MEDIUM TEMPERATURE, HIGH EFFICIENCY TRACKING AND NON-TRACKING SOLAR ENERGY COLLECTORS FOR RURAL AND INDUSTRIAL APPLICATION

FINAL REPORT

May, 1981 to December, 1984

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5 May 1981 to 31 December 1984

submitted by

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March, 1985

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ABSTRACT

In a collaborate research program sponsored by the Department of Science and Technology, the Government of India and the Agency for International Development, of the U.S. State Department, it was proposed to develop cost-effective parabolic, single-axis, tracking solar energy collectors and to use these collectors in a demonstration system such as agricultural pumping, industrial hot water and steam production, thermal power and/or space heating and cooling in rural India.

The collector and prototype system development was to have been a three-year effort and constituted the first phase of a demonstration project. The second phase (also proposed for a three-year period but not funded) was to have begun after completion of the first phase and was to be devoted to the commercialization of the collectors developed and to system development, demonstration and commercialization appropriate to rural India.

The first phase was completed as proposed. In addition a 180 m^2 collector area demonstration system is currently being installed in a government silk factory in Mysore as a retrofit to the existing boiler plant. The system is scheduled for completion in April, 1985. It should be in operation in September, 1985.

The project is a collaborative effort between the Indian Institute of Science, Bangalore, on the Indian side and the University of Houston, Houston, Texas on the USA side.

SUMMARY

In the fall of 1977 I was invited by the United States Department of Energy (DOE) to attend the 1977 International Solar Energy Society (ISES) Biennial Congress in New Delhi, in January, 1978. There was interest in developing some joint solar energy projects between Indian and American institutions. In a manner still unknown to me I was assigned to visit two institutions in India (The Indian Institute of Science (IISc) in Bangalore and the Punjab Agricultural University (PAU) in Ludhiana). The group at the IISc was headed by Dr. Ramakrishna Rao, and they were interested in developing single-axis, tracking, parabolic solar collectors for rural and industrial uses. The group at the PAU was headed by Dr. K.D. Mannan, and they were interested in low temperature and domestic applications: thermo-syphon water heating, air heaters, non-tracking concentrators and cookers. As a result of my short discussions with both groups, I prepared a proposal which was officially submitted to the DOE on March 1, 1978. After the DOE decided it was not interested in the projects after all, the proposal (still involving both the IISc and the PAU) was submitted to the Agency for International Development (AID) on July 21, 1978. In January, 1981, the University of Houston received work that the "project" had been funded. However, only the first three years of the proposed five-year, two-phase project was funded. And one of the collaborative institutions, the PAU, had been dropped from the project. It was never clear whether only phase one was funded or if the overlapping first year of phase two was included. It was also not clear what was to be done about the work proposed to be done with the PAU.

The timeline and task list submitted with all reports including

this one have been taken from the original proposal (which included the PAU). All the proposed work with the IISc has been completed. Not all the work proposed with the PAU was completed. In particular, the unfinished tasks include the design of the non-tracking concentrators (although the optical analysis was completed), the thermal system design for the non-tracking system and the air heater technology assessment.

The following discussion will be limited to the major activities performed at the University of Houston-University Park (UHUP). Details on the other activities performed at or at the direction of UH-UP can be found in the section entitled Comments on Project Objectives in this report.

Travel, especially international travel, is often viewed as a luxury. However, I feel that it was a very important part of this project and that the work could not have been completed without it. Technology transfer was a key element of this project, both between the IISc and the UHUP and between the UHUP and the American solar community. Interaction with and on-site visits to the successful American solar demonstration projects were very important since the design details necessary to make a project successful are not published and are therefore only available through personal contact. In addition, telephone conversations and technical reports cannot replace a personal inspection during which contact with the technicians and the hardware itself yield detailed answers and even give rise to new and important questions.

