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SOLAREX

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TERMINAL REPORT

SILICON TECHNOLOGY DEVELOPMENT CENTRE

ISLAMABAD, PAKISTAN.

CONTRACT NO. 82/18

SUBMITTED TO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

VIENNA INTERNATIONAL CENTRE

P.O. BOX 300

A-1400 VIENNA, AUSTRIA

DECEMBER 1984

SUBMITTED BY

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ABSTRACT

The Pakistan National Institute of Silicon Technology has been equipped and staffed. Four senior research officers completed six-month fellowships working mostly in the United States at Solarex and other U.S. organizations to provide a cadre of people to man this organization. Equipment and supplies to sustain the Laboratory are in place or on order. Several key pieces of equipment are not yet operational; the silicon purification equipment, the silicon crystal growing apparatus, the inner-diameter saw to slice the silicon ingot into wafers, and the dicing saw. Despite the shortage of these important items of equipment, the STDC staff has demonstrated a capability of making and encapsulating solar cells starting with wafers acquired from outside STDC.

The program was severely delayed as compared to its original schedule. Solarex extended the contract expiration date six months to November 1984. The delays mostly stemmed from the slow pace of construction of the building. It appears that facility completion is not likely until late in 1985.

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1.0 INTRODUCTION

This is a report which summarizes the activity of the Solarex Corporation in fulfillment of UNIDO Contract 82/16, Project No. ST/PAK/80/001, Activity Code ST/02/31.8. The general scope of the contract is to assist the Government of Pakistan in its efforts to establish a "Development Centre for Silicon Technology"* in Islamabad, Pakistan.

1.1 Purpose of Report

The report fulfills the requirement of para. 2.10 d) of the contract. It reports on all significant activity in fulfillment of the contract.

1.2 Plan of Treatment

The report is organized along the lines of the major activities done by Solarex, i.e., training in U.S. of Pakistani scientists, Solarex assistance in laboratory design, Solarex assistance in choosing and delivering equipment, on-site activity (in Pakistan) of Solarex advisors. Finally, there is a section on the Solarex view of the program, general recommendations to the UNIDO on future programs of this type, and specific recommendations on the STDC effort.

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*Through the short history of the program, the name of the organization has had several variations. In this report, the terms "Silicon Technology Development Centre (STDC)", and the current term "National Institute of Silicon Technology" are used.

2.0 PRELIMINARY

2.1 Scope of Contract

The aim of the Project is to assist the Government of Pakistan in establishing a silicon technology research and development centre. In this context, the aim of the Contract (Reference 1) is to provide the Government with the services of specialists with the widest possible practical experience in this field who shall be responsible, inter alia, for:

a. Preparing all the necessary technical information, including drawings, designs and layouts, required for the establishment of a Silicon Technology Research and Development Centre.

b. Preparing the technical specifications of the equipment required for the said centre (the equipment was purchased by UNIDO and the Contractor's specialists assisted UNIDO in this undertaking as and when required).

c. Assisting Pakistani counterparts in installing and operating the equipment purchased by UNIDO.

d. Initiating research and development activities, with full participation of the Pakistani counterparts, on the basis of a detailed work plan prepared in cooperation with the UNIDO Senior Industrial Development Field Advisor and the Pakistani counterparts in the Project Area.

e. Providing appropriate on-the-job training to Pakistani counterpart personnel.

f. Preparing, designing, organizing and conducting training programs for a selected number of Pakistani counterparts (4-5) assigned to the Contractor's facilities in the USA.

g. Promoting understanding of the usefulness of the project for Pakistan and of the role which photovoltaic and silicon micro-chip techniques can play in the development of Pakistan.

h. Introducing the use of photovoltaic and silicon micro-chip demonstration kits in a selected number of teaching and research and development institutions in the Project Area.

2.2 Schedule

In response to UNIDO Tender No. 82/07-ST/PAK/80/TC1, Solarex submitted a proposal dated 1 April 1982. After evaluation by appropriate U.N. personnel, a contract was signed by D. Gardellin, representing the UNIDO on 10 May 1982, and Mr. C. Wrigley representing Solarex on 19 May 1982.

One of the first tasks was to establish a detailed schedule. This was accomplished during a trip by Dr. John Wohlgemuth and Mr. Michael Giuliano in late May - early June 1982. Meetings were held in Vienna and Islamabad. The schedule (as reported in the first quarterly report, May - July 1982, Reference 2) was as shown in Figure 1.

Noted on the schedule are the actual times each of these key activities were accomplished or the status as of 30 November 1984.

3.0 PAKISTANI SCIENTIST TRAINING AT SOLAREX

3.1 Planning

Dr. John Wohlgemuth and Mr. Michael Giuliano visited Islamabad during the period 30 May - 3 June 1982. During this time the general schedule and scope of training were agreed upon in meetings with Dr. Atique Mufti, STDC Director and Dr. Kamal Hussain, UNDP Senior Industrial Development Field Advisor in Islamabad.

It was considered that, from the standpoint of convenience and efficiency in training, the arrival of the Pakistan trainees in the U.S.A. should be accomplished in stages with the arrival of the first trainee in August 1982. The scientists were to arrive immediately after the departure of the Director, STDC from the U.S.A. after his visit of July 1982 in connection with finalization of the equipment list. The arrival of subsequent scientists (two more plus the Director) would take place in subsequent monthly intervals. A formal lecture series would be conducted for the entire group, approximately November 1982.

FIGURE 1

SCHEDULE AND MILESTONE CHART

AS DEVELOPED AMONG SOLAREX, UNIDO, UNDP AND STDC IN JUNE 1982 (REFERENCE 1)
(Notations on chart are actual data or explanatory notes)

PROGRAM ITEM	1982 M J J A S O N D / 1983 J F M A M J J A S O N D / 1984 J F M A M
1. Visit of Solarex program manager to Pakistan	Δ (30 May-2 Jun 82)
2. Preliminary planning and equipment list	Δ (30 May-2 Jun 82)
3. Visit of Director STDC to USA to finalize equipment list	——— (August 1982)
4. First Pakistani trainee at Solarex	——— (T. Hussain - 12Oct82-4Apr83)
5. Submission of finalized list of equipment to UNIDO	Δ (10 August 1982)
6. Last date for receiving tenders by UNIDO	Δ (30 September 1982)
7. Start of construction of building (Administrative Block)	Δ (Estimate early 1984)
8. Finalization of detailed drawings for Laboratory Block	Δ (November 1982)
9. Second Pakistani trainee at Solarex	——— (K. Ahmad - 13Nov82-14May83)
10. Submission of tenders received by UNIDO to Director, STDC	Δ (19-22 October 1982)
11. Finalization and approvals of equipment list	Δ (19-22 October 1982)
12. Start of construction of laboratory wing	Δ (Estimate early 1984)

FIGURE 1 (continued)

SCHEDULE AND MILESTONE CHART

AS DEVELOPED AMONG SOLAREX, UNIDC, UNDP AND STDC IN JUNE 1982 (REFERENCE 1)
(Notations on chart are actual data or explanatory notes)

PROGRAM ITEM	1982: M J J A S O N D / 1983: J F M A M J J A S O N D / 1984: J F M A M
13. Third Pakistani trainee at Solarex	(Dr. Qazi - 30Nov82-13May83)
14. Director STDC at Solarex for finalization of equipment list	(Visit did not take place)
15. Final submission to UNIDO, Director will also stay for study tour/training	(Did not take place)
16. Arrival of equipment	(Jul83-Dec83-some later)
17. Arrival of Dr. Wohlgemuth in Pakistan to assess progress of the project	(Mr. Wrigley replaced Dr. Wohlgemuth 4 Jul 83)
18. J. Creager of Solarex in Pakistan for equipment and laboratory setup	(13 Feb - 9 Apr 84)
19. M. Giuliano of Solarex in Pakistan for solar cell design and fabrication	(Did not take place)
20. J. Hoelscher of Solarex in Pakistan for module design and fabrication	(F. Artiglier did this function 27Feb-19Mar 84
21. J. Creager of Solarex in Pakistan for continued laboratory setup and cell processing	(Did not occur but other advisors filled this function Sep-Oct 1984)
22. J. Anderson of Solarex in Pakistan for silicon purification and crystal growth	(Task was subcontracted to Battelle - Has not taken place as of Nov 1984)

Prior to this, training would be more informal, where each trainee would have an opportunity to monitor day-to-day methods and procedures in the solid state laboratory at Solarex. In this way a very detailed and practical experience would be acquired encompassing the various aspects of silicon preparation, processing for solar cells, and measurement/analysis techniques.

The formal lecture series would include aspects of silicon preparation purification and crystal growing, solar cell design, physics of operation, electrical and optical measurements, module design considerations, and systems aspects.

Return of the Pakistani scientists from the U.S.A. was scheduled on or before February/March 1983.

During a meeting in early August 1982, in which Dr. Mufti visited Solarex, the scope of the training program for Dr. Mufti and the scientists was agreed to. It consisted of the following:

GENERAL TRAINING SUGGESTED FOR ALL THE SCIENTISTS
(Including Dr. Mufti)

a.	Formal Lectures	Two weeks
b.	Silicon Growth	Three weeks (suggested places for work/visit - Solarex, Siltec; Kayex-Hamco or any other crystal growth house)
c.	Silicon Purification	Two weeks (Union Carbide, Solarex, Dow Corning, JPL or any other)

d.	Analysis of Impurities	Two weeks (Solarex, University of Maryland)
e.	Tests and Measurements	Two weeks (Solarex, JPL)
f.	Analytical Equipment Manufacturers Visit	One week (Perkin-Elmer and others)
g.	Cell Process	Two weeks (Solarex)
h.	Lamination and Encapsulation	Three weeks (Solarex)

VISITS

a. Lamar University - One Week

b. University of Maryland - One Week

c. Visits to as many places as can be arranged according to time availability (all in the United States)

1. U.S. National Bureau of Standards
2. Spire Corporation - manufacturer of equipment and modules
3. Crystal Systems - polycrystalline silicon company
4. Solar Energy Research Institute
5. Mobil Tyco - a photovoltaic manufacturer
6. Sandia National Laboratories - a U.S. Federal Contract Research Center with expertise in photovoltaics
7. Northeast Research Experiment Station - site of prototype photovoltaic systems
8. ARCO Solar - a photovoltaic manufacturer
9. Motorola - a photovoltaic manufacturer
10. Jet Propulsion Laboratory - technical advisor to U.S. Department of Energy with special expertise in photovoltaic engineering

3.2 Rationale on Training

We attempted to provide a good mix of "hands-on" experience in the laboratory as well as lecture and theory. The latter was particularly concentrated in a two week intensive seminar given at Solarex during the last two weeks in January 1983 (Figure 2).

