kWe with direct normal insolation (DNInsol) of 1000 W/m^2. Using the Almería meteo data and the recorded operation data from these 9 kWe systems, a simulation code could be developed and verified. Key overall system data and input/output characteristics were then elaborated for the 25 kWe system (See Fig. 2.3.7), giving a maximum net system efficiency of approximately 26% at 1000 W/m^2 insolation. System performance and annual energy output were calculated with typical Almería Meteo data for 1994/95 and Barstow for 1976.

Daily values of DNInsol [kWh] and daily energy output [kWh] are determined by integrating the insolation and the power output data over a complete day. The daily energy output was calculated for several sets of typical daily solar insolation (See Fig. 2.3.8).

Daily energy production "Wel,day" was calculated for each day using the I/O characteristic and then summarized for one year.

Figure 2.3.9 presents a monthly summary of the whole year for the Almería site, showing a close relationship between insolation and energy production. The monthly accumulated energy Wel,mon calculated averages out to approximately 4000 kWh/ dish.

A comparison of the simulation results of the Almería and Barstow demonstrates far better system performance for the Barstow site due to its better meteorological conditions.

The annual insolated solar energy on the dish area and the calculated yearly electrical energy are presented for both sites in Fig. 2.3.11.

A summary of the results of the for the 25 kWe dish/Stirling system simulation shows that at a site like Almería with yearly insolation of about 2070 kWh/m^2/yr (197.096 kWh/dish/yr) more than 45.110 kWh electric energy could be produced by one dish with an annual efficiency of approximately 22.9%.

On a site with meteorological conditions similar to Barstow which provides 2840 kWh/m^2/yr direct normal insolation (269.800 kWh/dish/yr) about 63970 kWh electricity could be produced. This represents an annual efficiency of 23.7%.

Encouraged by these promising results, the PSA efforts will be intensified in the following years guiding the dish/Stirling technology into the market.

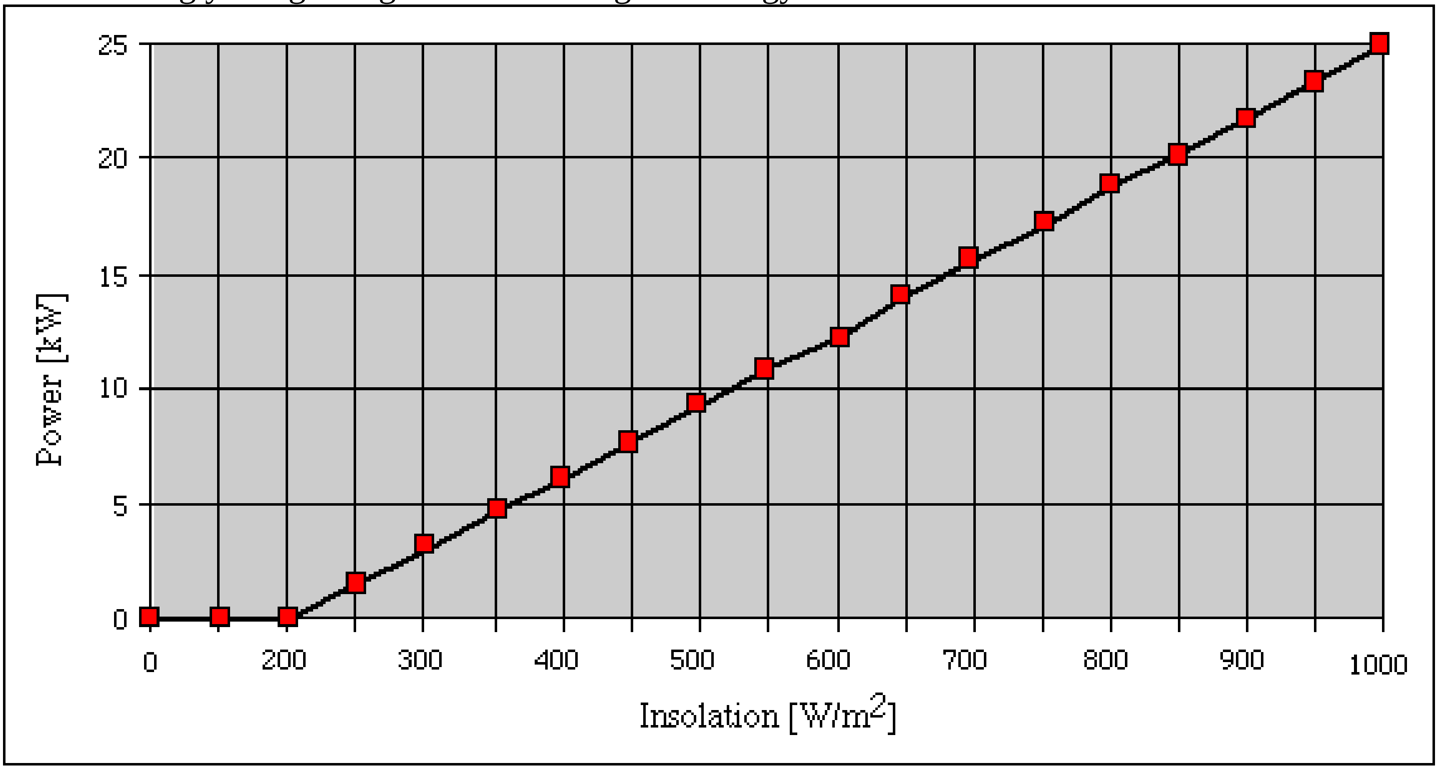

Fig. 2.3.7: Expected input/output of the 25 kW dish/Stirling system

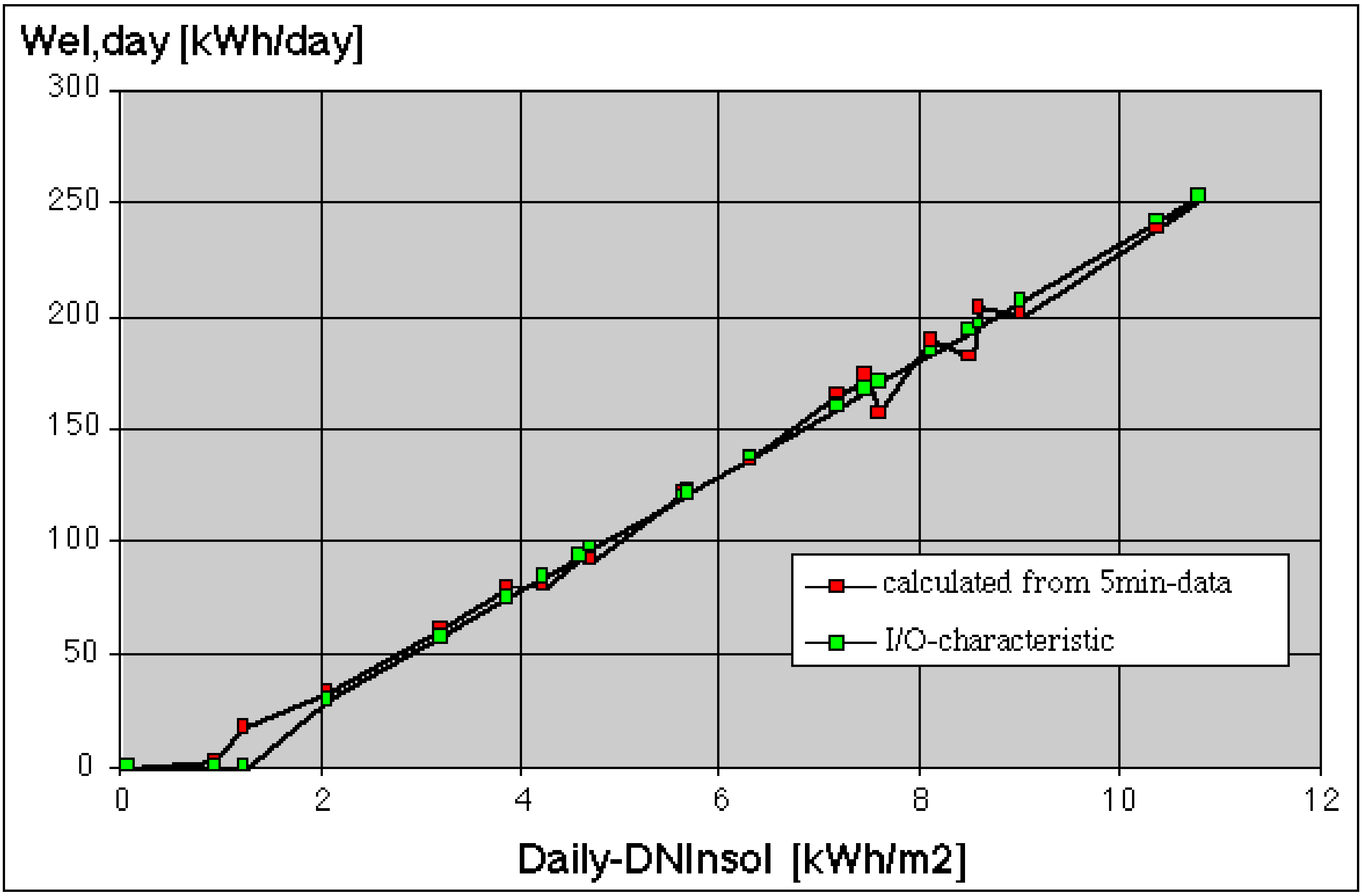

Fig. 2.3.8: Expected input/output for daily energy production

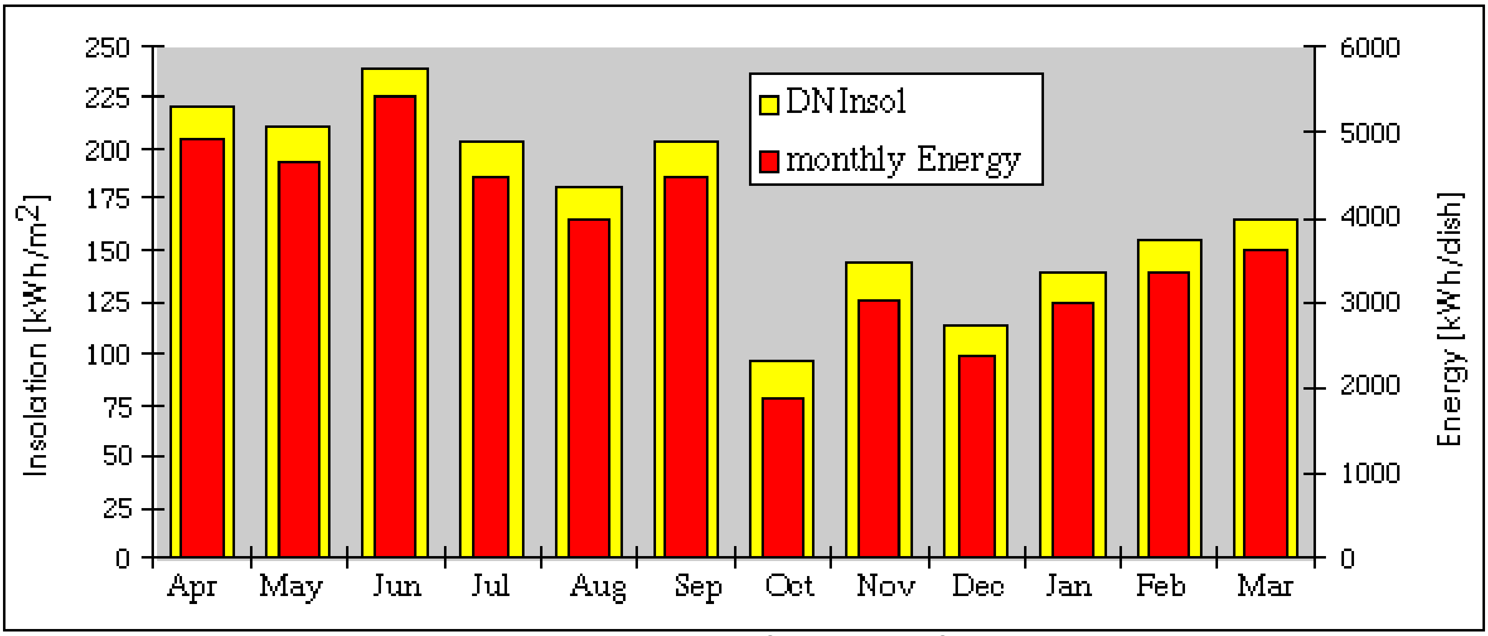

Fig. 2.3.9: Monthly energy output calculated for Almería for the period 1.4.97 to 31.3.95