Direct communication with Bangalore proved to be ineffective. Rarely were telephone lines available and working when calling from Houston to Bangalore. With the additional problem of the twelve-hour

local time difference, telephone communication was frustrating. The telex to Bangalore was also a problem. The operators in Houston had great difficulty getting a line in India. The most reliable communication link was the mail with a twelve to fourteen day delivery time. Hence, most discussions between Bangalore and Houston had a thirty-day response time. Therefore, the limited time that the investigators had together as a result of the international travel was extremely busy, and had I had the project to do over I would encourage more or at least longer visits to the two principal institutions.

The major technical activity at the UH-UP was the model development for the simulation of the performance of the linear-focusing, parabolic trough system. This work was the subject of two lengthy technical reports (a total of 322 pages) and has resulted in four publications to date. (A list of reports and publications resulting from this project is given in Appendix C.) Two major contributions resulted from this activity:

1. For the first time deterministic (non-random) error analysis was included in the optical model of the parabolic trough.
2. A design methodology was developed for the design of parabolic trough concentrators in different design environments (economic, technical and geographic) with different constraints and sets of objectives.

These two contributions make it possible to extend the considerable design and analysis methods developed over the past ten years in the United States for a relatively high technology environment to a less technically developed environment like India.

An important question arose early in the project: Would it be better to design and build a tracking, parabolic trough, solar collector demonstration system using exclusively materials available in India or to allow the use of some imported materials as well. Given the only moderate success of the tracking solar thermal systems world-wide utilizing the technology of the "developed" countries, it seemed foolish to ignore these developments. One could also seriously question whether a successful design could even be implemented using only materials available in India. Therefore, it was decided to import selectively critical materials and components not available in India when it was felt that the technical success of the project was in question without them. This philosophy led to a design based on a commercial product available in the United States but modified for the Indian technical environment. Specifically, thin, flexible glass mirrors, high pressure flexible hoses and an electronic tracking control system were purchased in the United States for importation. An attempt was made to purchase and import the drive system as well. However, as explained later in this report and in previous reports there were several problems, and the attempt was finally abandoned. Except for these three items the entire solar demonstration project was constructed with Indian materials and components. The additional equipment purchases for the IISc were for instrumentation to monitor and evaluate the demonstration system.

The purchase of equipment for the IISc by the UHUP represented a significant amount of effort due to the lengthy process involved for the Indian importation and the lack of good communication between the IISc and the UHUP as discussed previously. The problems involved have been

discussed in previous semi-annual reports and is briefly restated in the section entitled, Comments on Project Objectives, in this report.

The optics of non-tracking concentrating solar collectors is complicated by the great variety of physical designs available and the relatively wide range of sun locations that must be accommodated (morning to evening and winter to summer). We had been working on this problem for about six years prior to the beginning of this project. This work continued and resulted in a technical report as part of this project.

Finally, an experimental study was made of the design of a class of storage tanks for use in flat-plate, solar, thermosyphon, water heating systems. While not in support of the IISc effort, the task was in the original proposal and in fact is in support of a very appropriate solar technology for India.

SUMMARY OF STAFF

Principal Investigator

Richard B. Bannerot

Faculty Associates

Farrokh Mistree

Stanley J. Kleis

Halil M. Guven*

Robert M. Nerem

Research Assistants

Gary Kwan

S. Kumar

Y. Wu

Halil Guven

Student Assistants

Mohamed Arwer

Ibrahim Khanmohamed

Brian Goble

*Received Ph.D. in December, 1983 and was appointed to Visiting Faculty position.

COMMENTS ON PROJECT OBJECTIVES

The program description outline and timeline taken from the revised proposal, is reproduced as Appendix A of this document. The progress on objectives is presented below in a format paralleling that utilized in the program description outlines.

TRIPS (international travel): The international travel is summarized below. Additional details can be found in the Semi-Annual Reports.