In between the formal activities, the trainees had ample opportunity for self study and consultation with local experts at Solarex. In addition to the training at Solarex, there was local travel to places like the National Bureau of Standards, University of Maryland, and Perkin-Elmer. A short trip to Battelle Laboratories in Columbus, Ohio was taken for an orientation to the silicon purification and polycrystalline formation process.

In January 1982, Solarex became aware of budget restrictions on travel for the trainees to locations other than Solarex. Travel planning had to be revised and a substitute minimum travel plan and budget were submitted to UNIDO and STDC for approval. During this same period of time, Solarex was notified that the U.S. Department of Energy had decreed that foreign (to U.S.) nationals were not to be given any access to the various government-supported laboratories such as the Jet Propulsion Laboratory, Sandia National Laboratories, or the Solar Energy Research Institute. Plans had progressed to the point where the trainees were planning to visit all these places. Protests by Solarex were to no avail and the trainees never did get to visit these institutions.

FIGURE 2

CLASSROOM TRAINING OUTLINE

Week I - 17-21 January 1983

17	18	19	20	21
REGNAULT	REGNAULT	GIULIANO	VENDURA	WOHLGEMUTH
Silicon Reduction Silicon Purification	Crystallization Crystals Wafering	PN Junction - Physics Diffusion Length	Relationship of Crystal and PN Junction Physics to Processing	Design of STDC Solar Cell
VENDURA/GIULIANO	JOHNSON	VENDURA	WOHLGEMUTH	PETERSEN
Concept of Energy Bands Impurities Crystal Defects	Crystal Defect Analysis	PN Junction Profiles	Solar Cell Physics Conversion Eff. BSF AR Coating	Laboratory Chemistry Waste Disposal Safety

WEEK II - 24-28 January 1983

24	25	26	27	28
CULIK	CULIK	HOELSCHER	STARLEY	MCKEGG/GIBSON
I-V Character- istics Test Measurement Calibration	I-V Character- istics Test Measurement Calibration	Paneling - Electrical and Mechanical	System Sizing	Batteries General Applications of PV Systems
PETERSEN	PETERSEN	HOELSCHER/PETERSEN	PROM/VAN TILBURY	GIULIANO/HUFNAGEL
Paneling Materials	Paneling Encapsulation	Paneling Environ- mental Life Testing	System Components System Controls	Visit to Breeder WOHLGEMUTH Design and process- ing of STDC solar cells

During the negotiations among UNIDO-Vienna, STDC, the Carl Duisberg Society (the agency which administered the travel money for the trainees), and Solarex, the money for travel was not forthcoming in time for some of the trips. Solarex advanced the funds necessary for the trainees to make the trips. It should be noted that the planning, coordination, cancellations, and re-scheduling of these trips involved a significant expenditure of man hours by the Solarex staff. This magnitude of support was never programmed into the internal Solarex budget.

3.3 Actual Training Accomplished

The first three trainees had their schedule well integrated. Many of their trips were taken together. However, the late arrival of Dr. Parvez Akhter presented some scheduling problems. A summary of the actual training for each of the trainees follows:.

3.3.1 MR. TAJAMMUL HUSSAIN

12 October 82 - Arrival at Solarex

12 - 15 OCT 82

Orientation.

18 - 22 OCT 82

Cell processing laboratory; seminar at National Bureau of Standards.

25 - 29 OCT 82

Cell processing laboratory; FTIR (Fourier Transform Infra-red) seminar in Beltsville, Maryland; seminar at Solarex on crystal defect analysis; visit to Solarex Breeder plant in Frederick, Maryland for dedication ceremonies.

1 - 5 NOV 1982

Cell test and measurements; seminar by T. Ciszek of SERI (Solar Energy Research Institute) given at University of Maryland, College Park, Maryland.

8 - 12 NOV 82

Cell test and measurements.

15 - 19 NOV 82

Encapsulation and lamination.

22 - 26 NOV 82

Encapsulation and lamination.

29 NOV - 3 DEC 82

Material analysis equipment and procedures at University of Maryland.

6 - 31 DEC 82

Instruction on silicon production, purification and ingot wafering by Dr. Regnault of Semix.

3 - 7 JAN 83

Nickel plating and solder metallization technology at Solarex.

10 - 14 JAN 83

Battelle-Columbus for training in silicon purification processes, observation of equipment operation and discussions of specifics in equipment installation and facilities requirement update for STDC.

17-28 JAN 83

Two week lecture series at Solarex including trip to Breeder facility in Frederick, Maryland (Appendix B).

28 FEB 83 - 11 MAR 83

Two weeks at Kayex-Hamco for hands-on training in silicon crystal growth and ID diamond-saw wafering.

21-25 MAR 83

Two weeks at Battelle Columbus Laboratories.

29 MAR 83

Final oral review of all subjects of training with various specialists from Solarex Corporation and Semix Incorporated.

4 APR 83

Departure from Solarex.

4-9 APR 83

Visit to Elkem Spiegeviert in Norway to discuss silicon reduction from quartzite ore to metallic silicon (ready for the purification process to follow) by use of electric arc furnace.

11 APR 83

Return to Pakistan at end of six-month period in trainee fellowship.

3.3.2 MR. KHALID AHMAD

13 November 82 - Arrival at Solarex

15 - 19 NOV 82

Orientation and laboratory tours; attended seminar talks at Solarex on various aspects of solar cells and arrays.

22 - 26 NOV 82

Observation of cell processing laboratory procedures and equipment.

29 NOV - 3 DEC 82

Introduction to cell measurement and I-V curves, determination of diffusion parameters; use of microscope to observe silicon crystal defects; observed repair of filament evaporator.

6 - 10 DEC 82

Discussions with J. Creager regarding DI water system and items being provided by Solarex for the STDC Laboratory; more detailed study of diffusion parameters. Visit to University of Maryland electron microscope and x-ray analysis facility.

13 - 17 DEC 82

Photolithography of wafers; metallization - front evaporation of Ti-Pd, "lift-off" process, back surface reflector (BSR), back evaporation of Ti-Pd; metallization - silver plating.

20 - 24 DEC 82

Demonstration of the use of a monochromator in light spot analysis of solar cells; dark I-V measurements; observed technique for measurement of reflectivity and emissivity; nickel plating details; deposition of AR coating (Ta_2O_5).

27 - 31 DEC 82

Continued discussions with J. Creager regarding items for delivery to STDC; meeting with J. Hoelscher about laminator and encapsulation; instruction at Solarex on Beckman Dk-2A ratio recording spectrophotometer.

3 - 7 JAN 83

Miscellaneous training on diffusion and 4-point probe measurement; also nickel plating discussions with R. Petersen; training on quantum yield measurement using the monochrometer.

10 - 14 JAN 83

Trip to Battelle Columbus Laboratories to review process and schedules; hands-on practice of soldering of cells and interconnects in preparation for lamination.

17-28 JAN 83

Two week lecture series at Solarex including trip to Breeder facility in Frederick, Maryland.

6 - 17 FEB 83

Trip to Arizona State University (near Phoenix, Arizona) for short course and side visits to Solavolt and Photowatt (in the same area).

27 FEB -11 MAR 83

Two weeks at Kayex-Hamco (Rochester, New York) for hands-on training in silicon crystal growth and ID diamond-saw wafering.

14 MAR - 22 APR 83

Design from concept through final grid-pattern drawings for three different technologies of solar cells.

26 APR 83

Final oral review of all subjects of training with various specialists from Solarex Corporation and Semix Incorporated.

4 - 6 MAY 83

Trip to Spire, Inc. and Mobil Solar in the Boston, Massachusetts area for familiarization with ion-implantation/annealing technology and direct growth of silicon ribbon for solar cells.

14 MAY 83

Return to Pakistan at end of six-month period in trainee fellowship.

3.3.3 DR. ISHTIAQ QAZI

30 November 1982 - Arrival at Solarex

1 - 3 DEC 82

Orientation and laboratory tours at Solarex; discussions with Dr. R. Petersen on selection of analytical instruments and techniques; also electroplating.

8 - 10 DEC 82

Three day visit to University of Maryland Electron Microscope Facility and Department of Geology, observed Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM), spark cutting, Secondary Ion Mass Spectroscopy (SIMS), x-ray diffraction and x-ray fluorescence.

13 - 17 DEC 82

Detailed observation of solar cell manufacture in the Solarex R&D laboratory; initial discussions with J. Hoelscher on module fabrication; visits to National Bureau of Standards library for literature surveys.

20 - 24 DEC 82

Continued chemical processing training on etching, diffusion, Back Surface Field (BSF) formation, nickel and silver plating; also continued study of various aspects of Inductively Coupled Argon Plasma/Atomic Absorption (ICAP/AA) and Fourier Transform Infrared (FTIR) spectroscopy.

27 - 31 DEC 82

Training regarding β-ray backscatter measurements; additional library research and review.

3 - 7 JAN 83

Hands-on practice of etching silicon wafers, phosphorus diffusion and nickel plating; continued discussions with J. Hoelscher regarding module design; continued discussions with Dr. Petersen regarding the use and specification of FTIR instruments.

10 - 14 JAN 83

Visit to Battelle Columbus Laboratories to review process and system for purification and manufacture of polycrystalline silicon; meeting with sales engineers on ICAP instrumentation; visit to National Bureau of Standards Atomic Absorption Laboratory; hands-on practice of soldering to four inch solar cells.

17 - 28 JAN 83

Two week lecture series at Solarex including trip to Breeder facility in Frederick, Maryland.

27 FEB - 12 MAR 83

Trip to Kayex-Hamco, Rochester, New York for crystal growing and wafering training.