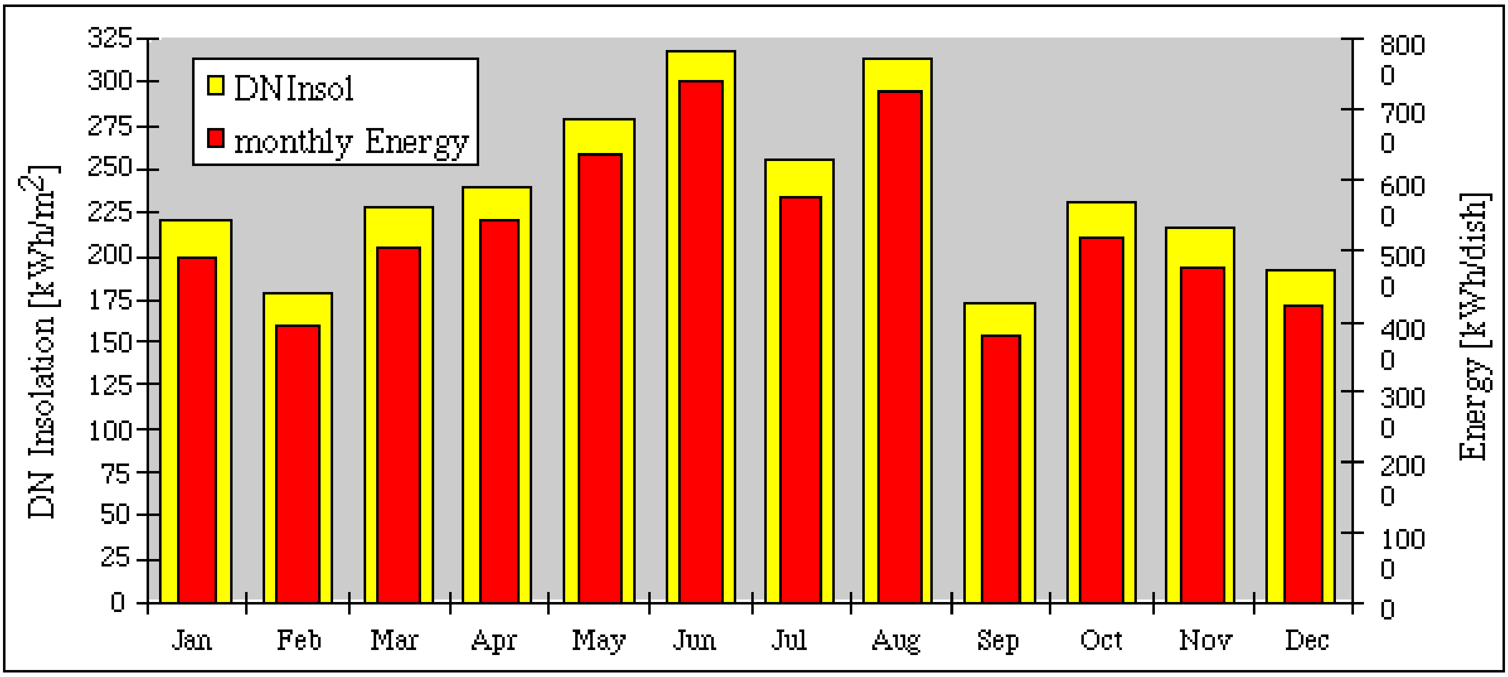

Fig. 2.3.10: Calculated monthly energy output for the period 1.1.76 until 31.12.76, Barstow

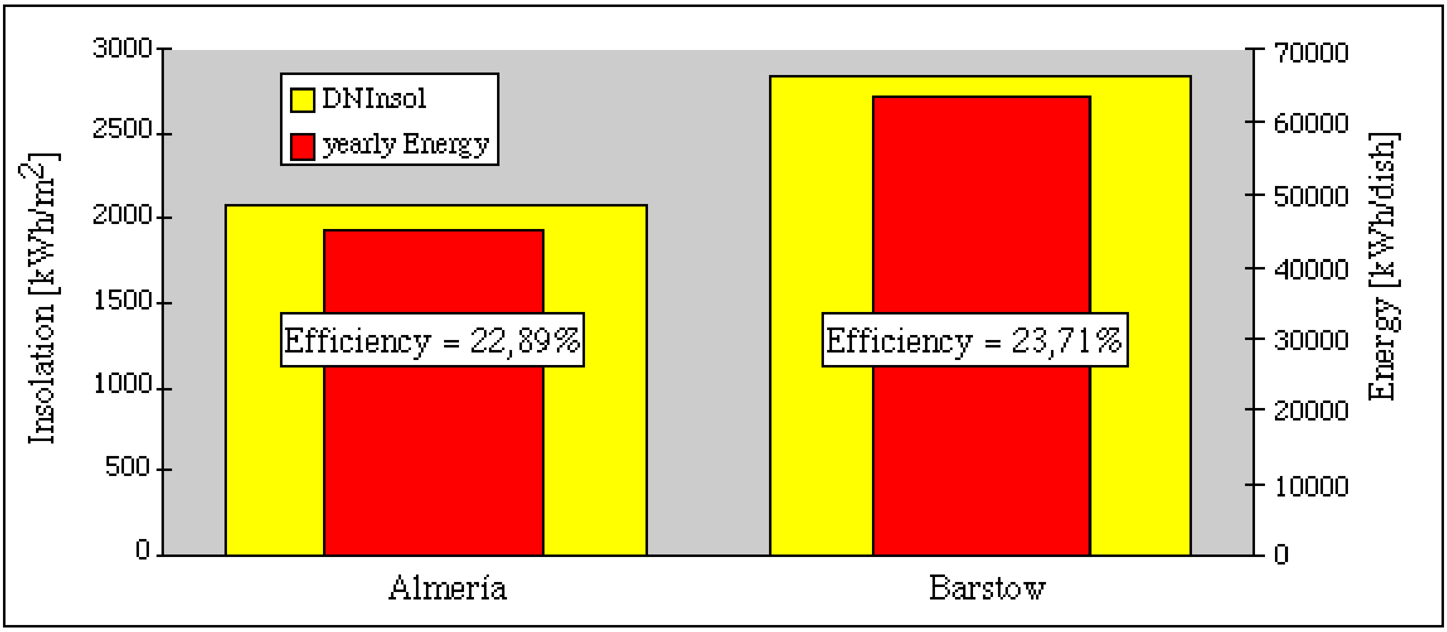

Fig. 2.3.11: Energy output for one year, comparison Barstow-Almería

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2.4.1.1 - Falling Particle Receiver

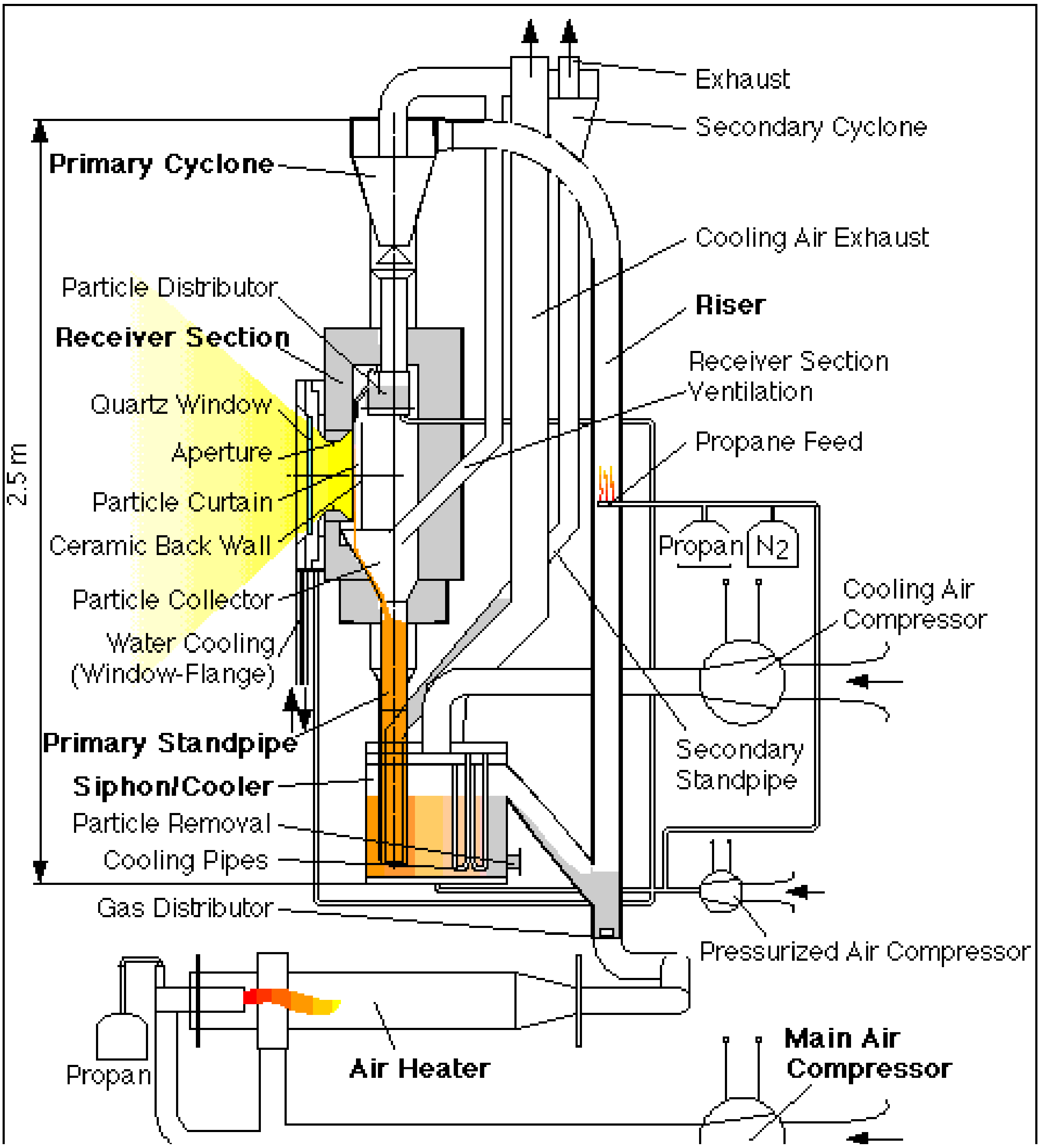
Background

For several years, the development of receivers for highly concentrated solar irradiation has focused on *volumetric* receivers. In these receivers, absorption is not on a surface, but within, for example, a wire-knit or ceramic foam, volume. Usually, the receiver design is a tightly integrated absorbant structure. An alternative is the use of small moving particles as the absorbing medium, as in the so-called *particle* receivers. The particles may be inert (e.g., to reach high temperatures for a thermodynamic cycle), chemically reactive (e.g., for the gasification of solid hydrocarbons or biomass) or catalytically active (e.g., for methane reforming). The greatest advantage of chemical receivers is the fact that a storable energy carrier is directly produced in a single step, without the need for electricity. A thermodynamic advantage of the particle receiver is the principle of direct absorption, meaning the irradiative energy is transferred directly to the reactants.

Based on the results of former investigations, the current concept of the falling particle receiver was designed during 1994-95 at DLR Stuttgart. The basic component of a falling particle receiver is a circulating fluidized bed (CFB) with a specially designed irradiation component in the downcomer (See Fig. 2.4.1). First, ambient air is sucked in by a compressor. On demand, the air can be heated with a propane-fired burner. This is necessary for non-irradiated pre-tests, for the simulation of a heat exchanger, and for quicker heating of the whole system. After this, the blowing air enters the riser via a gas distributor, which transports the circulating particles (inert SiC, or SiO) to the top. Propane may serve as an additional energy source. At the top of the riser, a cyclone separator separates the particles from the air. After a second cleaning in the secondary cyclone, the air is blown back out into the atmosphere as exhaust. Below the cyclone, the particles enter the particle distributor, an auxiliary fluidized bed that operates under conditions of minimal fluidization. Its task is the creation of a curtain of particles adapted to the diameter of the focal spot. It is in this particle curtain where the real irradiation occurs. A quartz window in front of the curtain prevents air and particles from escaping. The window is protected from particle deposits by an auxiliary radial air inflow. Underneath the receiver section, the particles pass through a particle collector to the standpipe. The particles must be distributed to maintain the pressure balance in the CFB. Below the standpipe is a siphon with an integrated fluidized bed cooler. Besides the removal of surplus energy from the machine, it is also used for the calorimetric measurement of the circulating particle mass flow. After leaving the siphon, the particles return to the riser in a closed loop.

Testing in the PSA Solar Furnace

After assembly of the receiver, some pretests without irradiation were performed in Stuttgart. The receiver was then transported to PSA and installed in the Solar Furnace in December '95. The measurement campaign, carried out by the FPR test team from 1/96 to 4/96, will determine the most important fluid and thermodynamic parameters, such as pressure, temperature, efficiency, flow stability, controllability, air demand, heat losses at various temperatures, flow, and particle temperatures. Another important aim is to demonstrate that it is possible to protect the window from particle deposits. Major PSA contributions consist in the preparation of the Solar Furnace (gas system, cooling water, exhaust pipe, security) and providing the solar specific measurement equipment, i.e., an IR-camera for monitoring the receiver temperature and a slow-scan CCD-camera system for solar flux measurement.