20 May - 14 June 1981: Dr. Bannerot was in India.

30 August - 24 October 1981: Dr. Rao was in the United States.

20 March - 19 June 1982: Mr. Thomas and Dr. Mohan were in the United States.

12 August - 3 September 1983: Dr. Bannerot was in Australia (ISES Congress) and in India.

5 June - 6 July 1984: Dr. Rao and Mr. Thomas were in the United States.

I. LINEAR FOCUSING

Short Term Review of Concentrators:

As described in the First Semi-Annual Report, Dr. Rao's trip during 30 August to 24 October 1981, included a first-hand inspection of many solar demonstration sites in the United States where parabolic trough collectors were utilized. He also visited several solar manufacturers.

Long Term Review of Concentrators:

Dr. Guven carried on this activity throughout the project.

Model Development

Dr. Guven and for a time Mr. Kumar carried out this activity. Mr. Kumar investigated the thermal losses from receivers. Dr. Guven developed the optical model and then incorporated the thermal aspects into a collector model. His work is described in two technical reports (Technical Reports 1 and 2 in Appendix C). A copy of the computer program was sent to the IISc. Dr. Guven continues to respond to questions from the IISc on running the program and interpreting the results.

Testing Facilities (Review):

In his Spring, 1982, trip to the United States, Mr. Thomas accomplished this review in his visit to eight demonstration sites and numerous other research facilities. Details of his trip are included in an appendix to the Second Semi-Annual Report.

II. SELECTIVE COATING

Technology Assessment:

The visits of Drs. Rao and Mohan in the Fall, 1981 and the Spring, 1982, respectively, completed this task. Contacts were established with people at various laboratories and industries in the United States.

Details of the trips can be found in the First and Second Semi-Annual Reports.

III. NON-TRACKING

Optics:

These studies were performed primarily by Mr. Kwan and are described in a technical report (Technical Report 3 in Appendix C).

Collector Design:

As described in the Summary no work was done in this area. This activity was to be done with the second Indian institution which was dropped from the project.

IV. THERMAL SYSTEM DESIGN

Tracking:

After Mr. Thomas' visit in the Spring, 1982, it was decided to use a Honeywell flux-tracker system. As discussed in the Fifth Semi-Annual Report, this product was withdrawn from the market before we could procure it. As described in the Fifth, Sixth and Seventh Semi-Annual Reports , several attempts were made to purchase other systems. Finally, a purchase was made from a company in Denver that bought a license to manufacture the Honeywell system.

V. FLAT PLATE THERMO-SYPHON SYSTEM DESIGN

Mr. Wu carried out this activity between December, 1982 and May, 1984. The activity is described in a technical report (Technical Report 4 in Appendix C).

VI. MATERIAL EVALUATION AND DEGRADATION

None of this activity took place at the University of Houston. However, several instruments were purchased and sent to Bangalore to carry out this activity there.

VII. AIR HEATERS TECHNOLOGY ASSESSMENT

No activity took place in this area. It was originally part of the proposal but was to be done with the second Indian Institution which was dropped from the project.

VIII. EQUIPMENT SPECIFICATION AND PROCUREMENT

The University of Houston prepared purchase orders based on instructions from the Indian Institute of Science. While in principle this activity appeared straight-forward, it was responsible for considerable effort and many problems. By the end of the project most of these problems had been worked out. The major problems were the 10% withholding on payment until arrival in India was confirmed (some companies would not accept this constraint) and the year-long processing for importation into India.

The purchases made during the contract period are listed on the next page:

Device and Services	$ 13,106.00
Eppley Laboratory	7,776.00
Glaverbel	9,011.00
Hewlett-Packard	325.00
Hewlett-Packard	100.00
Hewlett-Packard	18,545.60
Hoffer Flow Control	1,568.00
Hoffer Flow Controls	2,213.00
Hydro-Flex Corp.	10,820.12
Hydro-Flex Corp.	10,013.67
Industrial Solar Technology	10,825.00
International Technology Corp.	5,919.50
MKS Instruments	1,754.00
Olympic Solar Corp.	4,903.76
Schott Optical Glass	309.00
Spectra-Physics	1,749.00
Thomas A. Read	2,468.25
TOTAL EXPENDITURES	$ 101,406.90

Three additional requests to purchase were received but the purchases could not be made (See Appendix B for a letter of explanation).