15 MAR - APR 22 83

Further discussions with R. Petersen on selection of analytical instruments and techniques; also electroplating and electroless plating. Further detailed observation of solar cell manufacture in the Solarex R&D Laboratory; further discussion with J. Hoelscher on module fabrication. Further training regarding β-ray backscatter measurements; additional library research and review.

4 - 8 MAY 83

Second visit to Battelle Columbus Laboratories to review process and system for purification and manufacture of polycrystalline silicon.

11 MAY 83

Final oral review of all subjects of training with various specialists from Solarex Corporation and Semix Incorporated.

13 MAY 83

Depart Solarex.

16 - 29 MAY 83

Stop at University of Aston, Birmingham, U.K. for two weeks on return trip to Pakistan to study x-ray diffraction, micro-probe techniques and other analytical techniques pertinent to microanalysis of solar cells.

29 MAY 83

Return to Pakistan at end of six month trainee fellowship.

3.3.4 DR. PARVEZ AKHTER

17 March 1983 - Arrival at Solarex

Dr. Akhter's late arrival presented Solarex with scheduling and logistical problems. One of the most acute was the fact that the P&D laboratory, where the other trainees did much of the cell-processing hands-on work was in the process of a major physical move. This move took longer than expected and negated any opportunity to duplicate the other three trainees' program. However, Solarex at about the same time, was establishing the cell-processing line of their new Aerospace Division. The Aerospace Division was established to make space cells for which the quality control and processing specifications are much more exacting. Dr. Akhter spent several weeks there experiencing all the day-to-day problems that are encountered in trying to make a solar cell manufacturing line operational. He worked closely with the Aerospace group in writing and refining cell processing procedures.

The two-week training session which was held for the other three trainees was not duplicated in a formal way. Rather, individual sessions were held (where possible) with the scientists or engineers at Solarex who delivered the lectures to the group the first time.

Several trips were taken by Dr. Akhter:

- <u>12 - 25 JUN 83</u>: Training visit to Arizona State University in Tempe, Arizona. Study of measurements and solar cell performance analysis under concentrated sunlight in the range from one to a few hundred times irradiance concentration, discussions of photovoltaic water pumping systems, DC to AC inverters and storage battery sizing for various irradiance conditions. Also, visits to Photowatt, Solavolt, and a U.S. Government photovoltaic system installation at Fort Huachuca, Arizona.

- 5 - 9 JUL 83: Visit to Battelle Columbus Laboratories to become familiar with operating the generation/purification system. Unfortunately, Battelle still had progressed little, but Dr. Akhter did become familiar with the portion that was operational and spent several days in discussions on design and theory of operation.

- 18 - 23 JUL 83: Training visit to Kayex-Hamco in Rochester, New York to discuss and observe operation of Czochralski silicon crystal growth, and to discuss operation of inner-diameter precision wafering machines as will be installed at the STDC.

- 1 SEP 83: Visit to Institute of Energy Conversion, University of Delaware, Newark, Delaware. In this concentrated one-day visit Dr. Akhter was given an opportunity to see state-of-the-art equipment such as glow discharge, chemical and physical vapor deposition systems to grow thin film; SEM, Auger and x-ray spectroscopy, laser scanning and spectral response systems to characterize photovoltaic materials and devices.

3.3.5 Two Week Lecture Series

The two week lecture series involved many engineers and scientists at Solarex otherwise not particularly associated with the Pakistani trainees. The schedule is shown in Figure 2. More details are in Reference 2. Notes as taken by Tajammul Hussain are in Appendix B.

3.4 General Comments About Trainee Fellowships in the U.S.

The trainees were set up in an office area where the Solarex R&D scientists and engineers had their offices. Over their six month's time in the U.S., they and many of the Solarex staff became well acquainted. In fact to this day there are personal friendships that were established with the trainees. This informal relationship helped the Pakistani scientists absorb so much material in a short time.

The trainees were allowed virtually unlimited access to the Solarex copy machines. The trainees made full use of this privilege, taking several boxes of copied reports back to Pakistan.

There was one area of administrative difficulty - the issue of proprietary data and processes. Since the contract calls for training in photovoltaic technology and the people at Solarex naturally are most familiar with the Solarex processes, it was practically impossible to separate the two.

This was handled in two ways:

1. Where the Solarex process is proprietary, such as the silicon purification and crystal formation, no detailed exposure was given to the trainees. Rather, since the Pakistanis were to use single crystal silicon, which required a fundamentally different process than Solarex uses, arrangements were made to allow the trainees to visit Kayex-Hamco, the manufacturer of equipment to be installed in Pakistan.

2. There were a few steps in the cell and module line which were proprietary. The details were not divulged to the trainees. However, they were in the same area and, consistent with Solarex policy, each of the trainees were asked to sign a non-disclosure statement, which they all did (Appendix A).

4.0 LABORATORY EQUIPMENT

4.1 Plans

Solarex's participation in the procurement of equipment began almost immediately after the award of the contract. In meetings held in Islamabad 30 May - 3 June 1982, Dr. John Wohlgemuth and Mr. Michael Giuliano of Solarex, in coordination with Dr. Mufti and Mr. Kamal Hussain (UNDP SIDFA-Islamabad), generated a list of general guidelines as to what was going to happen at the

STDC. Based on these general guidelines a generic list of equipment, supplies and tasks was generated. This is detailed in Reference 2.

When Dr. Wohlgemuth and Mr. Giuliano returned to the U.S., the Solarex staff was tasked to put together a detailed list of equipment, seek potential suppliers, and obtain the best cost estimate they could so that this could be used for budget estimating purposes.

This data was used to formulate a recommended list of equipment. In early August 1982, Dr. Mufti visited Solarex during which time this list was thoroughly discussed with him. With Dr. Mufti's concurrence, each item was prioritized as to its relative necessity. These categories were:

A Absolutely necessary.

B Absolutely necessary but due to limited funds purchase may have to be postponed.

C Required but can do without initially; later addition is strongly recommended.

D Lower priority; recommended for later.

Please see Appendix C for the entire listing.

4.2 Procurement Action

Dr. Wohlgemuth and Dr. Mufti travelled to New York on 10 and 11 August 1982 to meet with Dr. Nijhawan of UNDP, Dr. Usmani of the United Nations and Dr. Lovejoy of the United Nations. The equipment requirements for the STDC were discussed and the list of equipment developed by Dr. Mufti and Solarex was reviewed item by item. Priorities were established and it was decided to request bids only for top priority items at that time. Because of the large number of fairly small items required for the laboratory, it was decided to only request separate quotes on large capital items. The other items would be broken down into an expendable and non-expendable package for which bids would be solicited. Appendix C shows the breakdown that was approved at the New York meeting. This list was utilized by the UNIDO staff in Vienna to prepare the Request for Quotation Documents. The request for quote was issued on 25 August 1982 with a requested response date of not later than 30 September 1982 (Reference 4).

After the bids were received in Vienna, Mr. M. Giuliano of Solarex attended a meeting on 19-22 October in Vienna to assist UNIDO in proposal evaluation. Also in attendance were Dr. Mufti of STDC, Dr. Nihjawan, Dr. Usmani, Mr. Gardellin, and Ms. Koellish of the United Nations and Mr. Masihuddin of the Government of Pakistan. All of the equipment bids were reviewed and recommendations made as to which bids should be accepted. Details of the meeting are summarized in Reference 5. Briefly stated the winning proposals were as follows:

Crystal Grower	Hamco
Inner Diamater (ID) Saw	Hamco
Polysilicon Reactor Facility	Battelle-Columbus
Diffusion Furnace System	Solarex (Using Thermco Equipment)
Dual Filament Evaporator and Electron Beam Evaporator	Leybold-Heraeus
Environmental Test Chamber	Associated Environmental Systems
Laminator	Solarex
82/2 Non-Consumable Package	Solarex
82/3 Consumable Items	Solarex

NOTE: On items 82/2 and 82/3, quantities were reduced to conform to budget constraints.

Subsequently, Solarex received UNIDC Purchase Order 15-2-K0911 (Appendix D) dated 3 November 1982.

4.3 Solarex Supplied Equipment

The Government of Pakistan issued a purchase order to Solarex for package 82/2. This package consisted of items 15 to 35 on the original UNIDC list (except item 22) (Appendix E). Item 22, the deionized water system, was ordered separately from Culligan.

The Solarex staff then set about procuring the equipment represented by these two purchase orders. Where it was feasible and timely, the Pakistan trainees at Solarex were consulted about the equipment.

The equipment was assembled over a period of time, packed and actually left Solarex in May - June 1983.

4.4 Shipment Damage

Solarex was verbally notified that there was shipping damage to some of the equipment in July-August 1983. The details of the damage were not known until November 1983 when during a visit to Solarex, Dr. Mufti brought some photographs of the damage. A UNIDOGRAM dated 9 January 1984 was received by Solarex which contained a survey report by the insurance agent (Reference 6). Using this report and the photographs supplied to us by Dr. Mufti, replacement parts were ordered and dispatched to Islamabad. It was hoped that Mr. Artigliere and Mr. Creager could repair the damage during their upcoming visits to STDC.

4.4.1 EQUIPMENT AND SUPPLIES THAT SUSTAINED DAMAGE DURING SHIPMENT

- Laminator: Severe damage to vacuum manifold, vacuum motor supports were broken, temperature controller inoperable, top lid knocked out of alignment, other damage (see Reference 7 for details).

- Dicing Saw (Item 25 of Pakistan-procured equipment) was discovered to be damaged during Mr. Creager's visit (see Reference 8 for details).

- Diffusion Furnace (Item 9 of UNIDC Purchase Order 15-2-K0911) sustained some damage but Mr. Creager was able to repair sufficiently to make work.

- Polysilicon Reactor Facility sustained some shipping damage. Extent is unknown to Solarex at time of writing this report, but has been evaluated on-site by Battelle's David Seifert.

- Tempered Glass Sheets -

4 Sheets	17 1/8" x 41 5/8"	Broken
7 Sheets	17 1/4" x 11 11/16"	Broken

- One lb of aluminum paste, Item 47, was missing.

- Leybold-Heraeus vacuum system sustained some damage - repaired by Leybold-Heraeus engineer during September - October 1984.