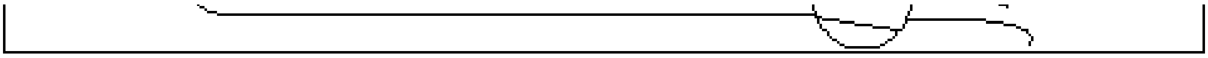


Fig. 2.4.1: Schematic of Falling Particle Receiver

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2.4.1.2 - RAS Advanced Salt Receiver

The Internal Film Receiver (IFR) concept as a cost-effective alternative to the conventional in-tube molten salt technology is presently being evaluated at the PSA. The Advanced Salt Receiver (RAS), a joint project of CIEMAT/SNL/DLR, consists of a molten salt loop including the IFR, a storage vessel, a security tank, a submerged salt pump and a salt/air heat exchanger (See Fig. 2.4.2). The project is in the 3rd phase of the test plan, (tests at different incident fluxes). In addition to the data acquisition system, an infrared camera system obtained from SODEAN was used for measuring temperatures on the back of the panel. PSA's Hermes-II system was used for measuring the front panel temperatures as well as the incident flux for power and efficiency calculations (See Fig. 2.4.3). Several tests have been performed with varied molten salt flow and incident flux conditions in order to evaluate system performance. The panel strainer attachment has been modified to eliminate panel deformation due to thermal expansion. The heat exchanger was repaired after the weldings at the inlet/outlet manifold tube bundle had been examined where there was heavy stress at the weldings and a strong amount of chlorides in the pre-test salts and water caused rapid oxidation. The heat tracing has been reinforced or replaced in the whole circuit to avoid plugging the tubes.

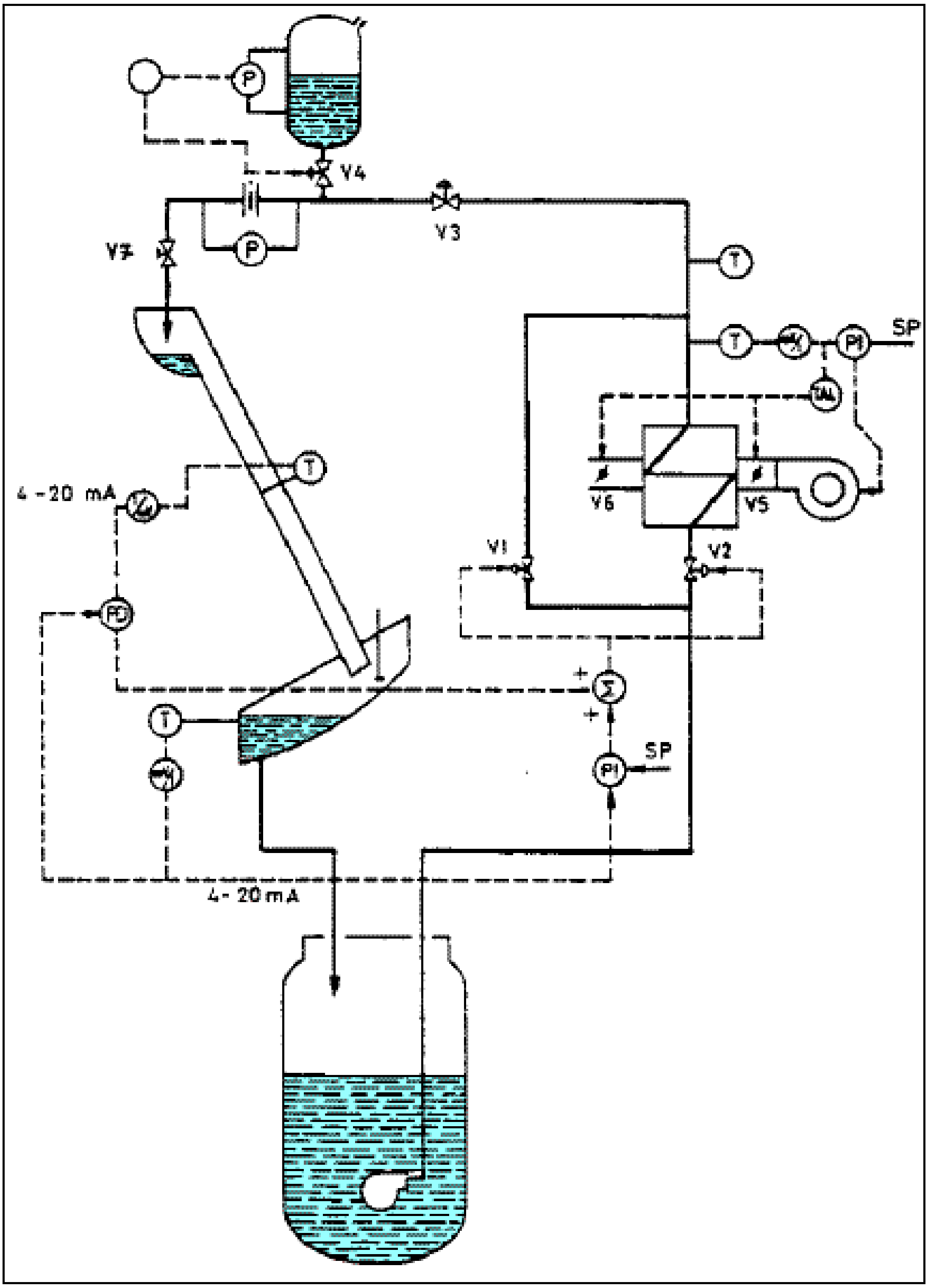

Fig. 2.4.2: Schematic of the RAS Installation

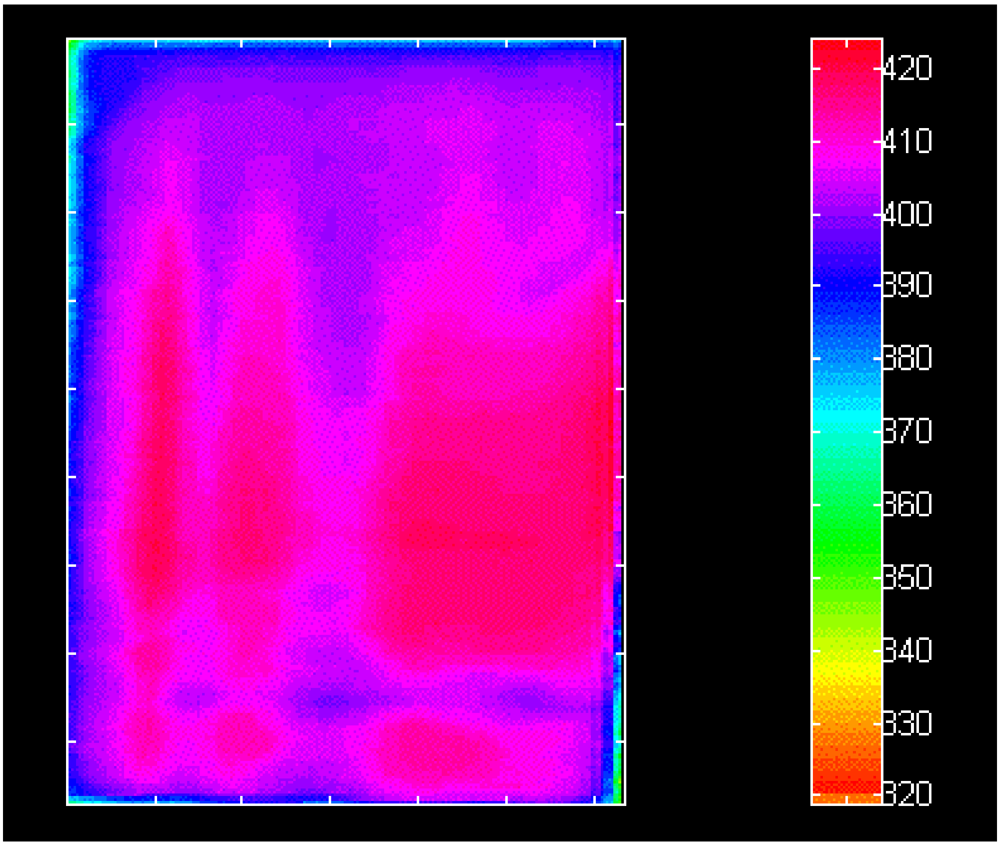

Fig. 2.4.3: Infrared Image of RAS panel taken during a typical test

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2.4.1.3 - Volumetric Air Receivers in the CRS/SSPS testbed

The second main line of research in central solar receivers is the volumetric concept, which is, at present, is being developed in the CRS/SSPS testbed. The CATREC-II, a metal-foil receiver, was operated with changes in the air flow distribution.

A new volumetric receiver, the Cor-Rec, a Cordierite-ceramic absorber, replaced the preceding one. It consists of 33 modules built up in an arc structure. As the flow in each module is adjustable, no other modifications were required.

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2.4.1.4 - TSA: Control of Flux Distribution on Absorber with an Advanced Automatic Heliostat Field Control

During the successful PHOEBUS Technology Program Solar Air Receiver (TSA) test campaign in 1993 and 1994, the optimization of receiver and steam generator control was one of the major achievements. With the optimized control strategy, short start-up times and wide control ranges, even during cloud transients, were achieved. The only problem remaining was a **H**eliostat **F**ield **C**ontrol (HFC) capable of automatically achieving and maintaining the appropriate flux distribution on the absorber. Even though semi-automatic sequences for system start-up and shut-down had been successfully established during the TSA tests, considerably reducing start-up time and saving a lot of routine operator work, adjusting the individual heliostat group aiming-point coordinates and the number of heliostats in each group to keep absorber temperatures within the desired range was still the most time-consuming operation activity.

These operating experiences stimulated the PSA "Automatic Heliostat Field Control" activities. The definition, implementation and testing of advanced control routines using 40 receiver temperatures from thermocouples as feedback for closed loop control is being carried out in cooperation with the University of Sevilla and the company DISEL, Madrid. The first strategy from the University of Sevilla, implemented and tested in late 1995, already showed very promising results. After the adaptation of control parameters and gradually increasing absorber temperatures, automatic operation was performed for the first time in autumn of 1995.

The main objectives of the **A**dvanced **H**eliostat **F**ield **C**ontrol (AHFC) are:

- keep the receiver within permissible working limits during an operating day,
- compensate heliostat field deficiencies (canting, tracking, etc) by modifying aiming-point coordinates and/or heliostats aiming-point as necessary,
- minimize the operating personnel time necessary to manually maintain the desired flux profile,

- minimize time required to observe the receiver temperatures, alarms, trips, etc.

Tests Performed in 1995

In the first semester of 1995, there were 43 testing days with a total of 120 operating hours, mainly focused on determining the temperature range of each absorbing element at different operating conditions, working temperatures and receiver powers.

The custom-made GENESIS driver (process control and visualization software) was installed and configured in July, allowing the receiver temperatures to be sent over a serial line (RS232) to the control computer. On September 20th, the first version of the control system developed by Seville University was installed.

First phase tests performed from then till the end of the year were aimed at control optimization at 500 and 600 °C. Besides the improvement with the AHFC, all control actions are previously accepted or rejected by the operator. By the end of the year, under normal operating conditions, all actions were being accepted.

Results show deviation from the control ranges of each one of the absorber elements to be similar to those obtained with the manual operation of the heliostat field.

Fig. 2.4.5 shows the average maximum and minimum values of an operating day in automatic control mode after system startup for steady state outlet temperature CT05. The graphic below it (Fig. 2.4.6) shows ranges set the same day for each element.

The control system permits adjustment of the control range for each absorber element according to the average receiver temperature given by the CT015 thermocouple. This permits operation with automatic control within an ample range of temperatures (500-700 °C).