Poellmitz Associates	$ 4,550.00
Winsmith	19,100.00
Winsmith	13,800.00

The original total budget for equipment was $106,250. As can be seen above only $101,406.90 was spent. This under-expenditure was due primarily to the problems that developed with the Winsmith Company as described in the letter in Appendix B. The tracking guidance system from Industrial Solar Technology was substituted at the last minute by showing them to be a sole source for the system. Another reason for the underexpenditure was that the large Hewlett-Packard purchase was originally priced at over $27,000. A special price was later worked out saving about $9,000.

IX. LITERATURE SURVEYS

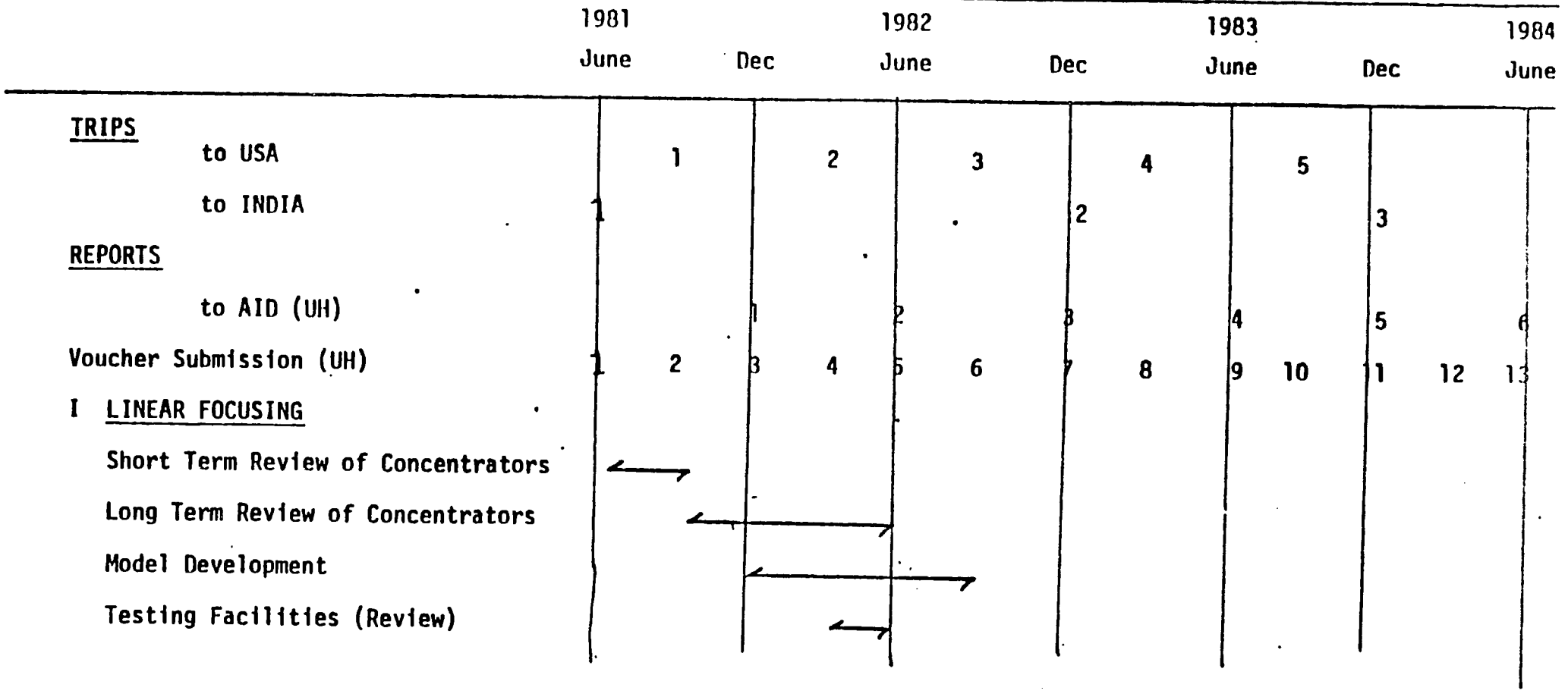
Reports, articles and other papers were sent to India throughout the project.