There was another problem with the equipment Solarex shipped to Pakistan. Items:

49(f)	75 gms, ESI 6-564-350-B Solder Paste
59(n)	1 can Dow-Corning 1200 Primer

41(c)	20 ea 5' x 5' Chrome Blanks
(d)	2 gal AZ-2400 Shipley Resist
(e)	4 gal AZ-2401 Shipley Developer

were included in a carton which was to be kept refrigerated. Proper labeling or instructions were not put on the box. The perishable materials were replaced at no cost to UNIDO or the Pakistan Government.

4.5 Solarex Assistance in Obtaining Export License

There was another problem with equipment procurement which Solarex was asked to assist in resolving. It dealt with the Perkin-Elmer ICP/AA and FTIR instruments. Though these pieces of equipment were purchased separately, Solarex was apprised in early 1984 that there was a problem with the U.S. export license. After investigation in cooperation with Perkin-Elmer, STDC, and the Pakistan distributor for Perkin-Elmer, ZELIN, it was determined that early in the licensing procedure, there had been a typographical error in the license request. The abbreviation for photovoltaics, "PV" had mistakenly been typed "PU". U.S. government officials were prepared to disallow the export license. Through many meetings, telephone calls, both in the U.S. and Pakistan, the problem was finally resolved with the export license being issued.

4.6 Silicon Purification System

The contract for building one of the key components of the STDC laboratory, the silicon purification system, was awarded to Battelle-Columbus. Because of the uniqueness of this equipment, from the beginning it required special handling. These problems were compounded from Solarex's point of view because the Solarex proprietary process of producing silicon is fundamentally different from that being built by Battelle. Originally, the on-site advisor in this process was to be Dr. Jack Anderson, then later Dr. William Regnault, both of whom worked with the part of Solarex which makes silicon wafers (formerly Semix, Inc.). However, it was recognized that there would be a learning curve that even people of this stature would have to go through.

During his visit to Islamabad in July 1983, Mr. Wrigley discussed the possibility of contractually getting someone from Battelle to do this on-site training. This was agreed to in principle at that time. After a long period of negotiation about terms, a subcontract was issued from Solarex to Battelle (with the full knowledge and cooperation of UNIDO) on 17 September 1984. A separate report by Battelle will now have to be submitted to UNIDO after such effort is performed under yet a new contract.

5.0 STDC BUILDING

5.1 Planning

From the beginning of the movement to establish the Silicon Technology Development Centre, the idea of a new building to house the centre was an integral part of the plan. Solarex had a key responsibility in this regard and assisted the STDC staff, the architect, and UNIDO by giving technical advice.

During the orientation meeting in early June 1982, in which J. Wohlgemuth and M. Giuliano of Solarex participated, the baseline plan was that there was to be an administration building of 13,000 sq ft and an adjoining laboratory building of 11,000 sq ft. A tentative general layout was sketched out, which could be detailed later.

During the period June - October 1982, the laboratory layout, as portrayed during the Islamabad visit in June 1982, was changed in accordance with a new layout provided to us by the architects (Rizki and Company of Karachi). Solarex recommendations regarding room size and arrangements were changed accordingly and submitted along with detailed specifications for utility requirements of electricity, water, exhaust, drainage, etc. This was done on a laboratory by laboratory basis and included the following separate areas: a cell process laboratory, a laboratory for the purification and preparation of polysilicon, a crystal growing laboratory, a laboratory for wafering of silicon ingots, a cell and module test area, a module encapsulation laboratory and an analysis laboratory for x-ray, ICP/AA and FTIR equipment.

Details of utility requirements were based on Solarex experience as well as inputs from other equipment suppliers such as Battelle Columbus Laboratories and Kayex-Hamco who were awarded contracts to deliver equipment for silicon purification, crystal growth and wafering.

Separately, we provided additional details of construction related to installation of equipment to the architectural firm of Rizki and Company in Karachi per their request through Dr. Mufti.

These discussions culminated in the issuance of Solarex Drawing No. 1299 (two sheets) on 24 November 1982 (Appendix G). Since that time there have been many discussions with STDC about details of the building layout and utility requirements. When there were trainees at Solarex, these details were discussed with them.

5.2 Effects of Late Construction of Building

The slow pace of construction of the STDC building (discussed elsewhere in this report) was not under Solarex purview. However, it should be noted that Solarex expended considerable effort in providing advice on the equipment requirements for various temporary buildings.

For instance, in 1983, when it became obvious that the permanent building would not be finished on time, Solarex, in response to a STDC request, submitted a series of seven drawings detailing the layout and requirements for the temporary laboratory in the National Physical Sciences Laboratory building (Reference 9). These proved useless because the space depicted on these drawings was never made available to the STDC. In addition, there have been many discussions between Battelle and STDC on the requirements peculiar to their (Battelle) equipment. Solarex was only partially involved in the details of those discussions.

6.0 SOLAREX ON-SITE ADVISORS

6.1 Activity Summary

Eight different advisors spent time in Islamabad at the STDC. These people and their time in Islamabad are:

Joseph Creager	13 February - 9 April, 1984
Fiore Artigliere	27 February - 19 March, 1984
Charles Y. Wrigley, Team Leader	26 March - 10 April, 1984
Fauzia Uddin	22 April - 2 May, 1984
James F. Hoelscher	17 September - 15 October, 1984
Donald R. Warfield	24 September - 8 October, 1984
George Storti	1 October - 1 November, 1984
J. Christopher Scharf	1 October - 29 October 1984

Individual trip reports are compiled in Reference 10, copies of which were furnished to Mr. Gardellin, Dr. Stephens, and Dr. Mufti. A brief summary of their activities follow:

Mr. Joseph Creager was the first Solarex advisor to go to Pakistan (13 February - 9 April 1984). His expertise is in cell-processing equipment. At STDC, he worked with the STDC staff in setting up the basic cell processing equipment in the old National Physical Science Laboratory.

Mr. Fiore Artigliere was the second Solarex advisor in Pakistan. His time overlapped Mr. Creager, running from 27 February - 19 March 1984. Mr. Artigliere's expertise is in design of the laminator and in the laminating process itself. He repaired the laminator shipping damage and taught the STDC staff on details of module making.

Mr. Charles Y. Wrigley, the Solarex Team Leader, visited Pakistan from 26 March - 10 April 1984. Mr. Wrigley worked with Dr. Mufti, UNDP, and others to stimulate getting the facilities going. In addition, Mr. Wrigley worked with Mr. Creager and the STDC staff to commission some of the cell processing and measurement equipment.

Ms. Fauzia Uddin, an expert on diagnostic and measurement equipment, visited STDC during the period 22 April - 2 May 1984. She worked with the STDC staff on spectral response measuring equipment and the betascope. She was also present when the equipment was moved from the National Physical Science Laboratory to the second temporary building.

Mr. James Hoelscher, whose expertise is encapsulation, module, and system design, visited STDC during the period 17 September - 15 October 1984. Mr. Hoelscher delivered lectures on encapsulation and module design and worked with the STDC staff in developing a unique module and systems design. Several modules were fabricated.

Mr. Donald Warfield, whose expertise is in cell processing equipment and procedures, visited STDC from 24 September - 8 October 1984. He worked with the STDC staff in setting up detailed cell processing procedures and resolved several equipment problems that had been plaguing the STDC staff.

Dr. George Storti, whose expertise is in photovoltaics physics, visited Islamabad during the period 1 October - 1 November 1984. He worked with the STDC staff in integrating the solar cell equipment, especially the titanium-palladium silver metallization system and the Leybold-Heraeus antireflective coating equipment into a functioning cell laboratory.

Mr. J. Christopher Scharf's expertise is in cell processing procedures and equipment. He worked with Mr. Warfield, Dr. Storti, and the STDC staff in integrating the various cell-processing steps. He visited Islamabad from 1 - 29 October 1984.

6.2 Problems Associated With On-Site Training Program

A common problem existed for all the Solarex on-site advisors - the delay and in some cases inoperability of key pieces of equipment. Much of Mr. Creager's and Mr. Artigliere's time in February - April 1984 was spent repairing or installing equipment - in effect taking away time that could have been used in training. Only in September/ October 1984, when the last four Solarex advisors were in Islamabad, were the two Leybold-Heraeus vacuum deposition systems commissioned (affording the on-site advisors only a small amount of time to use the equipment). The Kayex crystal puller and wafering saw, and the Tempress-Micro-automation dicing saw were never operational. Although some on-site training was accomplished, it certainly was not as much as could have been done had all the equipment been commissioned on schedule. It is a tribute to the resourcefulness of the advisors and the STDC staff that they were able to get as much training done as they did.

There were other problems. The STDC policy of giving everyone the same training (regardless of speciality, experience, or capability) proved to be very difficult to impossible to accomplish. Attendance of the staff was sporadic. If there had been a few key people identified for each operation, much more useful training could have been given. In addition, activity at the laboratory was subject to interruption from tours and other visitors.

7.0 A VIEW OF THE PROGRAM FROM THE SOLAREX PERSPECTIVE

The Solarex Corporation has been proud to serve as the technical advising company for the establishment of the Pakistan National Institute of Silicon Technology. All of the people at Solarex who have worked with the various facets of this project wish fervently that all of the ideals espoused in the objectives could one day be realized. However, from the view of Solarex management, the minimum capability that STDC now possesses has come at a heavy penalty - both financially and risk of reputation. The following section is a frank discussion of some of the problems encountered by Solarex on this project. Section 8 gives recommendations for other projects should the UNIDO be so inclined.

7.1 Solarex Objectives

When Solarex entered into this contract in 1982, the company inducement centered around the following potential benefits:

- Expectation that Solarex could do the job and enhance its reputation.

- Exposure of Solarex to the United Nations for possible future efforts patterned along the lines of the Pakistan effort.

- Expectation of a reasonable profit, though it was recognized from the outset that this was a high risk endeavor.

- Favorable company exposure in Pakistan, which is a country with significant photovoltaics business potential.

7.2 General Delays

Almost from the outset, there were delays. The first three Pakistan trainees arrived later than originally planned. Dr. Mufti's visit in which he was to participate in training with the rest of the scientists never did take place. The fourth trainee arrived four months later than predicted. Because the trainees worked side-by-side with Solarex R&D and production personnel, this made for a significant problem in coordinating activities with the trainees and the normal activities at Solarex.