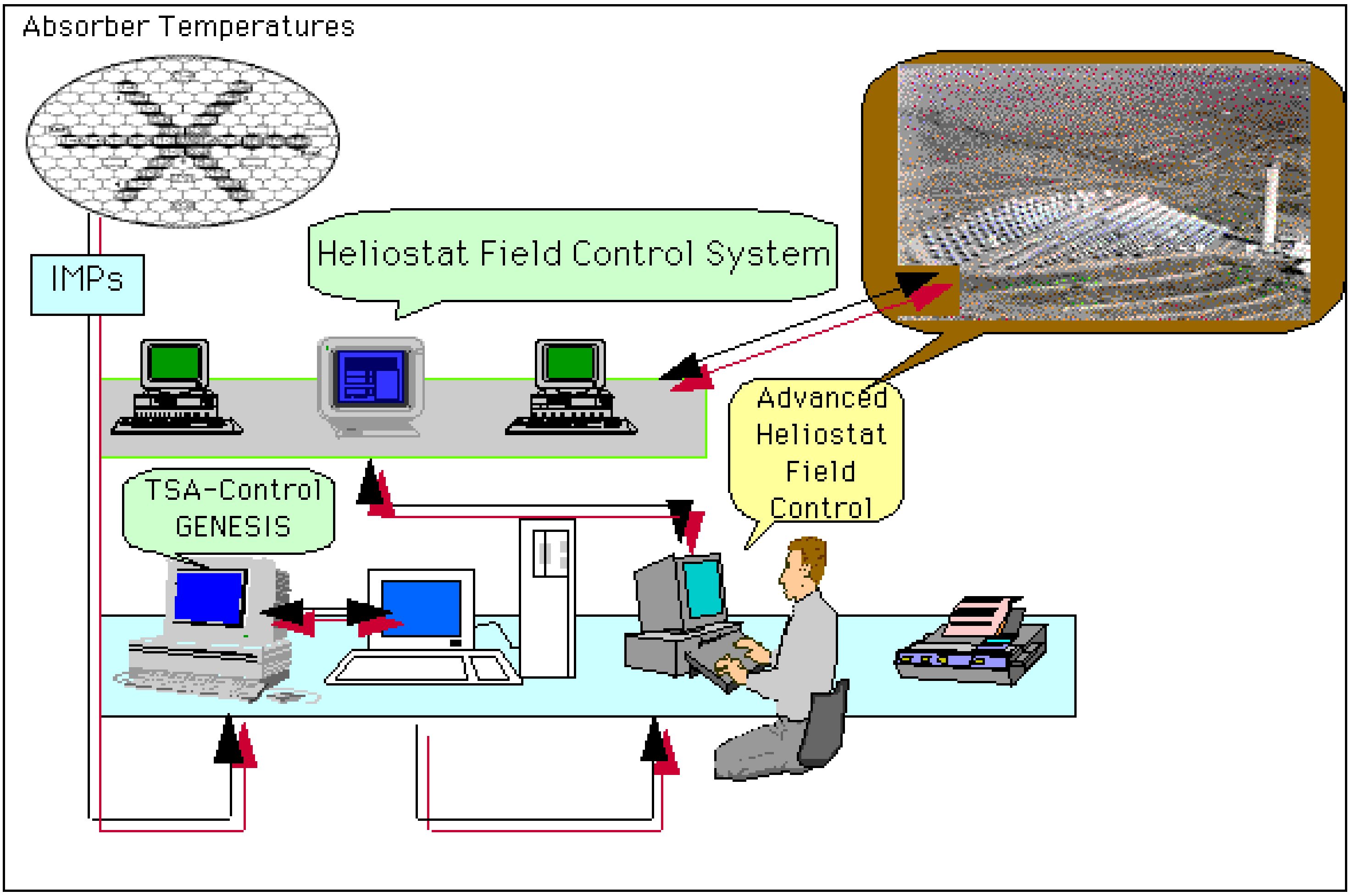

Fig. 2.4.4: Main objectives of the AHFC

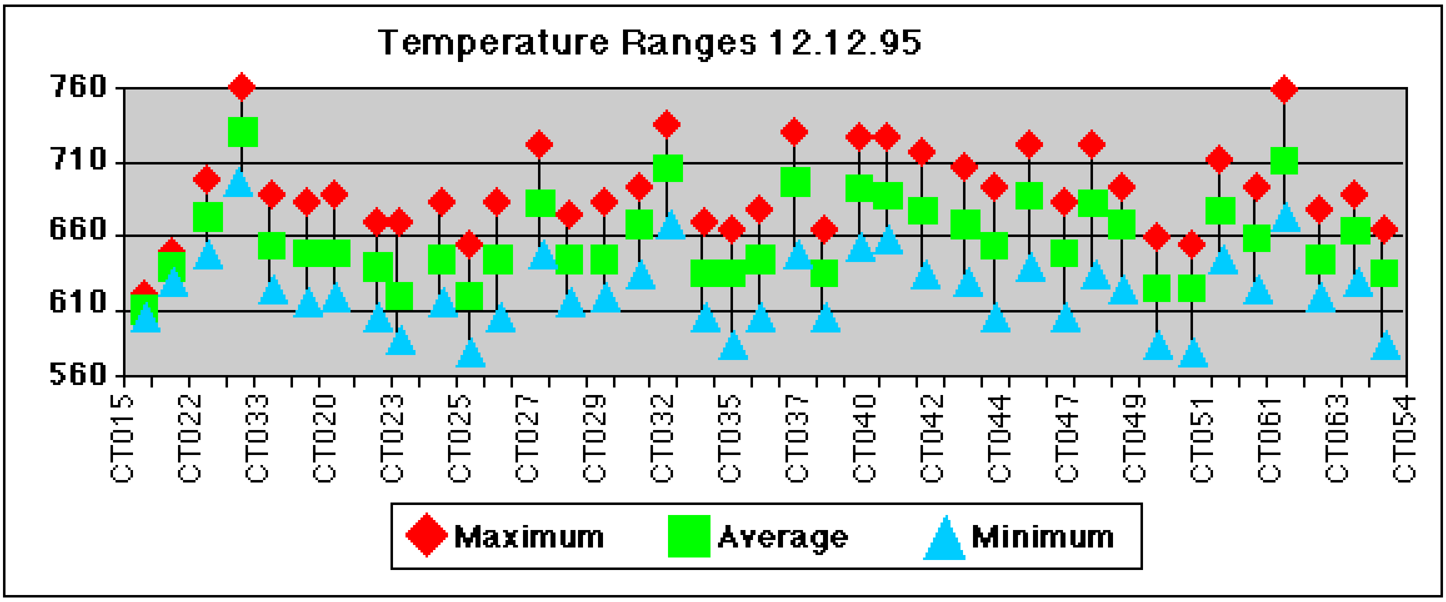

Fig. 2.4.5: Air Outlet Temperature Ranges during operation

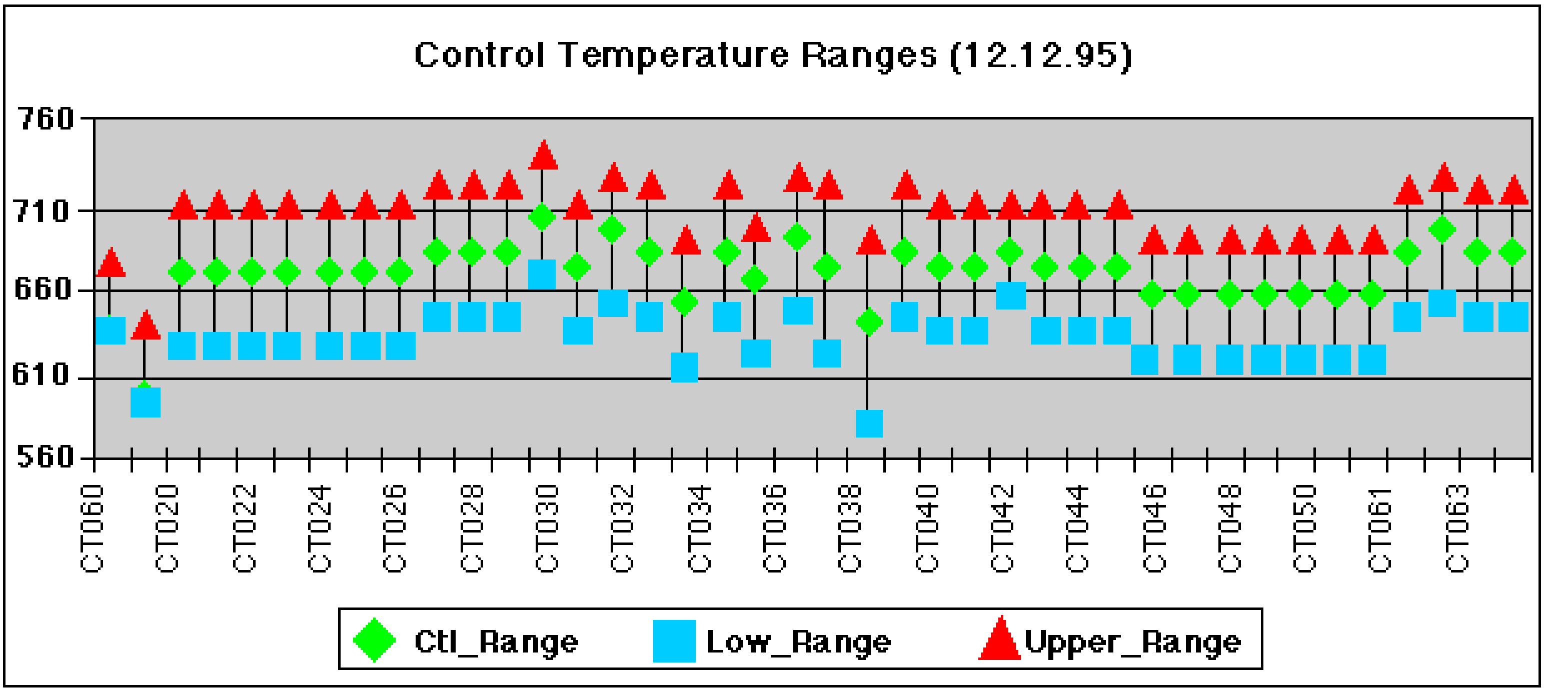

Fig. 2.4.6: Control Temperature Ranges during operation

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2.4.2.1 - ASM 150 Stretched Membrane Heliostat

Within the "Heliostat Technology Program", the ASM 150 150 m^2 advanced stretched-membrane heliostat erected at the PSA by the German firms L&C Steinmüller, Schlaich Bergermann und Partner and Fichtner Development Engineering, is now being evaluated in a long-term test program through 1996.

Fig. 2.4.7: Prototype ASM 150 Heliostat at PSA
(32 kb)

Heliostat Erection

LCS assembly of the ASM started on January 9, 1995 and, after 7 weeks, was ready for commissioning on February 25, 1995. Eight distinct steps were involved:

- the concentrator ring was formed on site with a four-stage bending machine,
- both membranes were pre-stressed with a stretching tool which had been used for 17m dish-Stirling systems in Saudi Arabia (Schlaich, J., 1987),
- both membranes were laser-welded to the concentrator ring,
- thin glass mirror tiles were glued to the front membrane,
- the pre-fabricated of the tracking unit structure was erected on the concrete foundation,
- the concentrator was hung into the tracking unit,
- azimuth and elevation rings and their respective chain drives were completed,
- electric components, consisting of blower, motors, limit switches, encoders and local controller unit were installed.

All these steps were accomplished on site.

Heliostat Evaluation

HERMES flux measurements were carried out to determine the heliostat performance at different times of the day and the year. To measure the influence of elliptical distortions caused by the heliostat's astigmatism at all times except when on-axis, a series of HERMES pictures were taken on one day from approximately 2 hours before until about 2 hours after solar noon.

The key parameter to be determined was the 90% radius, i.e., the radius of a circle containing 90% of the radiation reflected by the heliostat on the target (Figure 2.4.8). The 90% radius decreases from approximately 2.6 m three hours before solar noon to 2.3 m at solar noon and then increases again.

Further tests to determine the heliostat's tracking quality, power consumption, long-term mirror reflectivity and reliability are being performed. Close cooperation between LCS, SBP, FDE and PSA led to significant improvements in tracking accuracy during the first part of the measurement campaign.

Conclusions

First ASM 150 stretched-metal-membrane heliostat tests have proven that excellent optical quality has been achieved with 1.5 mrad, clearly surpassing the design 2.6 mrad and has already been further improved by adapted control parameters. The system optimization is still in progress.

The drive concept with natural reduction gear requires small economic drive units, with moderate power consumption. During the second part of the evaluation in 1996, the focus will be on reduction of parasitics and effect of the wind on heliostat performance. Control will also be further improved. Now, with the ASM 150 heliostat erected and operating and after the success of the TSA test program including receiver, steam generator and heat storage, all hardware components for a future PHOEBUS power plant are available.

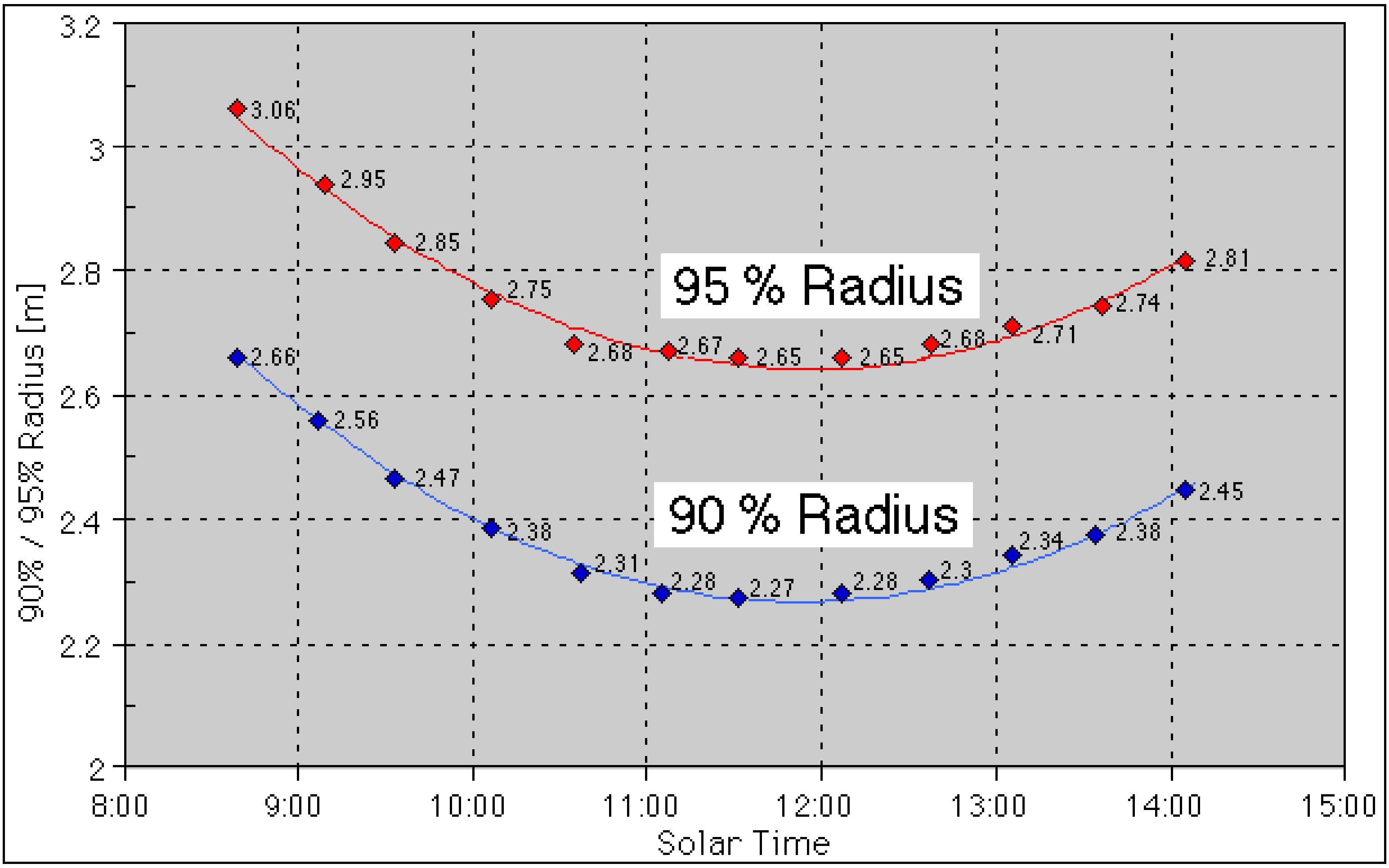

Fig. 2.4.8: Power radius vs. time of day (Date: February 23, 1996)