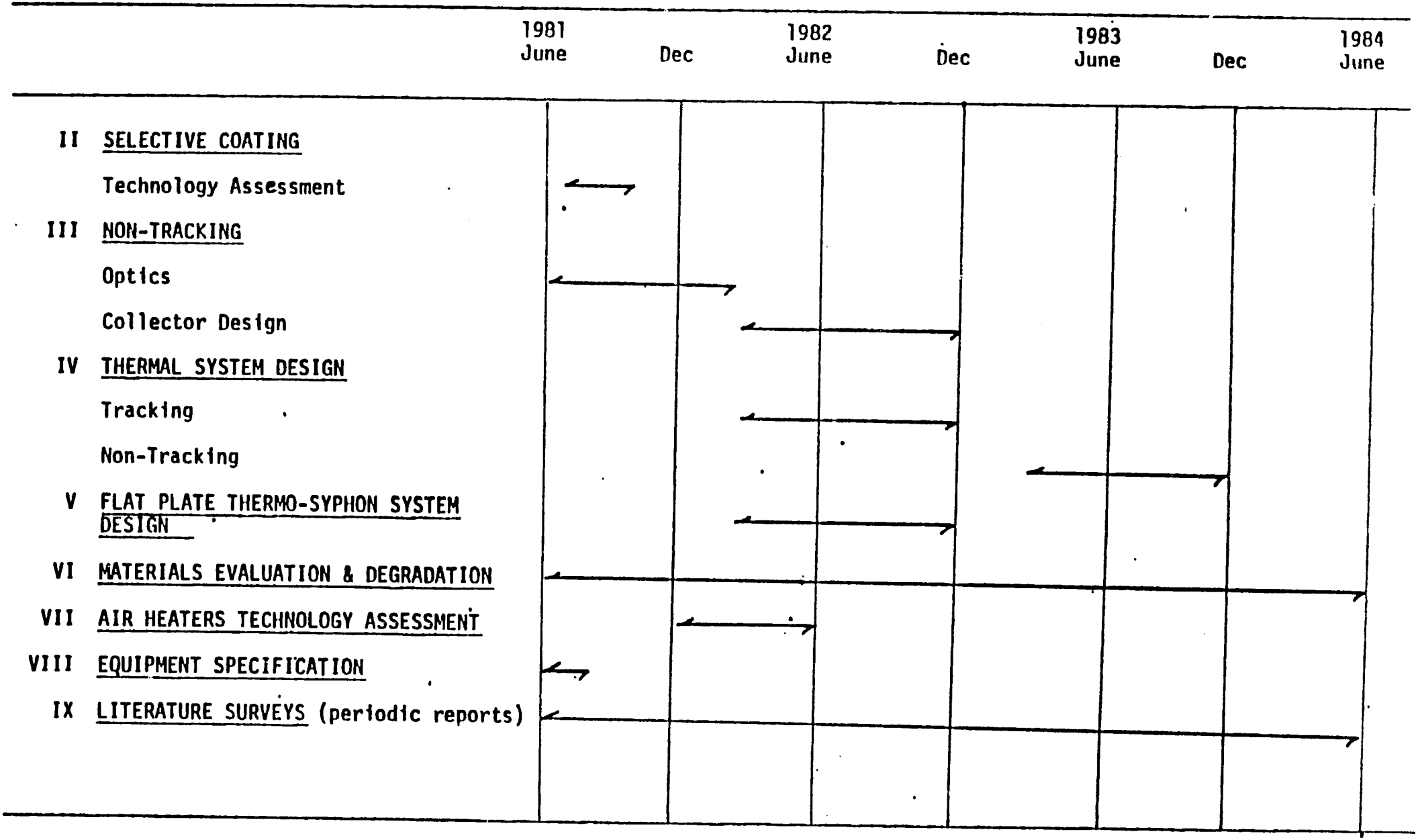
APPENDIX A

PROGRAM DESCRIPTION OUTLINE AND TIMELINE

INDO-US COLLABORATIVE PROJECT ON "MEDIUM TEMPERATURE, HIGH EFFICIENCY TRACKING AND NON-TRACKING SOLAR ENERGY COLLECTORS FOR RURAL AND INDUSTRIAL APPLICATION"

PROGRAM OF CENTRAL CAMPUS OF HOUSTON UNIVERSITY




1981
June
Dec
1982
June
Dec
1983
June
Dec
1984
June
II SELECTIVE COATING
Technology Assessment
III NON-TRACKING
Optics
Collector Design
IV THERMAL SYSTEM DESIGN
Tracking
Non-Tracking
V FLAT PLATE THERMO-SYPHON SYSTEM DESIGN
VI MATERIALS EVALUATION & DEGRADATION
VII AIR HEATERS TECHNOLOGY ASSESSMENT
VIII EQUIPMENT SPECIFICATION
IX LITERATURE SURVEYS (periodic reports)

APPENDIX B

LETTER OF EXPLANATION CONCERNING PURCHASES FROM WINSMITH

Houston
University
Park

4800 Calhoun Road
Houston, Texas 77004
713.749.2437

November 28, 1984

Dr. M. Ramakrishna Rao
Regional Instrumentation Center
Indian Institute of Science
Bangalore 560012
INDIA

Dear Dr. Rao:

The purchase orders were finally issued for the Hewlett-Packard Automatic Data Acquisition System. Because of the change in the order due to the reduction in cost and subsequent increase in the order, there were many administrative problems. I have enclosed a copy of the University of Houston purchse order. Since the final purchase order differs in form, but not really in substance, from the original IISc order, I thought you may need it for importation.

The Hydo-flex order was up-graded to its original statement on the Proforma Invoice (all attached).

The Swagelok order from Thomas Read Company is still being processed.

It is now apparent that we will be unable to purchase the Winsmith Speed Reducers with motors. There are many reasons which I shall attempt to explain. First, the order was originally delayed because Winsmith would not agree to the USAID requirement of 90% on shipment, 10% on delivery. We finally got that straightened out last summer. I discussed the order with Winsmith in August. Your estimate did not include packing, shipping or documentation. Winsmith was initially unwilling to handle shipping. Finally, they agreed and quoted a price over the phone. However, when their quotation came in September, they did not include the packing, shipping or documentation and our purchasing department was unwilling to accept a telephone quotation. The complete quotation finally came at the end of September. They required a 16-week (minimum) construction period. The University would not place the order because at that time the contract ended in less than three months (31 December). I sent a telegram to Mr. Berry. He clarified that payment could be made up to 31 March. Then Winsmith indicated that 16 weeks may not be enough time. (I talked with Al Lewandewski at SERI, and he said Sandia had ordered a set of Winsmith gears and it took over 9 months for delivery). The Univesity is willing to issue a purchase order stating that shipment

must take place before 15 March. Winsmith would not accept this condition and wanted the University to pay before shipment. The University cannot do this. So we are at a stalemate.