7.3 Building Delays

The most disheartening phase of the entire program, however, was the pace at which the facility in Islamabad progressed. Originally, the schedule called for the building being completed at about the same time the trainees were to complete their training in the U.S.A. However, as of the date of this report, the completion is still in the future. This has had all sorts of reprecussions: A series of "temporary" facilities were devised, which initially were to be only for equipment proofing but eventually prevented the Solarex on-site advisors from doing what they were supposed to. Even the temporary equipment installations were far delayed. Plans were made to schedule advisors, then had to be rescheduled (sometimes several times). Since all of the advisors had other full time jobs at Solarex, this presented tremendous coordination problems.

Indeed the program stretched out so long that many of the Solarex principals involved in establishing the program are no longer with the company. The two people who signed the proposal documents for Solarex, Dr. Lindmayer (President), and Dr. Wohlgemuth (Team Leader), are no longer in their previous positions. Of the six people listed on the original contract as key people, only Dr. R. Petersen and Mr. D. Warfield are still with the company. These changes come about for a variety of reasons (not untypical for an American high-technology company). However, it should be noted that the replacement people were as qualified or better suited to their respective specialties as were the original people.

7.4 Contract Extension

During Mr. Wrigley's visit to Islamabad in March/April 1984, it became obvious that by the contractual deadline of May 1984, there was no hope of effectively using the rescheduled services of the Solarex advisors on-site. The contract end date was extended at the suggestion of Mr. Wrigley to November 1984 at no cost to the United Nations or Pakistan. This was done despite the fact that this inevitably meant people at Solarex headquarters would spend more time and further internally overrun the budget for this project. It was, however, understood that STDC would be ready to run the rest of the equipment (other than Battelle's) in June 1984.

7.5 Slow Progress in Summer 1984

There seemed to be a general lack of progress in the Summer of 1984 on the part of the Pakistanis. For instance, from April 1984 when Mr. Creager left Islamabad to September 1984 when the first of the last four Solarex advisors arrived, not much had really been accomplished in getting up the equipment. True, it was set up in the second "temporary" building, which took some effort pushing the bureaucracy.

7.6 Problems in Getting the Right Supplies to the Right People

It was observed by all the on-site advisors that there was simply not enough basic material - cells, silicon wafers, processing chemicals, expendible supplies, and tools - to actually do much research. Furthermore, the administrative controls over these supplies were such as to almost prevent anything from being done, perhaps engendered by fears of inappropriate unauthorized use. Numerous other practices were noted by the advisors that made for aggravating delays.

7.7 Objections of the STDC Director

During the visit of the last four Solarex advisors in September and October 1984, Dr. Mufti repeatedly expressed his displeasure at Solarex performance. His specific objections centered around a number of issues, which were unfortunately really a result of the delays which hampered all parties to the point where only a "time-remaining" attempt could be made to complete some activities.

7.8 Solarex Position on STDC Director's Objections

As to the qualifications of the on-site advisors, Solarex stands by their qualifications.

- Mr. J. Creager has started several cell lines at Solarex. Further, because of the equipment damage and the fact that the necessary plumbing, electrical, and physical facilities were delayed past the start of his visit, Mr. Creager did an outstanding job in getting results.

- Mr. F. Artigliere designed, initiated the contract for fabrication, assembled, and checked out the laminator prior to it leaving Solarex. He has done the same thing for four other laminators built for use at Solarex. Since the laminator was nearly destroyed in shipment, perhaps Mr. Artigliere was the one person on earth who could effectively put the machine back together again. He would have been perfectly justified to declare the laminator damaged beyond repair and wait another six months for the insurance to clear and have another machine delivered. The fact that he made the machine work with repair equipment is a tribute to his ingenuity. The fact that he left earlier than planned was a result of a replacement pump being held up in Customs (Reference 7).

- Ms. F. Uddin was in Pakistan for a very limited purpose - to assist the STDC staff in using spectral response equipment and betascope instruments. Using these instruments was her job at Solarex. She was the best person for that particular task. She had another asset, she is a native of Pakistan and speaks Urdu as a mother language.

- Mr. C. Wrigley is the senior research and development person at Solarex. Along with wide-ranging experience in solar cell research, Mr. Wrigley is a Vice President at Solarex. Part of his responsibility is the laboratory, after which much of the STDC equipment and processes are patterned. The fact that this program was taken on by an officer is an indication of the corporate support that this project had at Solarex.

- Mr. J. Hoelscher has managed a number of development programs at Solarex which involved new module technology - including the development of lamination technology. He most recently was a project manager in the Solarex systems group and was one of the people who taught the Pakistani scientists when they were at Solarex.

- Mr. D. Warfield has extensive experience in setting up a number of solar cell manufacturing lines and laboratory operations - exactly what he attempted to do at STDC.

- Dr. G. Storti is one of the foremost photovoltaic physicists. That we were able to get him at all was a stroke of timing luck. He simply was not available another time.

- Mr. C. Scharf assisted Dr. Storti and finished out the work started by Mr. Warfield. He has experience in the Solarex R&D laboratory fabricating cells - the same thing he did at STDC.

7.9 Expiration of Contract

Solarex fully understands that the STDC is not yet fully operational and that there is still much work to be done. The decision not to extend the contract a second time was primarily a timing and cost decision. Solarex had already overspent its budget and any further activity would have made that situation worse.

8.0 RECOMMENDATIONS FOR FURTHER ACTION BY UNIDO AND/OR THE GOVERNMENT

1. The most urgent requirement - expedite action to complete the permanent building.

2. In the short term, a senior technical advisor/consultant should be retained to work on-site with STDC for an additional six weeks to two months in order to consolidate gains already made and to complete all the work associated with cell fabrication.

3. For the long term, an expert advisor in photovoltaics should be engaged once or twice yearly for approximately one week at a time to review STDC activities and provide advice for future activities.

4. Introduce a system so that the hands-on technicians and scientists have proper equipment and supplies (and enough) consistent with their jobs.

5. At all levels strive to meet schedules.

6. In the near term, continue direct negotiations with Battelle, Kayex, and Leybold-Heraeus to make absolutely sure that a capability to use their respective equipment is retained by the STDC staff.

7. Resolve the various insurance claims resulting from shipping damage.

8.1 Other U.N. Efforts of a Similar Nature

During the pre-contractual period, there were informal discussions that this project in Pakistan might be the precursor to other similar endeavors in other developing countries. Solarex does not know how this thought has progressed in UNIDO, but from a perspective of a supplier of goods and services associated with the Pakistan job, we offer these recommendations.

1. First and foremost - the contract should have clear language that if the project is delayed due to no fault of the contractor, there should be a recognition of that by UNIDO in the form of renegotiating the terms of the contract. It should be clearly understood that the dynamic nature of high technology business in the eighties in the industrialized world makes keeping a team together very long extremely difficult.

2. The host government at all levels should strive to meet UNIDO schedules. Unrealistic schedules should never be allowed to formalize.

3. There should be a clear understanding by all parties of the nature of an on-site advisor. The advisor <u>advises</u>. He (or she) does <u>not</u> direct people in the organization; does <u>not</u>

make policy decisions regarding use of the host organization human or material resources; and does not set priorities for the organization. The advisor is not in the chain of command.

4. There should be a clear chain of command in the host organization such that if the No. 1 person is unavailable, there is someone else delegated who has the authority, responsibility, and initiative to get on with the program.

9.0 CONCLUSIONS

1. The STDC has the capability to fabricate solar cells from the silicon wafer stage through module fabrication.

2. The STDC has the capability to make solar cells using two different metallization methods: nickel solder and titanium-palladium-silver.

3. No training was given on-site in the use of the following equipment because it was not operational:

   - Silicon purification equipment
   - Dicing saw
   - Inner-diameter saw
   - Silicon crystal growing equipment

4. STDC has a minimum capability to use the Leybold-Heraeus vacuum deposition equipment. Key people should be sent to the Leybold-Heraeus factory in Germany for further training.

5. Delay in completing the laboratory building in Islamabad has been a severe detriment to the project.

6. Four Pakistani scientists completed training in the U.S. and learned a great deal. If they retain what they learned and teach others, the STDC ideals should be realized.

7. The stretch-out of the facility and equipment installation program had a detrimental effect on the effectiveness of the Solarex on-site training. It prevented Solarex from sending the appropriate number of on-site advisors in a timely fashion.

8. Because of the delay in the program, and the lack of confidence that the situation would quickly get better, Solarex management did not extend its contractual on-site date beyond November 1984.

9. Equipment has been ordered or is on hand to produce small photovoltaic systems starting with metallurgical grade silicon.

REFERENCES

1. UNIDO Contract No. 82/18, 7 May 1982.

2. Solarex Quarterly Report No. 1, May - July 1982.

3. Solarex Quarterly Report No. 3, November 1982 - January 1983.

4. UNIDO Request for Proposal for ST/PAK/80/T01 Dated 25 August 1982.

5. Solarex Quarterly Report No. 2, August - October 1982.

6. UNIDOGRAM, Signed by D. Gardellin, 9 January 1984.

7. Activity Report - Fiore Artigliere, 27 February - 19 March 1984 at STDC.

8. Activity Report - Joseph Creager, 13 February - 9 April 1984 at STDC.

9. STDC Laboratory Floor Plan, Solarex Drawing No. C-10553-00, 7 Sheets, 18 October 1983.

10. Solarex Letter to Mr. D. Gardellin which contained Solarex on-site advisors' trip report, 8 November 1984.

11. National Institute of Technology letter to Dr. Storti, 25 October 1984.

12. Activity Report - James F. Hoelscher, 17 September - 15 October 1984 at STDC.

13. Activity Report - Donald R. Warfield, 24 September - 8 October 1984.

14. Activity Report - J. Christopher Scharf, 1 - 29 October 1984.

APPENDIX A

CONFIDENTIALITY AGREEMENT

CONFIDENTIALITY AGREEMENT

Solarex is pleased to have the opportunity of training you in the design and fabrication of solar cells and modules, including some aspects of silicon purification, crystal growth and slicing.