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2.4.2.2 - New Heliostat On-Axis Canting Method for Facetted Heliostats

Heliostats track the sun on two axes in order to keep the sun's reflected image at any set or time-dependent position on the receiver aperture, depending on the operating strategy. The quality of the power delivered on the receiver depends on many factors, but mostly on the quality of the heliostat reflecting surface. PSA's standard heliostats use twelve spatially oriented or canted focusing mirrors (facets), mounted on a pedestal. Among other heliostat performance characteristics, canting is especially important, because the canting procedure must guarantee that the heliostat as a whole has its own focal length, i. e., every facet projects its own reflected sunshape at the same location on the target. On and off-axis canting strategies are both possible for heliostats in solar tower plants. The first assumes that the theliostat is an optically centered system, i. e., perfectly focused at a point along its optical axis; the second one optimises the facet orientation for a specific sun-heliostat-receiver geometry. On-axis canting, recognized as the most suitable method for a solar power tower plant, is an extraordinarily subtle task. Traditional methods such as inclinometer procedures or references with laser beam from 2f, imply horizontal and vertical canting, respectively, extreme positions never attainable in operation, thus making it necessary to make either estimated or measured compensation, depending on the angle of the heliostat facet support at the elevation and azimuth design point angles (usually, March 21st at solar noon). And even then, final tuning is usually required. The nature of the method itself and the tools employed also contribute to the drastic slow-down this task causes.
In order to both speed up and improve this task, a new on-axis canting method was developed at PSA in 1995. The heliostat is canted at any azimuth and elevation from the optic centroid of the reflecting area, using as a reference a laser beam which travels to any canting position in unison with the reflected beam. Any heliostat can then be canted at the design elevation angle with neither compensation nor error due to long-distance references, because the maximum length of the laser reference beam is only as long as the longest heliostat beam, regardles of the position of sun. Canting may be done at any time (even at night) and on a random number of heliostats simultaneously. Thus this simple tool and methodology have finally accelerated what has always been a slow and delicate labor.

Fig. 2.4.9: New canting method at PSA
(31 kb)

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2.4.2.3 - Advanced Tracking Control: Intelligent Local Controller & Heliostat Radio Control

A new "intelligent" solar tracking controller based on solar vector calculation by a microcontroller and reading of axis positions with optic encoders is being developed. By adapting the appropriate software, this equipment may be used for local heliostat control (two-axis tracking and calculation of the reflected ray), parabolic trough collectors (one-axis solar tracking) or for any other element that requires solar orientation. The equipment combines the center's accumulated O&M experience and a marketable design. New concepts and improvements included are:

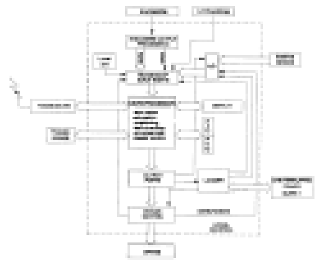

Fig. 2.4.10: Schematic of "intelligent" solar tracker controller
(21 kb)

- Self-calculates solar vector and positions of up to two axes.
- Faster response by using quick assimilation commands and several motor speeds.
- Flexibility resulting from the use of several commercial models of incremental and absolute optic encoders with resolutions of up to 65536 pulses per revolution.
- Since the electrical consumption is minimized, power supply can be conventional or photovoltaic.
- On request of the user, it can make emergency decisions under extreme external conditions, based on knowledge of the analogical variables read.
- Communications with central control can be by wire or by radio.
- Self-diagnosis of breakdowns.
- Cost has been optimized for marketing.

The telecontrolled communications system is an important innovation in the control philosophy employed up to now in solar collector fields. This leads to certain improvements such as:

- Elimination of canalization and laying of physical lines.
- Greater immunity to electrical discharges.
- Faster assimilation of commands than with a physical line.

The system is based on telecommunication with a central host through a series of microcontrollers (one in each collector) with a QAM modulation radiomodem at 9600 baud. Communication is bidirectional with confirmation of arrival of packages and hardware and software control providing highly secure data transmission.

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2.5.1 - Solar Photocatalytic Detoxification

The immediate aim of solar chemistry, one of the youngest fields of solar research, is the direct application of solar energy to drive chemical processes, with its most important long-term goal the improved storage and transport of solar energy. Two main approaches can be distinguished, thermochemical and photochemical applications. The PSA efforts in 1995 have concentrated, as in the years before, mainly on photochemistry, such as the work done in photocatalytic detoxification, one of the most active fields of solar chemical development worldwide (See Fig. 2.5.1) and the solar photochemical synthesis of fine chemicals. Another project aiming eventually at thermochemical applications, the Falling Particle Receiver, is reported on in Chapter 2.4.

The Solar Photocatalytic Detoxification Process uses the most energetic part of the solar spectrum, the ultraviolet - wavelength under 400 nm, to promote a strong oxidation reaction. This reaction takes place when UV radiation photoexcites a semiconductor catalyst in the presence of oxygen. Under these circumstances, hydroxyl radicals (OH°), which attack oxidizable contaminants, are generated, producing a progressive breakup of molecules that yields only carbon dioxide, water and diluted mineral acids (Fig. 2.5.1). The most commonly used catalyst is the semiconductor titanium dioxide (TiO_2), a cheap, non-toxic and abundant product commonly used in the manufacture of paint. In principle, it is possible to oxidize almost any chemical substance owing to the processís highly positive potential for oxidation.

Concern for the environment and reasonable expectations for its technical and economic feasibility are causing a rising interest in solar detoxification research (Fig. 2.5.2). The PSA Detox facility, unique in Europe, enables the engineering-scale testing required for development of such potential applications by Universities, Institutions and private companies with:

- Feasibility tests of specific applications.
- Definition of capabilities and limitations.
- Suggestions for improvements in the technology.
- Engineering-scale industrial experience.
- Demonstration of the "solar option" for potential industrial partners.

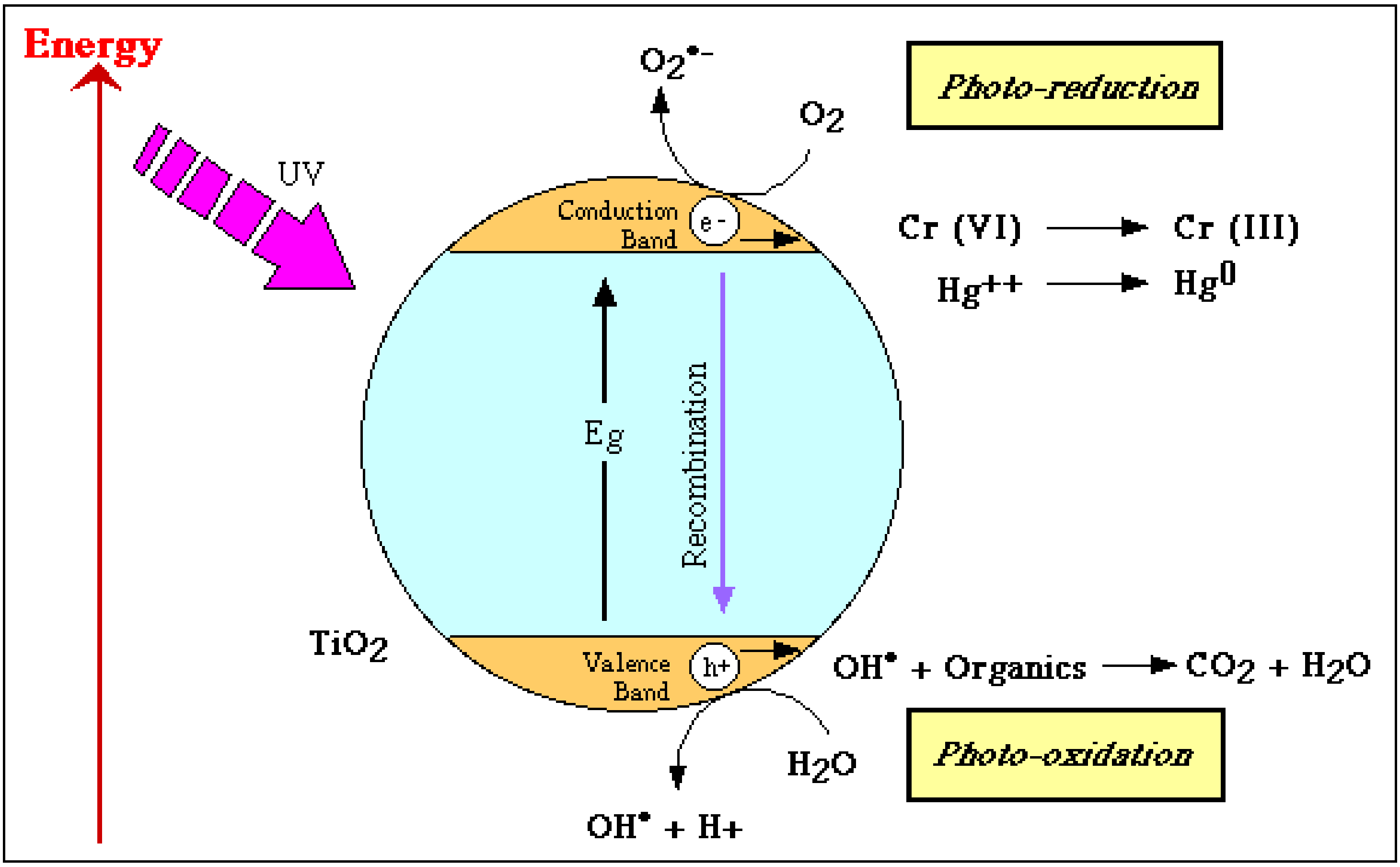

Fig. 2.5.1: Solar photocatalytic detoxification process

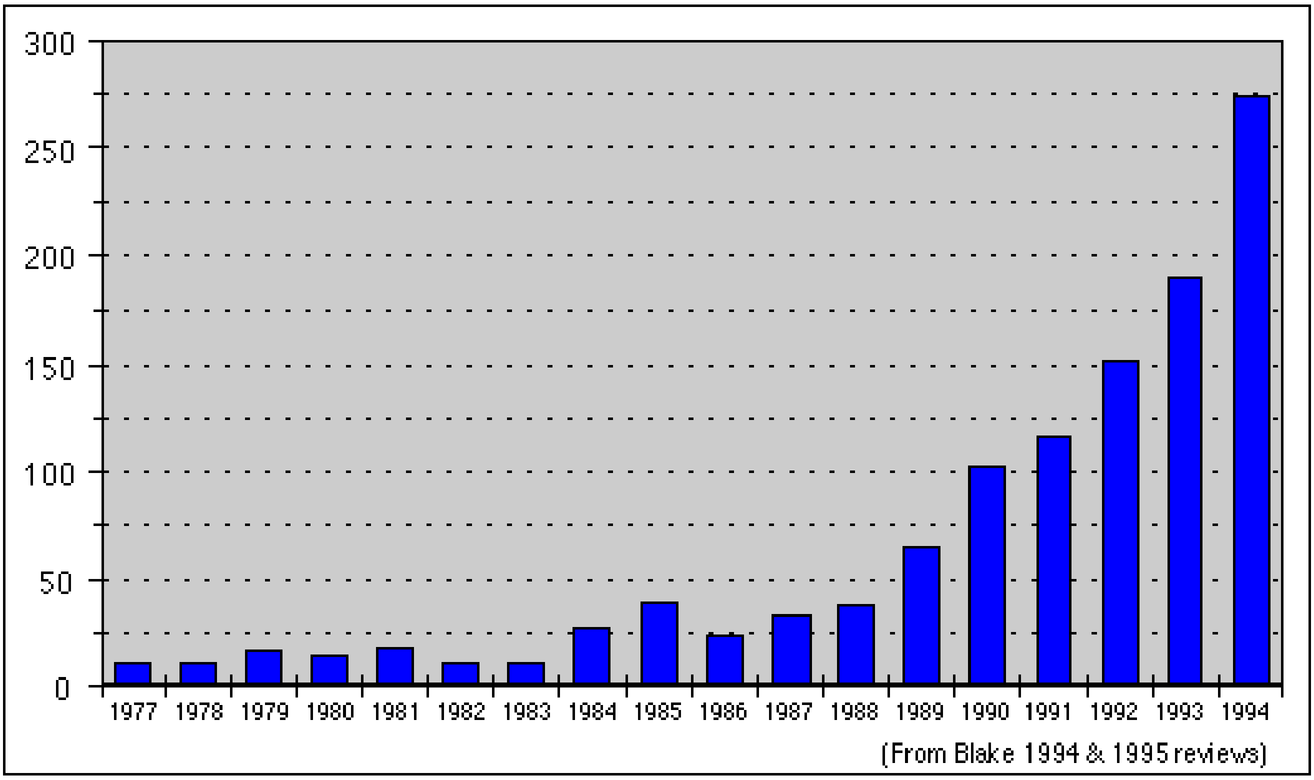

Fig. 2.5.2: Solar photocatalytic detoxification process

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2.5.2 - SOLFIN: Fine Chemical Synthesis