When it became evident that we might have the Winsmith money available, I checked into ordering the electronic weatherstation from Poellmitz Associates in Duxburg, Massachusetts. I have called them about ten times in the last four weeks and they have never answered the telephone. Since the order from the IISc is now over a year old and no shipping or documentation was included in the quotation, we cannot even place an order until Poellmitz responds.

We have packed the Televideo monitor for shipment (see enclosed letter). The H-P graphics plotter is being converted to 220 useage in town and will be shipped when the work is completed (see enclosed letter). The letters will also be shipped with the packages.

Finally, Sandia Laboratories has denied permission for Mr. Rush to "officially" travel to India. I am still working through Bob Ichord's office to get the Department of Energy, which runs Sandia, to intercede. In any event Mr. Rush says he may be willing to take vacation time if AID furnished the travel. I still do not have confirmation from Mr. Berry that the travel grant has been approved. It looks unlikely that anyone will be traveling to Bangalore soon.

I believe that is all the news. I hope things are going better for you in your construction phase in Mysore. In any event I hope all is well with you and your family.

Sincerely

Richard B. Bannerot
Principal Investigator

RBB/dg

cc: R. K. Berry

APPENDIX C

LIST OF REPORTS AND PUBLICATIONS

RESULTING FROM THE PROJECT

Publications

Halil Guven, F. Mistree and R.B. Bannerot, "Design Synthesis of Parabolic Trough Solar Collectors for Developing Countries,' Engineering Optimization, 1984, Vol. 7, pp. 173-194.

Halil Guven, F. Mistree, and R.B. Bannerot, "Determination of Error Tolerances for Optical Design of Parabolic Troughs," ASME-83-WA-Sol 1, presented at ASME Winter Annual Meeting, Boston, MA, Nov. 1984 and submitted to Solar Energy.

Halil Guven and R.B. Bannerot, " Derivation of Universal Error Parameters for Comprehensive Optical Analysis of Parabolic Troughs" Solar Engineering -1985. Proceedings of the joint ASME-ASES Solar Energy Conference, Knoxville, TN, March, 1985 and submitted to the ASME Journal of Solar Energy Engineering.

Halil Guven, F. Mistree and R.B. Bannerot, "A Conceptual Basis for the Design of Parabolic Troughs for Different Design Environments" Solar Engineering - 1985. Proceedings of the Joint ASME-ASES Solar Energy Conference, Knoxville, TN, March, 1985 and submitted to the ASME Journal of Solar Energy Engineering.

Bing Man Kwan and R.B. Bannerot, "Improved Optical Design of Non-Tracking Concentrators," ASME Journal of Solar Energy Engineering, August, 1984, pp. 271-6.

Reports

Richard B. Bannerot, "Medium Temperature, High Efficienty Tracking and Non-Tracking Solar Energy Collectors for Rural and Industrial Application"

First Semi-Annual Report, January, 1982
Second Semi-Annual Report, July, 1982
Third Semi-Annual Report, January, 1983
Fourth Semi-Annual Report, July, 1983
Fifth Semi-Annual Report, January, 1984
Sixth Semi-Annual Report, July, 1984
Seventh Semi-Annual Report, January, 1985

Halil Guven and R.B. Bannerot, "Optical and Thermal Analysis of Parabolic Trough Solar Collectors for Technically Less Developed Countries", Technical Report 1, June, 1984 (127 pages).

Halil Guven, F. Mistree, and R.B. Bannerot, "A Comprehensive Computer-Based Method for Design of Parabolic Trough Solar Collectors for Technically Less Developed Countries", Technical Report 2, August, 1984, (195 pages).

Bing Man Kwan and R.B. Bannerot, "Optical Designs for Non-Tracking Concentrators," Technical Report 3, September, 1984, (95 pages).

Li-Yun Wu and R.B. Bannerot, "An Experimental Investigation of the Effect of Water Removal and Replacement on the Thermal Stratification in a Horizontal Water Storage Tank", Technical Report 4, November, 1984 (171 pages).