Since you may encounter equipment and methods that are proprietary to Solarex and Semix, your agreement will be necessary to maintain confidential and proprietary all information regarding the equipment, methods and products utilized in our research and development and production facilities unless such information is already contained in patents or printed publications or becomes so in the future. Moreover, you will be notified of some particular areas, equipments or processes to which you will not have access because of their particularly proprietary nature. This will not have any adverse effect on your training program. It involves information which can only be divulged under specific licensing agreements.

The information to which you will have access will enable you to completely process solar cells and modules according to well established techniques, as well as some developmental processes. In the area of crystal growth, slicing, and silicon purification, Solarex and Semix will make every effort to provide you with basic knowledge and practical experience to the extent that Solarex and Semix (a) are actively involved in that process and (b) the process does not involve Solarex or Semix trade secrets. Where Solarex/Semix cannot provide information, every effort will be made to arrange trips to other laboratories where additional information may be obtained.

It is understood that the information intentionally provided to you by Solarex/Semix is for the purpose of implementation of the Silicon Technology Development Centre. However, any proprietary information encountered at Solarex or Semix is not to be released to any third parties unless it has already been published or has been obtained from an independent source. At the end of your stay at Solarex you will have a briefing with Solarex and Semix technical personnel which will serve to point out those topics considered to be proprietary information.

We thank you for respecting the rights of Solarex/Semix. Your signature after the words "Agreed to and accepted" will indicate that you will be bound by the terms of this confidentiality agreement.

SOLAREX CORPORATION

BY:____________________________

TITLE:___________________________

DATE:____________________________

Agreed to and accepted

BY:____________________________

____

DATE:____________________________

SEMIX INCORPORATED

BY:____________________________

TITLE:___________________________

DATE:____________________________

APPENDIX B

TRAINING REPORT ON TWO-WEEK LECTURE SERIES AT SOLAREX

17 - 28 JANUARY 1983

BY TAJAMMUL HUSSAIN

Appendix B

TRAINING REPORT by T. Hussain

PERIOD: 17-1-83 to 28-1-83
TITLE: Two-Week Lecture Series

The lectures were delivered by various speakers from Solarex on different topics. The schedule of these lectures is attached herewith. There were two sessions daily from 9:30 AM to 12:00 noon and from 3:00 PM to 5:30 PM.

Brief summaries of these lectures are as follows:

Jan. 17, 1983 - A.M.

a. Production of Metallurgical Grade Silicon

Dr. Bill Regnault delivered a lecture on the production of MG-silicon from quartz or quartzite using charcoal or wood chips as reducing agent in the arc furnace. An arc is produced in the furnace at low voltage and high current to dissipate maximum heat from the arc in the furnace. Material graded in size is fed from the top of the furnace.

The following reaction takes place during smelting in the arc furnace.

1. $2SiO_2 + 4C = SiC + SiO + 3O$
2. $2C + SiO = SiC + CO$
3. $SiC + 2SiO_2 = 3SiO + CO$
4. $2SiO = Si + SiO_2$
5. $SiO + O_2 = 2SiO_2$ - Reaction occurs at the surface of the molten metal.

Metallurgical grade silicon is tapped from a hole and casted.

Dow Corning is developing this process to produce solar grade silicon by initially using high grade (quality) raw materials such as quartz and black carbon or petroleum coke.

b. Purification of MG-silicon to Poly-silicon Siemens Process

This basic process with modifications is being used by various companies. The basic process is composed of:

i. Generation of Chlorosilanes:
$HCl(g) + \text{MG-silicon} = SiCL_4 + SiHCl_3 + SiH_2Cl_2 + \text{Heavies}.$

ii. Distillation:
Generally, three columns are used in fractional distillation to separate tri-dichlorosilane from $SiCl_4$, SiH_2Cl_2 and metal chlorides, etc.

iii. Decomposition of Trichlorosilane:

A reactor composed of a 1/4" diameter silicon rod is used and it is resistance heated by connecting to a power supply. Trichlorosilane (TCS) is decomposed and silicon is deposited on this rod.

$$4SiHCl_3 \xrightarrow[H_2(g)]{1000\text{-}1100^{\circ}C} 3SiCl_4 + Si + H_2(g)$$

Jan. 17, 1983 - P.M.

Dr. George Vendura discussed band theory relating to silicon solar cells; giving a brief description of mobility and diffusion length. Mr. Mike Giuliano discussed the effects of deep lying traps and impurities. Then Dr. Vendura discussed crystal imperfections:

i. Point defect: a) vacancy, b) interstitial, c) substitutional

ii. Line defect: a) edge dislocation, b) screw dislocation, c) combination of both.

Jan. 18, 1983 - A.M.

The lecture was delivered on crystal growth by Dr. William Regnault. He discussed the following points:

Crystal Growth
- i. Growth from melt
- ii. Growth from solution
- iii. Growth from solids

He then elaborated on crystal growth based on the Bridgeman technique (crystal grown in a container) and Czochralski technique (crystal pulled from the container).

Then he discussed wafering technologies, classifying them as:

i. Slurry (MBS and wire saw)
ii. Fixed abrasive technique (ID and wire (fast))

Internal diameter (ID) is a promising technique as it is high speed and automatable.

Jan. 18, 1983 - P.M.

In the afternoon, Mr. Scott Johnson delivered a lecture on crystallography stressing the types of defects in silicon crystal. He briefly described X-ray diffraction and preferential etching techniques to study defects in semicrystalline material.

Jan. 19, 1983 - A.M. and P.M.

1. Dr. George Vendura delivered a lecture on theoretical aspects of P-N junction formation, methods to form P-N junctions and application to solar cells.

2. Mr. Mike Giuliano discussed the physics of P-N junctions and elaborated some basic definitions of (i) diffusion length, (ii) lifetime of carriers, (iii) saturation current

Jan. 20, 1983 - A.M.

Dr. George Vendura discussed various preferential etching systems as microstructural examination tools and also discussed the various steps in cell processing to form P-N junctions. Laboratory conditions were discussed, stressing the need for cleanliness and necessary documentation for research records.

Jan. 20, 1983 - P.M.

Dr. John Wohlgemuth discussed solar cell physics covering the following topics:

i. Cell performance
ii. Solar cells and optics
iii. Physics of solar cells and electron-hole pair production
iv. Bulk recombination
v. Back surface field
vi. Back surface recombination
vii. Front surface recombination

Jan. 21, 1983

Dr. J. Wohlgemuth delivered a lecture on the design of solar cells covering the following topics:

i. Design of grid line pattern and bus-bars, considering (a) shadowing loss, and (b) metal resistance losses
ii. Quantum yield

This lecture was lengthy and very informative but could not be covered in a single session, so it was decided that Dr. Wohlgemuth would deliver another lecture in the final session of the series.

Jan. 24, 1983 - A.M.

Mr. Jerry Culik presented a solar cell model as an electronic device and described the various electrical characteristics of the solar cell and their significance. He discussed light and dark I-V curves, shunt resistance, series resistance, fill factor and efficiency of solar cells.

Jan. 24, 1983 - P.M.

Dr. Ray Petersen gave a lecture on "Paneling Materials." He discussed various materials as encapsulants, adhesives, primers, substrates and superstrates; then, encapsulation processes of (a) silicone casting process and (b) EVA lamination proce s. The EVA lamination process is cost effective and will be available in the STDC laboratory.

Jan. 25, 1983 -A.M. - Tests and Measurement - Mr. J. Culik

Testing of solar cells was explained and interpretation of data was discussed under the following topics:

1. I-V curve analysis
2. Dark I-V curve analysis
3. Saturation current
4. Reference cell and its calibration method

Air mass number was explained as the optical path length (in the atmosphere) that sunlight must travel to reach the measured surface.

AM0	above the atmosphere
AM1	earth's surface (normal incidence)
AM1.5	earth's surface at $\theta = 48^{o}$
AM2	earth's surface at $\theta = 60^{o}$

We discussed testing under steady state xenon and pulsed xenon simulators and compared this with actual testing under the sun.

Special note:

A precision spectral pyranometer is essential for the STDC laboratory to calibrate its own reference cells as a secondary standard. This was not included in the original list of equipment as a priority item.

Jan. 25, 1983 - P.M.

Dr. Ray Petersen discussed the silicone casting process and the EVA lamination process in detail.

Jan. 26, 1983 - A.M. and P.M. - Module Design and Testing - Mr. Jim Hoelscher

Design of modules was discussed from two aspects - electrical and mechanical. Design aspects were discussed from the standpoint of output power, minimum loss and durability to exposure to the atmosphere.

The following environment test can be conducted to ensure durability:

i. Thermal cycle test (+90°C to - 40°C)
ii. Humidity test at 80% RH (+85°C to -4°C)
iii. Mechanical loading
iv. Hail test
v. Hi-Pot test
vi. Hot spot test
vii. Temperature co-efficient

In the afternoon lecture, Hoelscher discussd the details of the above aspects including design and the problems encountered in practice.

Jan. 27, 1983 - A.M. - System Sizing - Mr. Dan Starley

Mr. Dan Starly lectured on power system sizing or estimating a power system for the requirements of a customer and for the environmental conditions. He illustrated with a model system to help in understanding of system sizing.

Jan. 27, 1983 - P.M. - Power Conditioning - Mr. Jack Van Tilling

To maintain a proper supply of power from the array to the battery system and load, two types of regulators are being used (1) series regulators and (2) shunt power regulators. Basic principles for these regulators were discussed.

Power Conditioning Unit (PCU) - Mr. Saunora Prom

Mr. Prom described a power conditioning unit, various kinds and their application to photovoltaic power systems.

Jan. 28, 1983 - AM

1. Battery Storage Systems - Mr. Alfred McKegg

   There are two types of battery systems available on the market, (1) automotive battery and (2) stationary battery. Low cycle and deep cycle batteries were explained. Deep cycle batteries are useful for photovoltaic power systems due to longer life and high storage of current. These kinds of batteries are being used in telephone and marine applications where a continuous current is required from the battery.

2. Examples of Power Systems - Mr. Roy Gibson

   Mr. Roy Gibson is in charge of contract management and system support. He described small power systems being built by Solarex.

   At noon, we went to visit the Breeder Plant in Frederick, Maryland, which is designed to produce 200kw of power at 300V. This power is being used in the same building to provide all the power needs to manufacture solar cells and panels as well as provide for heat and light in the building. There is no connection with a utility grid.