The main objective of this project is the use of low concentrating collector systems in the solar photochemical synthesis of fine chemicals. A considerable number of photochemical synthesis reactions come within the 300 - 400 nm UV-range where the photon flux density is low. Thus it is important to find ways to perform economical solar photochemical reactions in the UV-range. One possibility is the use of low concentrating collector systems, as studies in the field of photocatalytic detoxification show considerably higher absorption of UV-photons per aperture area for nonconcentrating systems. On the other hand, low-concentrating systems limit the space-time reaction rate inside the photoreactor, which could give rise to such problems as thermal side reactions.

Testing in a CPC-collector system with an optical concentration factor of about 1.5 and an overall volume of 10 - 30 l (irradiated 5 - 20 l) of various UV-activated photoreactions yielding potentially marketable products is therefore planned. Photochemistry research groups from several European countries will have access to the installation with EU-TMR programme funding. The layout of the installation can be seen in Fig. 2.5.7.

Though UV-photoreactions will be one of the main subjects under study within this project, the performance of other photochemical reactions in the visible range would be of equal interest for comparison with concentrating collector/reactor systems and to check the whole field of potential applications for possible future industrial collaboration.

The project was included within the PSA application for funding as a Large Scale Installation under the EU TMR Programme. After acceptance by the EU-commission, detailed planning for the necessary installation was started, operation is now planned for November, 1996. Four users from Germany, Spain, France and Italy have been selected for 1996 from the work programmes received by interested research groups.

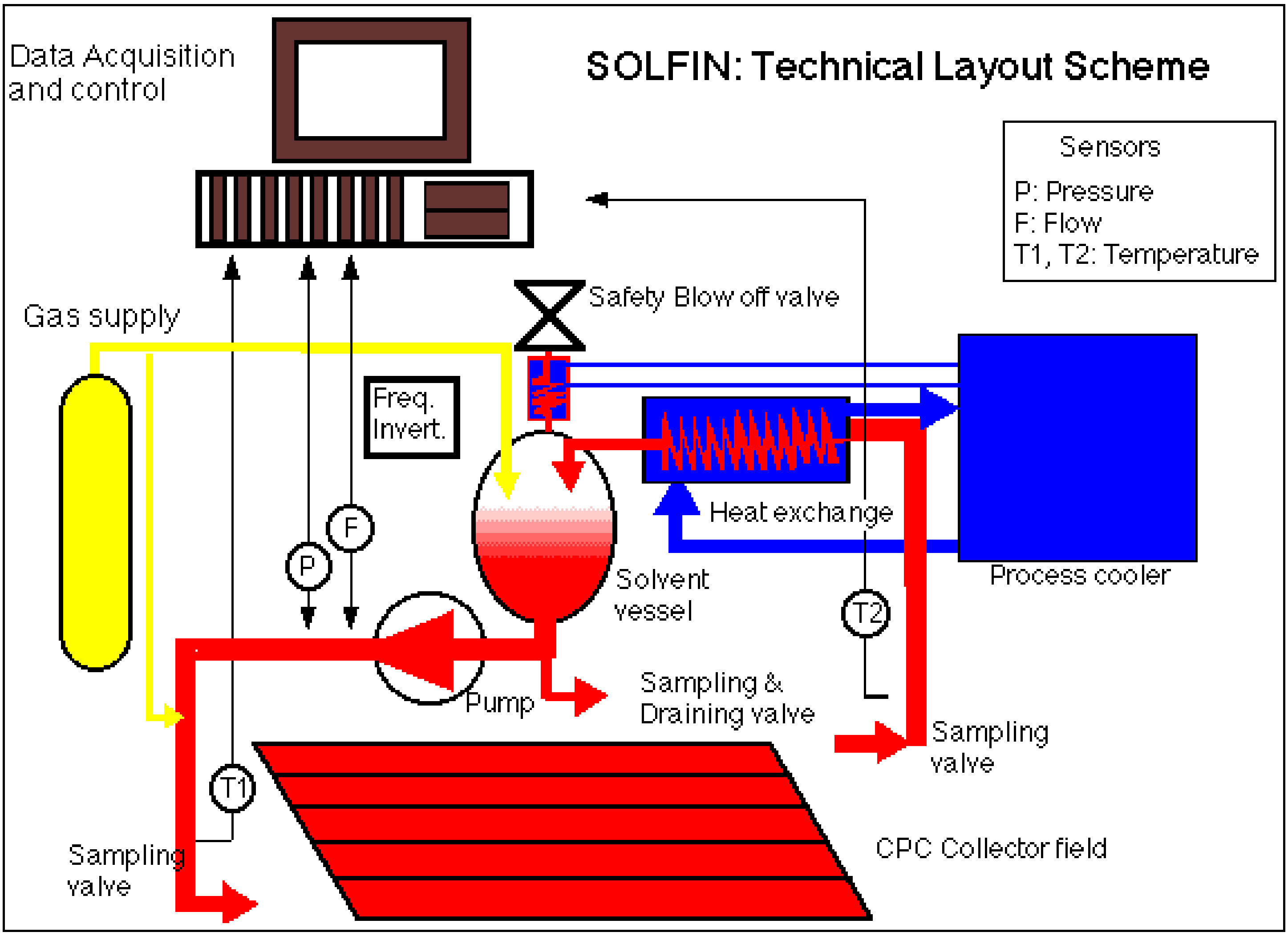

Fig. 2.5.7: Layout scheme of the Solfin installation

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2.6.2 - High Flux Concentration Facility (Solar Furnace)

Completed in 1991, the Solar Furnace was conceived as a necessary tool for further penetration into the field of very high temperatures and energy densities. The PSA can thus now cover all possible ranges of work in concentrated solar energy research.

Fig. 2.6.1: General view of the Solar Furnace
(45 kb)

From the moment of its inauguration, it has been devoted to Materials Testing, in full operation for the European Union "Access to Large-Scale Installations" programs.

To briefly describe the facility, the main components are: tracking mirrors (heliostats), concentrator, test table and shutter.

There are four MBB heliostats, each consisting of sixteen flat mirror facets. Every facet is 3.35 m^2 with 90% nominal reflectivity. They are distributed in such a way that the whole concentrator surface is illuminated. The 11.01 x 10.41 m concentrator is a modified McDonnell-Douglas dish concentrator with 89 curved facets in 9 vertical columns and 12 horizontal rows supported by a truss structure and totaling 98.51 m^2 reflective area. The concentrating optics, including a total nominal reflectivity of 92%, focal length of 7.45 m and focal height of 6.09 m with estimated focal point diameter of about 20 cm and total power of 60 kW, provide a peak flux of 3 MW/m^2.

The attenuator (shutter) consists of thirty 5.6 x 0.93 m slats and measures a total of 14. 4 x 11.2 m. It is controlled by PC and can be positioned in 15896 intermediate positions between 0° (open) and 55° (closed). An opening/time sequence can be previously programmed and then run automatically.

Finally, the programmable computer-controlled 0.7 x 0.6 m test table is movable on three axes, 0.92 m along the X-axis, 0.66 m on the Y-axis and 0.5 m on the Z axis. Thus, using the automatic capabilities of shutter and table, a test article can be submitted to any complex sequence of power during testing or several articles can be tested simultaneously.

Since 1993, a vacuum chamber for materials experiments in a controlled atmosphere, provided by the Russian IVTAN (High Temperature Institute of the Russian Academy of Sciences) by bilateral agreements between CIEMAT/IVTAN and DLR/IVTAN, is available in the HFCF.

Due to continuing diversification of its application and broadening of the range of experiments undertaken, in 1995, a great effort has been exerted in the improvement of the facility by installing some new components and improving others already existing.

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2.6.3 - CESA-1 - ESA Test Facilities

CESA-1 is, apart from a test plant for solar power plant components (heliostats, receivers, storage systems, etc.), a very flexible facility for thermal testing of large pieces of advanced materials, as demonstrated since 1988 in the various ESA test campaigns.

It consists of a field of 300 heliostats, able to generate up to 7 MW_{th} on the receiver with energy densities of up to 3.5 MW/m^2.

The receiver is the piece to be tested, which is installed in the 80-m tower at any of the several levels prepared as test beds. In particular, there are two test rooms devoted to materials testing, one at 45 m and another at 60 m. The 45-m level has been used for the Wing Leading Edge (WLE) and shingle tests and the 60-m level for the Nose Cap. A computerized control system for thermal testing was implemented in 1993, enabling testing of very large pieces and complex temperature profiles in semi-automatic mode. After the HERMES Program terminated, a new project called 'STAMP' was launched in 1995.

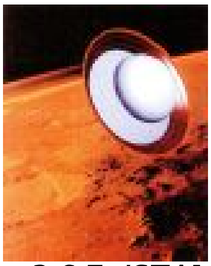

Fig. 2.6.7: 'STAMP' vehicle. Artistic View (28 kb)

2.6.3.1 - Activities within the STAMP Project and Expectations for the Future

The expectations for the future begin with an agreement with the French company, DASSAULT AVIATION, for a test setup which would enable the existing Nose Cap Facility to be used for a different piece within the new ESA STAMP Project, the code name for a program to send scientific probes to the surface of Mars, using a vehicle built by DORNIER.

This vehicle contains a capsule where the scientific material is placed and is thermally protected by a refractory shell made of SiC for entry in the Mars atmosphere. A reduced-scale penetrator has been manufactured and is going to be mechanically and thermally tested under DASSAULT supervision.

The thermal testing is the responsibility of the PSA, which must prepare the test assembly, including supports, cooling, instrumentation and procedure, while always observing ESA quality assurance rules. Special care must be taken in the preparation of the test because only one trial is possible due to the degradation of the material over 400°C, which happens very early in the just one minute-long test. A maximum temperature of about 1600°C is expected.

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2.5.1.1 - Main Results Achieved in 1995

a) PSA Facility Enlargement

The CPC installation, started in 1994, was improved during 1995, especially with additional process control equipment. Three UV-light measurements sensors are now used, an Epley-TUVR for global UV over a horizontal surface installed normal to the earth surface, an International Light-SED 400 for direct UV mounted on a platform with a sun-tracking system, and a third, a Kipp-Zonen CUV3, for global UV over a horizontal surface mounted right on the CPC-collector support platform at the same 37° angle. Global and direct UV irradiance are measured during all the experiments, enabling the evaluation of incident radiation dependant on the hour of day, clouds, atmospheric turbulence and other environmental variations. Furthermore, a new CPC collector (INETI, Portugal, Fig. 2.5.3), built with European technology, and a first version of a Solar Pond (very cheap non-concentrating solar collector) were installed and succesfully tested.

Fig. 2.5.3: View of the new CPC collector installation (first row) manufactured by SETSOL (Portugal)
(43 kb)

b) European Collaboration within the HCM Program

During 1995, the PSA Solar Detoxification Facility was widely used (43 weeks in total) by 4 different European Institutions for very successful work in the mineralization of organic compounds dissolved in water:

University of Torino: The comparative degradation of Atrazine, PCP and Dichlorophenol (DCP) in the Helioman and CPC systems was studied, including the mechanisms of degradation and the comparative performance of sodium persulfate ($Na_2S_2O_8$) and Oxone ($2KHSO_5KHSO_4K_2SO_4$) as additional oxidants. Both oxidants demonstrated considerable acceleration of degradation, although sodium persulfate with better performance, clearly appears to be the better alternative, as it is also available at lower prices and produces less additional sulfate during decomposition.

Institut für Solarenergieforschung GmbH Hannover (ISFH): The degradation of 4-Chlorophenol (4-CP) and Dichloracetic acid (DCA) in the CPC collector was studied under various process conditions, comparing several catalysts, namely the "classical" Degussa P-25 TiO_2 , the recently developed Hombikat UV100 TiO_2 (Sachtleben Chemie), and a platinized (1wt% Pt) P-25 catalyst. The Hombikat UV100 demonstrated faster degradation with DCA, as expected from laboratory results, but no advantage was observed with 4-CP. Sodium persulfate and hyrdrogen peroxide were used as additional oxidants, both showing considerable acceleration of the reaction rate. Persulfate proved to be the stronger oxidant, increasing the reaction rate proportional to the persulfate concentration within the 1 - 10 mM range.