APPENDIX C

RECOMMENDED LIST OF EQUIPMENT FOR STDC, PAKISTAN

RECOMMENDED LIST OF EQUIPMENT FOR STDC, PAKISTAN

KEY TO THE ABBREVIATIONS:

Q - Quotes

C - Catalog

R - Ready Stock: These items have to be purchased in bulk which may not be needed at the start of the project. However, Solarex can give a small amount of these items from its ready stock.

P - Pakistan Local

A - Absolutely necessary.

B - Absolutely necessary but due to limited funds purchase may have to be postponed. (Category changed to A_2 in the meeting with UNIDO officials on 10-8-82 at New York).

C - Required but can do without initially; later addition is strongly recommended.

D - Lower priority; recommended for later.

* - Duplicate listing

+ - Expendable

1. Dr. John Wohlgemuth
Solarex Team Leader to STDC

2. Dr. Atique Mufti
Director Silicon Tech Dev Centre, Pakistan

DATE: 9.8.82

THIS LIST CONSISTS OF SIX PARTS AND TWENTY THREE PAGES

S/N	ITEM	PURCH RECOM	PRIORITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
1-1	Cz Crystal Grower	Q	A_1		$155K	Capable of at least 4" Ingots (Cz)	Siltec Kayex-Hamco	Model 860D up to 6" ingots 18 Kg capacity Model CG800 up to 4" ingots 8 Kg capacity
1-2	Crucibles for Crystal Grower (25)	Q	A_1		3,000	Depedent on crystal grower	Thermal American Fused Quartz Quartz International	Needs drawing before quote
1-3	Polysilicon (300 Kg)	Q	A_1	18,000		300 Kg Semiconductor Grade	Hemlock Wacker Smiel General Electric	
1-4	Cylindrical Grinder	Q	C		$ 80K	Capable of handling up to 4" ingots	Siltec	Model 540
1-5	ID Saw	Q	A_1		$ 80K	Capable of cutting 4" round or square ingots	Meyer & Burger AG Kayex-Capco STC	TS 23-22" (Capable to 27") 700 - 22", 700B - 27" 22" 27" has recovery system
1-6	Chemical Hood	Q	C		$ 5.5K	6"	Semifab, Inc.	
1-7	Arc Furnace	Q	D		$ 1.2M	150 KVA silicon metal arc furnace with all supporting equipment. (Baghouse filters, transformers, control panel, pelletizer, motor-generator, electrodes, ladders, & walkways, etc.)	Lectromelt Elkem Demag Semix	Suggest one company be given general contract for purchase, installation, and run up of facility. (Existing facility.)

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
1-8	Laboratory Ball Mill	P(C)	A_2	$800				Necessary to grind met-grade silicon, could be eliminated if ground silicon is obtained such as Silso.
1-9	Grinding Jars	P(C)	A_2	$800 Each		2 needed, 2-2 1/2 Gal		
1-10	Procelain balls	P(C)	A_2	$ 10/Lb		1" Balls		
1-11	THE FOLLOWING IS A LIST OF SMALL ITEMS NECESSARY FOR THE PURUFICATION AND PRODUCTION OF $SiHCl_3$. THEY SHOULD ALL BE OBTAINABLE IN PAKISTAN FROM A CHEMICAL SUPPLY HOUSE.							
a)	Heating Mantle	P	A_1		$ 5,000	Capable of 650°C (2 needed)		
b)	Boiling Flasks	P	A_1			Box of 10		
c)	Distillation Column	P	A_1					
d)	Miscellaneous Tubing	P	A_1					
1-12	Silicon Reactor	Q	A_1		$70K	Custom designed unit for laboratory use only capable of 1Kg/Day	Lamar University	
1-13	Casting Station	Q	D			Solarex Proprietary Process - Subject to negotiations and License fees or Crystal Systems		

Analysis

S/N	ITEM	PURCH RECOM	PRIORITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
2-1	Beta-Ray Back-Scatter	Q	A_1		6,000	Twin Cities TC-1500 with voltage regulator, TC-PCP probe and low power radiation source.	Twin Cities International (UPA Technology has equivalent)	For measuring metallization thickness on cells.
2-2	pH Meter	P	A_1		600	Laboratory Quality pH Meter	Numerous supply houses	For measuring acidity of various chemical solutions.
2-3	ICP/AA Spectrometer	Q	A_1		97,500	Atomic Spectrophotometer incorporating flame and furnace atomic absorption techniques with inductively coupled plasma emission technique. Perkin-Elmer ICP/550 or equivalent.	Perkin-Elmer Corporation	For elemental analyses (primarily metals) in silicon.
2-4	FTIR and Accessories	Q	A_2		46,250	Fourier Transform Infra-Red Spectrophotometer and associated computer and accessories for determining carbon and oxygen content of silicon and epitaxial layer thicknesses.	Perkin-Elmer Corporation (Nicolet offers FTIR in a higher price class ~ $180,000). Digilab is another FTIR supplier.	Most common uses are for measuring carbon and oxygen concentrations in silicon and epitaxial layer thicknesses. Sometimes used for determining boron concentration and characterizing oxygen precipitates in silicon.
2-5	X-Ray Fluorescence	Q	A_1		95,000	Laboratory type automated x-ray fluorescence analyzer equipped to handle wafers up to six-inch diameter. Kevex Model 0700 or equivalent.	Kevex Corporation; EG&G Ortec; Princeton Gramma-Tech	Elemental analyses of dopants and impurities in silicon (for atomic number of 11 or greater). Phosphorus in phosphorus-doped films. Thicknesses of deposited thin films.
2-6	Laboratory Balances	P	A_1		2,000			

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
2-7	X-Ray Diffraction Equipment	Q	A1		50,000			
2-8	Mass Spectraphoto-meter	Q	D					
2-9	X-Ray Photoelectron Spectrometer	Q	D					

Cell Process

S/N	ITEM	PURCH RECOM	PRIORITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-1	Diffusion furnace 1 ea	Q	A_1		$21,525	3 tube, 6 inch diameter Thermco Model 3103 (Quote PR1177)	Thermoc Products Corporation Lindberg	
3-2	Laminar flow hood ✓ station - 1 ea	Q	C		5,050	To fit 3-1	See 3-1	
3-3	Screen printer - 1 ea 1 optional	Q Q	A_1 A_2		9,500 13,750	8"x10" screen - Presco Model 462 deHaart Model AOL-12	Affiliated Manufacturers, Inc. deHaart, Inc.	
3-4	Automatic screen 1 ea - Printer	Q	D		24,900 18,500	Presco 885 deHaart Model AOL-12-SE	See 3-3	
3-5	Screens - 10 ea	Q	A_1	3,335		Artwork and silk screens 8" x 10" frame (9776) to fit 3-3, 3-4. Stainless steel 90° 250 mesh, 150 mesh .001 inch emulsion, .0016 inch wire	See 3-3	150 mesh for Al artwork is $300 then each screen is $30. Patterns generated by Pakistan Local
3-5 A	Solvents			2,000				
3-6	Chemical hood 3 ea 2 in Pakistan	Q P	A_1 A_1		16,500 (Total)	Semifab Model SLFH/600 - 6 foot Item 2 on Quote 11013	Semifab, Inc.	? Pakistan Local
3-7	Diffusion Tube Cleaning hood - 1 ea	Q	C		7,310	Semifab Model reference	See 3-6	If no - get 1 each 8 foot 3-6.
3-8	Etch tank, covers 4 ea	P	A_1		130 (Total)	Stainle-s steel tanks - diameter >21 cm. Cole Parmer Model C-7206-80, C-7207-80.	Cole Parmer Instrument Co.	

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-9	Etch System	Q	D		5,090	a) Semifab hood with etch cutout #SLFH/600, 6' - like tab 1549-1 Quote 11013	See 3-6	
		C	D		700	b) Stainless steel tank w/2 1/2" FPT connectors Solarex design	Polyfab Corporation	
		C	D		100 (Total)	c) Ball valve, 1" stainless steel - #11-3600MT - 2 each	McArdle Desco	
		C	D		1,300 (Total)	d) Heating elements - 2 each 240V Ø 4.5 KW #MTS-345A stainless steel	Faber Renhoff	
		C	D		500 (Total)	e) Analog set point proportioning controller - Model 49 - J range o-200°C - 2 each Power 220V 50 Hz	Love Controls Corporation	
		C	D		25	f) Thermocouple - 2 each #1518-1, Type J, 4 ft	See 3-9E	
3-10	Hot plate - 6 ea	C	A1		1,130 (Total)	Ceramic top, stirr ; hot plate - 500°C, Corning #PC_1 - 4 ea, Corning #PC101 - 2 ea.	Fisher Scientific Company	? Pakistan Local
3-11	Silver plating system - 1 ea	Q	A1		1,125	a) Spray rinse tank and sink #P3024SD18	HBS Equipment Company	
					60	b) Footswitch #FC-FOV-50		
					300	c) Tank w/stainless steel anode bars with lid #TH25A		
					380	d) Filter housing #FCHT3 10		

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-11 (cont)	Silver plating system - 1 ea			200		e) Filter to fit 3-11d		
					160	f) Agitation tubing to fit 3-11c		
					500	g) Pump - Marathon - S2P81366V		
					755	h) Exhaust hood polypropylene 72" to fit 3-11a		
	Plating System Total			$200	$3,280			
3-12	Plating racks for silver plate 6 ea	C	A_1	420		Plating racks for nine each 4" silicon wafers	Tilton Rack and Basket	
3-13	Power supply for plating - 2 ea	P	A_1		1,000	Regulated power supply 0-20V, 0-3A Lambda #LF521FM Hewlett Packard #C284A	Lambda Electronics Hewlett Packard Company	
3-14	Belt Furnace - 1 ea	C	C		25,000	Metal muffler belt furnace 6" belt, 6' hot zone BTU #TFMC2578N36 Tempress #820 Watkins Johnson #6CM-77	BTU Engineering Corporation Tempress Watkins Johnson Company	
3-15	Small belt furnaces	Q	C		13,000	Metal muffler belt furnace 6" belt, 3' hot zone Watkins Johnson Model #6CM-39	See 3-14	Compare to ovens
3-16	Laboratory tanks	C	A_1		495	Molded rectangular tanks - Fluoroware Model, 2 ea E3201 Teflon, 2 ea E3202 cover, 10 ea RE3201 Polypro, 10 ea PE3202 cover	Fluoroware	