Instituto Nacional de Engenharia e Tecnologia Industrial (INETI): Tests of the detoxification of typical highly toxic contaminants of the Portuguese pulp, fertilizer and tanning industries, such as phenol and dichromate salts containing the toxic agent Cr(VI), were continued. The CPC proved to be very efficient in the reduction of Cr(VI) to Cr(III), while decomposition of a mixture of phenol and dichromate was investigated simultaneously in the Helioman collector. In both cases, the catalyst (P-25) concentration was increased, resulting in an approximately twofold increase in the CPC collectors and fourfold in the Helioman collector within the range of 0.2 - 5 g/l.

University of Barcelona: The comparative studies of phenol degradation in the Helioman and CPC collectors and the laboratory were continued in order to evaluate kinetic constants and model the photocatalytic process in different photoreactor systems. Furthermore, initial experiments with a prototype solar pond photoreactor system were begun with quite promising results in the degradation of phenol.

c) Pesticide Detoxification Project in El Ejido (Almería)

The Spanish province of Almería has undergone important economic growth during the last 15-20 years due to the large number of greenhouses, which benefit from the extremely sunny climate in the production of fruits and vegetables. Unfortunately, this development is accompanied by the intensive use of a wide variety of pesticides with the subsequent problem of disposing of empty plastic herbicide containers, which are usually burnt or buried. Since the problem has been growing in recent years (in Almería alone, around 1.5 million of these containers per year), a parallel rise in environmental consciousness in the region is becoming concerned with their recycling.

Solar photocatalytic detoxification might prove to be a feasible solution to this problem common to the Mediterranean area, demonstrating that an environmental technology can actively help to solve environmental water problems. The biological purification of water polluted by organic micropollutants is quite inefficient at low substrate levels and the current container recycling process includes washing the shredded plastic containers, causing water to become contaminated, in relatively small quantities, but with highly toxic and persistent compounds at concentrations of several hundred mg/l total organic carbon content.

The PSA is one of the promoters of a Consortium to organize the complete pesticide container recycling process and the treatment and reuse of the water. It includes detoxification testing of waste waters samples (Fig. 2.5.6) as a first step, followed by the design and construction of a solar detoxification plant at the plastic recycling center. The contract for this project was signed by CIEMAT and 10 municipalities, 3 nationwide companies and 2 local institutions at the end of 1995 and first test runs are scheduled for the first six months of 1996.

Following the demonstration of the technical and economic feasibility of this process, El Ejido, the main center of Almería greenhouse production, may become the first European town to include a solar photocatalytic detoxification plant in a real waste treatment process. This could be the first solar photocatalytic project to make the jump from the laboratory to industrial scale, with a solar industrial waste system that effectively destroys toxic compounds, a significant milestone in solar research.

All these activities have produced strong expansion of the nucleus of international researchers created in 1990. The PSA Solar Detoxification Pilot Plants have been visited by highly experienced researchers in this field from Turkey (TUBITAK), Jordania (Royal Sci. Inst.), Brasil (Univ. of Campinhas), Japan (Nat. Ins. of Materials and Chem. Research), Hungary (Hung. Acad. Sci.), Mexico (Univ. Autonoma Metropolitana), Argentina (Univ. of Buenos Aires) and Uruguay (Ministry of Environment) among others.

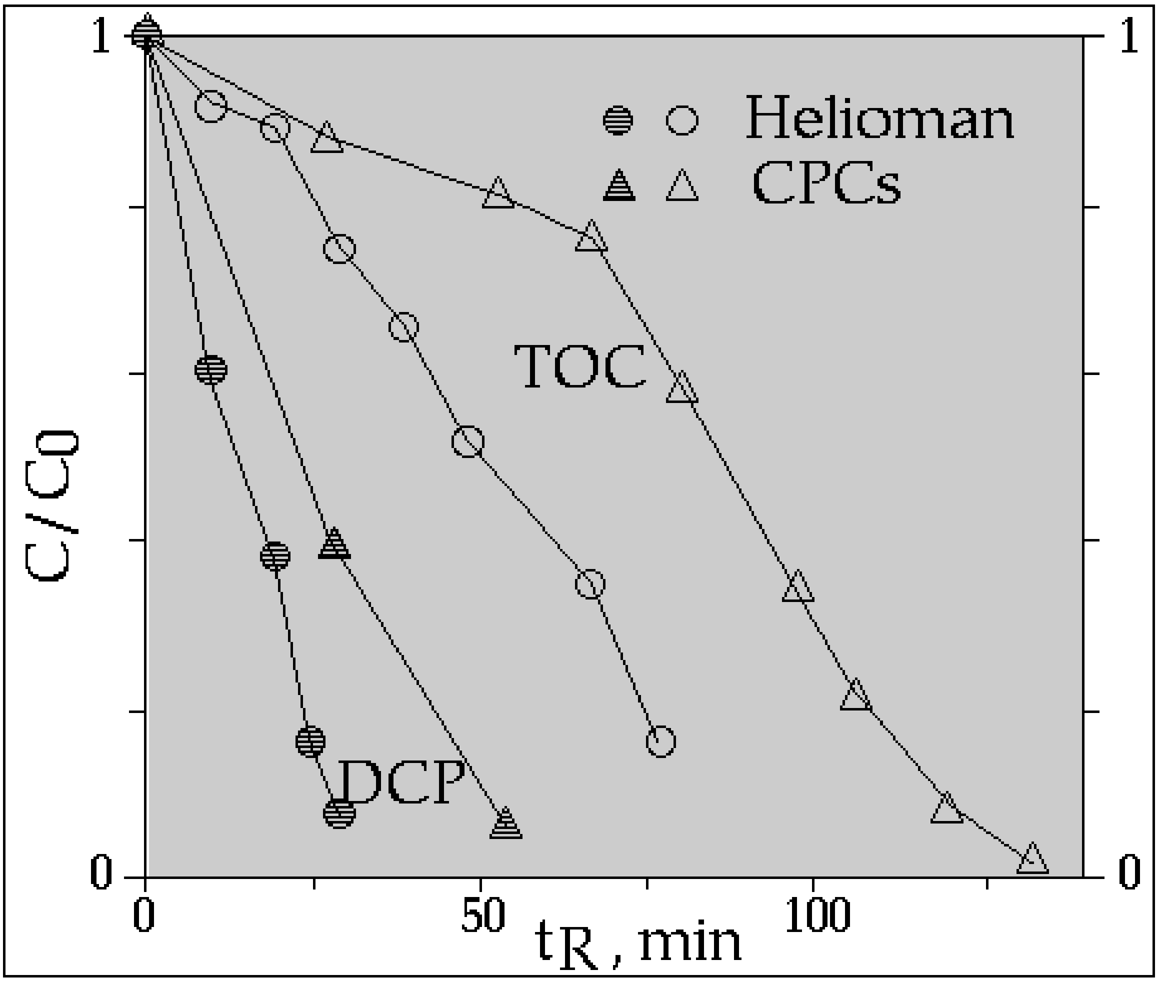

Fig. 2.5.4: DCP and TOC concentration decrease in Helioman and CPC systems

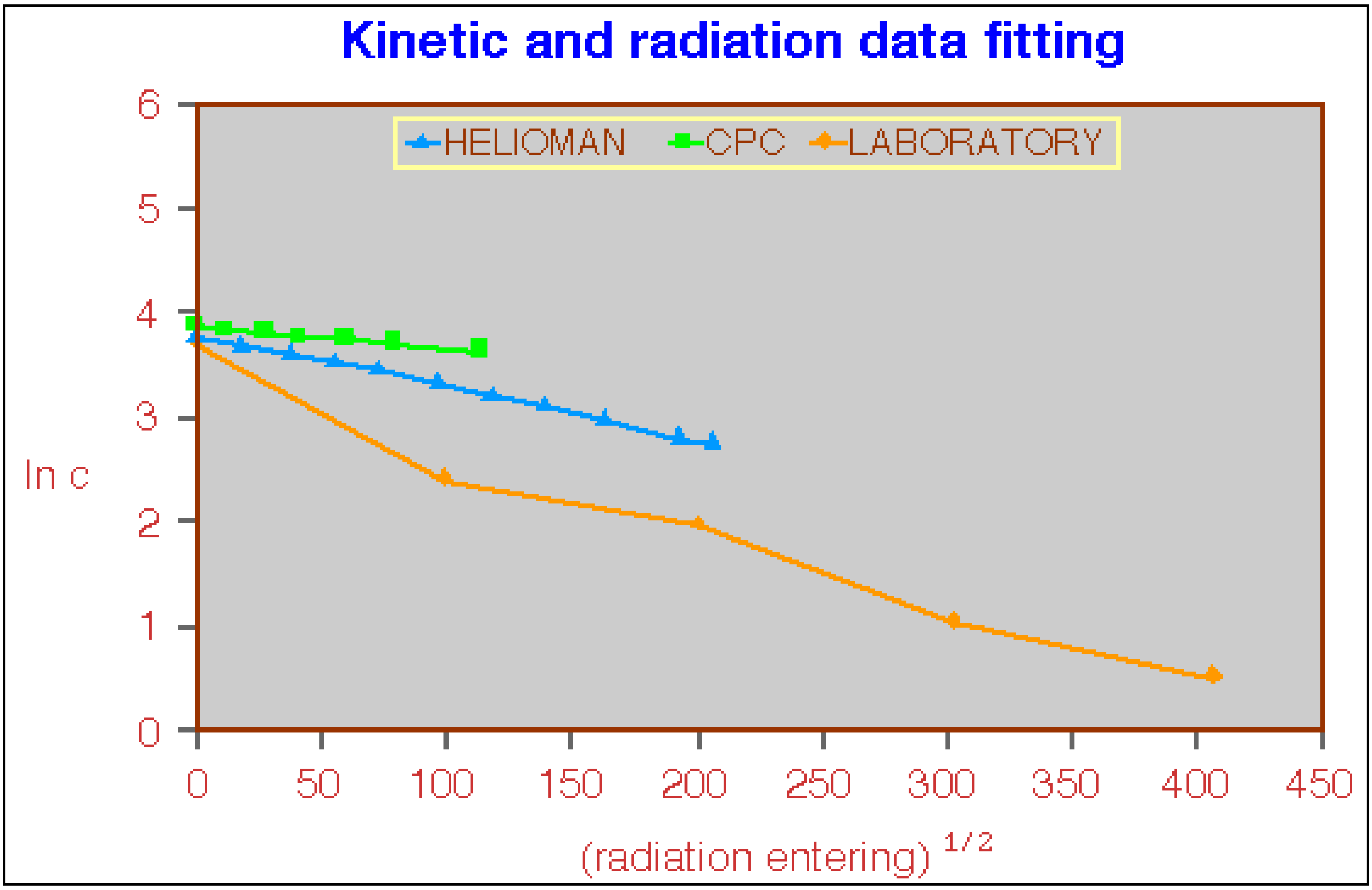

Fig. 2.5.5: Phenol concentration degradation as a function of square root of radiation

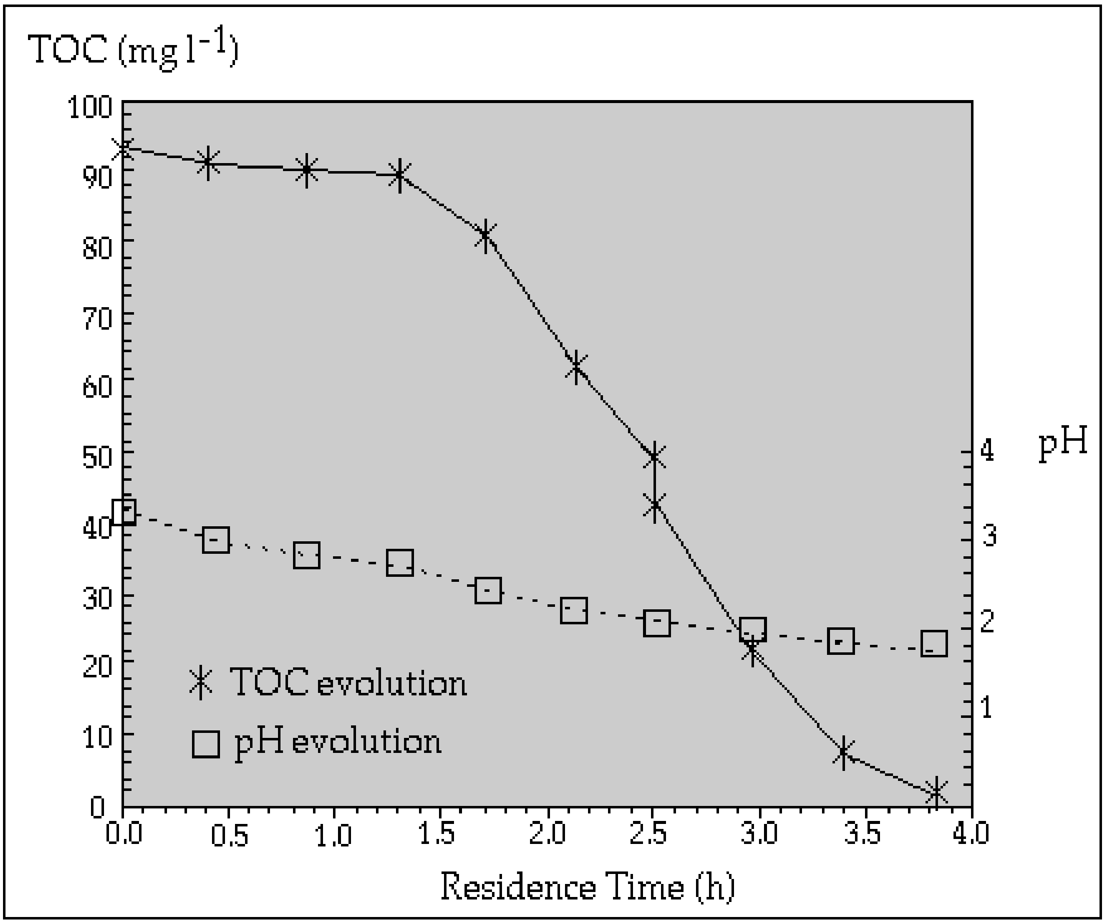

Fig. 2.5.6: TOC and pH during degradation of Rufast, a commercial pesticide containing 19% acrinatin (TiO_2 *conc: 200 mg/l; additional persulfate: 10 mM)*

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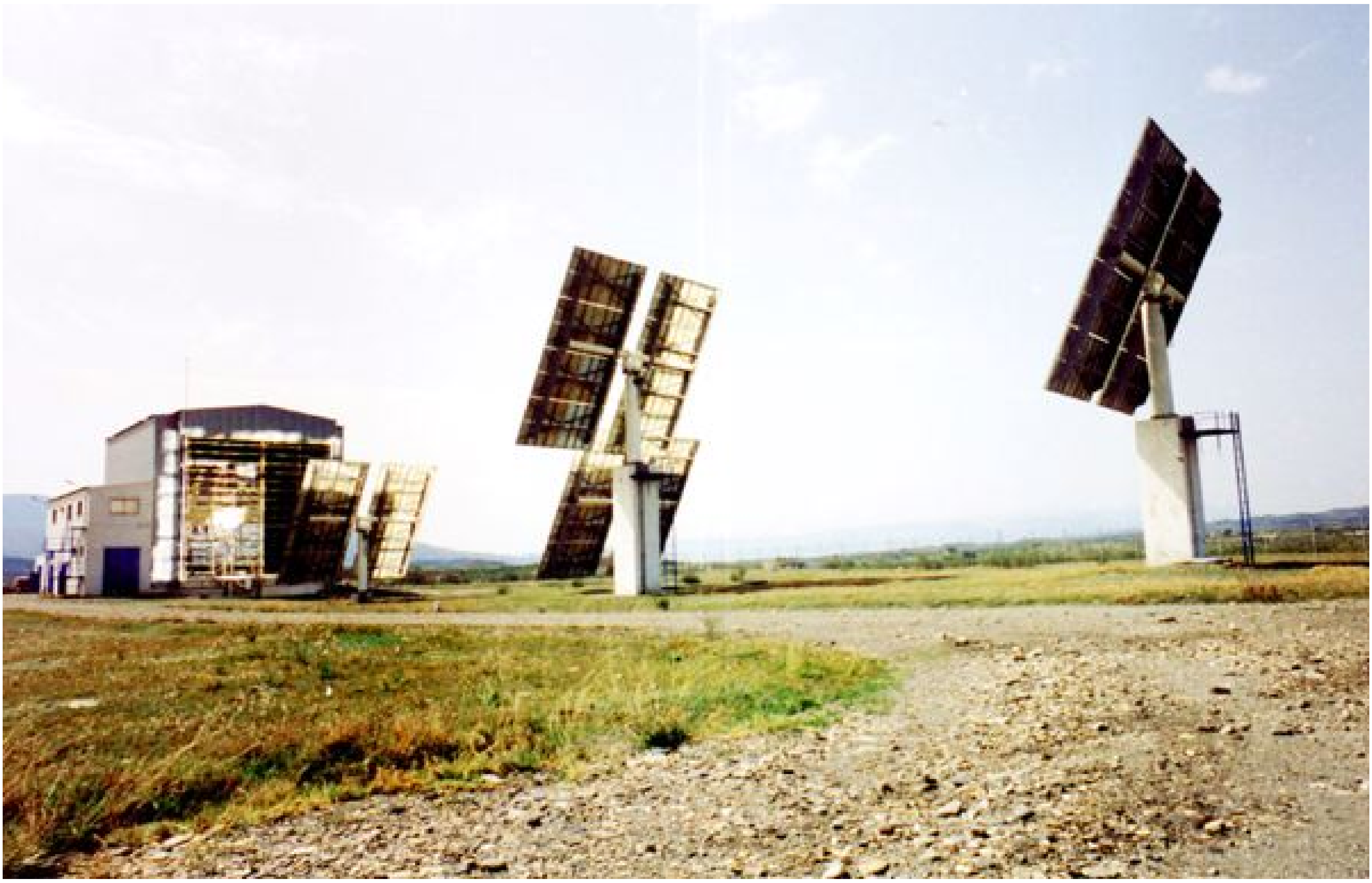

2.6.2.1 - Improvements Made in the Solar Furnace in 1995

Fig. 2.6.2: The new infrared system in operation
(49 kb)

The most important improvement in terms of technical magnitude, was the installation of an infrared thermography system (IR), with lens and filters appropriate for precision thermal mapping of temperatures up to 3000K (see Fig. 2.6.2). The wavelengths have been carefully selected (3 µm to 5.6 µm) to avoid errors due to concentrated sunlight. This system is particularly necessary given the treatment characteristics, since when sunlight is concentrated on a surface, it becomes inaccessible to conventional temperature measurement methods. This is because the high level of energy could destroy the sensor and second, the sensor itself would shade the surface under treatment.

The system is now running and a software modification is on its way which will allow the operator to modify the sample emissivity 'on-line'.

As a complement to this IR-System, a 'lightpipe' sensor for non-contact measurement of temperatures at short distances (a few mm) has also been acquired and set up.

Another important step forward has been taken with a new system of flux measurement in the focal plane. This optical measurement flux mapping system uses a combination of high resolution CCD camera and lambertian target, acquired in 1994. It provides detailed knowledge of the energy levels in the focal zone where the sample is going to be treated.

The third milestone was the acquisition of equipment for a PSA Metallurgical Laboratory, which enables quick, rough test performance results, which make it possible to modify the test parameters, if necessary, for the next test. It also makes long visits of invited researchers feasible.

Other improvements, based on designs made in 1994 were:

- Russian Vacuum Chamber in routine operation.
- A tilted-mirror for testing horizontal samples and a rotating device for 3D-sample thermal exposure are operating properly, widening the range of possible experiments.
- The first algorithms for automatic control of sample temperature by opening/closing the shutter have been implemented. This line of work is still ongoing and new, encouraging results are expected during

1996.

Some improvements planned for 1996 are:

- The installation of a "fast shutter", capable of providing thermal shock treatment of the test samples with an extremely fast opening/closing time of about 0.5 seconds.
- The design of a small new horizontal furnace based on a 2.5 m-diameter parabolic dish, with a focal length of about 1 m, capable of yielding more than 5 MW/m^2 under worst-case direct solar irradiation.

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2.6.2.2 - Activities Carried out in the HFCF

The PSA was selected in 1993 by the EU-DGXII as a host-facility for the 'Human Capital and Mobility, Access to Large-Scale Facilities Program'. Within it 6 European teams interested in research in concentrated solar energy applied for access to the Solar Furnace for advanced material treatments and optical concentrators.

During 1995, as a continuation of the activities undertaken in 1994, test campaigns were performed for 6 research groups. Activities with users may be summarized as follows:

Katholieke Universiteit Leuven (Belgium)

Jean-Pierre Celis, Responsible Scientist

These tests, carried out in May, attempted to obtain diffusion of a ceramic layer on a metal substrate. For this, the samples were placed in an inert atmosphere, inside the vacuum chamber and irradiated for different periods, from seconds to half an hour, in order to study the effect of exposure time on diffusion quality.

The next step is going to be the design and implementation of a wear-testing machine able to operate at the high temperatures produced during thermal treatment.

"Demokritos" National Center for Scientific Research (Greece)

Constantin Papastaikoudis, Responsible Scientist

The first test campaign, carried out during April and May of 1994, consisted of sintering pieces made of compressed alumina powder. A second campaign was carried out in October, 1995, with improved assembly and temperature control. Two big difficulties of these tests, which consisted of maintaining controlled temperatures for several hours, were first, maintain temperature control under significant variations in weather conditions and second, obtain a quasi-homogeneous temperature field on the samples during testing.

Trinity College; University of Dublin (Ireland)

Andrew Torrance, Responsible Scientist

Moving forward in treatment of 3D metal samples, two test campaigns were performed. The first one, in March, in transformation hardening of small cylindrical samples, exposed the samples to the solar beam and while rotating them to obtain a treated 'ring'. Different steels, rotating speeds and cooling media were used in order to assess the possibilities of the facility (Fig. 2.6.3).

Fig. 2.6.3: Hardened spot on a Trinity College cylindrical specimen
(17 kb)

The second campaign, in June-July, focused on treatment of a real industrial metal piece. The surface of a 'Renault' engine camshaft was treated by melting and resolidification whithout disturbing the rest of the piece (Fig. 2.6.4).

Fig. 2.6.4: View of treatened cam at 'Renault' engine's camshaft
(19 kb)

It was then that the need for temperature control was realized, since at that time it was still being performed by manually opening and closing the shutter.

Centro Nacional de Investigaciones Metalúrgicas (Spain)

Alfonso Vázquez, Responsible Scientist

The first stage of this group's tests, from December, 1994, to February, 1995, studied use of the controlled atmosphere in the vacuum chamber to avoid later mechanical treatment due to oxidation during surface treatment.

Fig. 2.6.5: The vacuum chamber under test at Solar Furnace
(70 kb)

A second campaign in July, consisted of demonstrating the feasibility of surface alloying cast iron substrates with high-quality materials like nickel or stainless steel.

A flat tilted mirror was developed and installed to redirect the solar beam toward a horizontal working plane in order to be able to work with melting materials.

2.6.2.3 - The "Concentrating Optical Device"

Design and construction of a second-stage concentrator to increase total concentration and, thereby, the maximum achievable temperature in the PSA Solar Furnace to above 2000°C was studied by the following two institutions:

Danish Technological Institute (Denmark)

Alexander Souproun, Responsible Scientist

This secondary concentrator should increase peak the flux in a 5 cm-diameter focal point from the current 3 MW/m^2 to 7.5 MW/m^2. The device, which uses the 'Thermal Loss Trap' concept, was tested at the Plataforma Solar in October, 1995, but due to the lack of an appropriate built-in cooling system, testing was minimum and could only reach 10 % of maximum power. Therefore, no definitive results could be obtained, but only some ideas for improvement.

Instituto Nacional de Engenharia e Tecnologia Industrial (Portugal)

João Farinha Mendes, Responsible Scientist

The PSA Solar Furnace was evaluated in 1994 by two world-class experts in *non-imaging optics* for the purpose of finding the most appropriate design for the SSC. The concept 'Tailored Edge Ray Device', (TERC) was finally chosen (See Fig. 2.6.6).

Fig. 2.6.6: INETI's secondary concentrator (15 kb)

The SSC, which in the beginning was designed to be placed within the solar furnace's vacuum chamber, was constructed by NORMINOVA of Portugal. Testing at the PSA was carried out in November and December and results were quite in compliance with theoretical values.

The new CCD flux measurement system was used for these tests, providing the flux maps necessary for evaluation of the secondary concentrator.

Top: 2.6.2.3 - The "Concentrating Optical Device"

Team Developers of the PSA Web site thank you for your visit.
We are always open to your suggestions.

2.6.2.4 - Activities within the 'PECO Initiative'

Also within the 'HCM' program, the PSA is the coordinator of a proposal under the 'PECO Initiative', the objective of which is to promote cooperation in research with the countries of Eastern Europe and former Soviet Union. Within this proposal, CIEMAT/IVTAN have agreed to collaborate in the testing of pieces pre-prepared by IVTAN for use in scientific satellites, in the above mentioned Vacuum Chamber. Under this proposal, three Russian scientists have been invited to the PSA to contribute their know-how in this field and also participate in testing. Part of the 1995 campaign was carried out in June and part in September.

As a further step forward in the cooperation between CIEMAT/DLR/IVTAN, a proposal has been prepared for the EU INCO Program, in 'Surface property monitoring of advanced materials under thermal treatment in a Solar Furnace'.

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2.6.2.5 - Activities within the 'INTAS' Program

Some activity has also taken place in the HCFC within the framework of the 'INTAS' program, coordinated by the German DLR. Specifically, some tests in melting and quenching of refractory oxides were performed under the supervision of DLR and the Uzbek 'Physics-Sun' scientific association in September.

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