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-17	Wafer cassettes	C	A_1		542	Wafer cassettes - Fluoroware model 6 ea A7240B teflon, 12 ea PA7240B poly, 6 ea A027, Handle PFA, 12 ea PA027, 18 ea A72-20-02	See 3-16	
3-18	Cascade rinse tanks 3 ea	C	A_1		720	Cascade rinse tank Fluoroware model E-64	See 3-16	
3-19	Spin dryer - 2 ea	Q	A_1		7,540 (Total)	Spin rinser dryer w/turntable frame for 4" wafers; 220V power, FSI#K120 Quote 3206RE	FSI Corporation	
3-20	Spin dryer accessories - 2 ea	Q	C		2,949	Accessories, spare parts for 3-19	See 3-19	
3-21	Self cleaning dryer - 2 ea	Q	D		8,800	Self cleaning spin rinser dryer w/turntable for 4" wafers; 220V power, FSI #8221, Quote 3210RE	See 3-19	
3-22	Self cleaning spin dryer accessories	Q	C		3,329	Accessories, spare parts for 3-21	See 3-19	
3-23	DI water system	Q	A_1		24,500	Dionizing water system - self regenerating - 3-10 gallons per minute, 8-10 meg ohm.	Culligan USA Culligan Pakistan	
3-23A	Chemicals		A_1	1000				
3-24	Filament Evaporator	Q	A_1		84,000	Airco Temescal Evaporator #BJD1800 with two filament sources with shutters, 2 2KVA power supplies, 2 Inficon XTM monitors, fixturing. Quote Q2440-619	Airco Temescal	
						Vecco 7760 integrated filament evaporator.	Vecco Industrial Equipment Division	

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-25	E Beam Evaporator System	Q	A_1		90,350	Airco Temescal evaporator 4' BJD 1800 with STIH270 four hearth E beam gun, CU-8-110 E beam power supply, XYS-8-1 Sweep controller, FDC-800 thickness rate monitor fixturing.	See 3-24	
						Veeco 7760 integrated E-beam evaporator		
3-26	Sputter system	Q	A_2		30,000	Perkin Elmer/Plasma Model 2400ASA sputtering system	Plasma Products Division Perkin Elmer	
	or						Varian Corporation	
3-26A	Sputter system interchangeable with 3-24 and 3-25							
3-27	Photolithography lamp	Q	A_1		9,315	Oriel lamp, 152 x 152 mm, Model 82230, Controller, Model 84350	Oriel Corporation Tamarack Scientific Company, Inc.	
3-28	Solder fountain	C	A_1		1,620	Wavedipper for molten solder, Electrovert Model WD-C-HT , Compound capacity	Electrovert, Inc.	
3-29	Solder fountain nozzle	R	A_1		105	Solder wave forming nozzle, 5" x 2" for 3-28	PolyFab Corporation	
3-30	Ultrasonic cleaners - 2 ea	Q	A_1		1,350	Ultrasonic cleaner, 6" x 10" and generator, Branson Model ATH610-6, 40 kH_2, standard intensity	Branson Cleaning Equipment Company Baron-Blakeslee	
	2 ea	Q	A_1 (later)		1,350			

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-31	Quartzware	Q	A_1		3,562	Quartzware: 6 ea diffusion tubes 135 mm OD x 80" w/5" stem w/28/15 ball, QI#6104, $331.40 ea 6 ea end caps w/stems, QI#6563, $60.10 ea 3 ea end caps w/hole instead of stem, QI#6563X, $58.40 ea 9 ea socket joints w/1/4 OD end, 28/15 socket, QI# Special, $12.90 ea 9 ea pushrod, 60" x 8 mm, QI#6755, $16.25 ea 6 ea storage tubes, Borasilica glass, 68 1/2" x 22 mm, QI6710, $23.50 ea 3 ea quartz sheath for TC wire, 8 x 12 mm, 60" long, QI#769, $18.20 ea 3 ea boat holders, QI#6749, $68.88 ea 6 ea boats, 4" wafer, 2" wide, 20" long, 60 wafer, 23 mil slot, QI#7038, $89.70 ea	Quartz International Corporation	
3-32	Bake ovens - 2 ea	Q	A_1		2,970 (Total)	Mechanical convection oven, stainless steel interior ambient to 260°C Dispatch #LAC13813 Blue M #HS/204-13FG #POM9-256-1EFG	Dispatch Industries Blue M Equipment	
3-33	Photolithography	Q	A_1		3,500	Photoresist spinner, single head Headway EC101 with CB15 large substrate bowl Chucks 2 ea E220/3 5/16" Chuck 1 ea E216G	Headway Research, Inc. Solitic, Inc.	
3-34	Epitaxy Reactor	Q	D		151,330	Chemical vapors deposition system w/single 4 inch reactor tube, specification #6018A for Model NTT6018-4	Nav-Tec Industries, Inc.	

S/N	ITEM	PURCH RECOM	PRIORITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-35	Wafer Dicing Saw	Q	A1		18,080	Wafer dicing saw, 30,000 RPM, XY for 4" substrates with microscope D1, Tempress 602, B2-220V, Al inch index	Tempress	
3-36	Wafer Dicing Saw Blades, 18 ea	C	A1	450		Tempress #14857, 5 micron grit, 30 mil long, 4 mil wide, 12 ea Tempress #16853, 30 micron grit, 40 mil long, 6 mil wide, 6 ea	Micro Automation	
3-37	Spray Deposition	Q	D		34,000	Integrated Technologies spray coater w/8095 intelligent drive system, explosion proof	Integrated Technologies, Inc.	
3-38	Nickel plate solution - 100 gal	C	A1	600		Alkaline electroless nickel plating solution, Halma electroless Ni, Standard Brenner plating solution mixed from basic chemicals	J. E. Holma Company Transene Company	
3-39	Solder - 180 lbs	Q	A1	1,260		63 Tin/37 Lead solder conforming to U.S. Mil. Spec Q9S571E, $6.72 per pound	Indium Corporation of America Alpha Metals, Inc.	
3-40	Al Paste - 10 lbs	C	A1	750		Metal organic silk screenable Al metal paste, Englehardt #3484 DuPont #CAP17449	Englehardt Industries Division Englehardt Mineral and Chemical Corporation E. I. duPont de Nemours and Company	
3-41	Ti Wire for Evaporation - 10 lbs	C	A1	2,500		High purity Titanium Wire (99.99 or better), .062" diameter, ~ $.55 a gram	Englehard - see 3-40 California Fine Wire Company	
3-42	Al wire for Evaporation - 20 lbs	C	A1	200		99.999 aluminum wire, 105 inch diameter - soft, bare	California Fine Wire Company See 3-41	

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-43	Pd wire for evaporation - 5 lbs	Q	A_1	6,500		99.95 purity Palladium wire, .02 in diameter, $90-95 per troy ounce	Englehardt - See 3-40	
3-44	Wire filamenets for evaporation	C	A_1	10,000		Wire filaments 9 wind GTE Sylvania # FS200-104, Code 5689, 4 per vacuum run, ∿ 8,500 required in 1.5 years	Sylvania GTE	
		C	C	20,000				
3-45	Silicon Wafers	Q	A_1	20,000		Monsanto Quality Silicon, 4", Cz, 100, P Borron, ∿ 2 ohm cm, $11.70 ea	Monsanto	
			C	22,000				
3-46	Silver anodes	Q	A_1	10,000		Fine silver plating anodes, 2" wide, .125" thick, 11" long, cost - Market price plus $.25 per troy on fabrication charge. 18 each per tank, requirement - 32 ea	Mitz Metallurigcal Corporation Handy and Harmon	
3-47	Silver solution components	C	A_1	5,000		Silver cyanide, 4.8 oz/gal Potassium cyanide, 8 oz/gal Potassium carbonate, 2 oz/gal Metallic silver, 3.5 tr oz/gal Free cyanide, 5.5 oz/gal		
3-48	Vacuum pump - 4 ea	C	A_1		1,200	Gast 0522-Z103-G18DX for 220V	Gast	
3-49	Miscellaneous Lab Equipment	C	A_1		15,000		Fisher Scientific	
3-49A	Glove, etc	C	A_1		—			

S/N	ITEM	PURCH RECOM	PRIORITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
3-50	Gasses	C	A_1	4,051		a) Ar UHP b) HE UHP c) Q2 UHP d) N2 UHP e) PH_3 1% in He f) PH_3 1% in Ar g) PH_3 1% in N_2	See 3-51	
3-51	Gas regulators	C	A_1		1,275	High velocity stainless steel 2 storage gas regulators, Model Matheson 3800, 1 for O_2 3 for inert gas, 1 for PH_3	Matheson Gas Products	
3-52	Photolithography	C	A_1	5,000		Hunt Resist, HPR 20C, $76 qt Developer LS12, $18 gal Shipley 2400 Resist developer for 2400 Chrome mask blanks - $17 ea Artwork - $200 each pattern	Hunt Shipley	
3-53	Dessicator/N_2/ Storage cabinets 3 ea	C	C		939	Clear plexiglass cabinet with N_2 feed thrus, 27x18x18, Ray #RD27, $313 ea	Ray Products	
3-54	Air Compressor	Q	A_1		4K	10 HP 2 stage air compressor w/ magnetic starter on 80 gallon horizontal tank, 150-175 PSI, 34 CFM (~ 25CFM minimum), Model #Z7501 Dayton Speedaire (for 220 50 Hz)	W. W. Granger Dayton Electric Manufacturing	
				500				
3-55				500				
3-56								

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
4-1	Pyranometer	C	C		1,300	Precision spectral pyranometer for measurement of global sun and sky radiation; Model PSP	Eppley Laboratory, Inc.	Telephone quote 7/26/82
4-2	DMM	C	A_1		420	DMM has special features of liquid crystal readout and 4 1/2 digit resolution for use with pyranometer or as general purpose bench-test or battery operated for outside use	John Fluke Mfg. Co., Inc. Model 8050A-01	October 1, 1981 catalog price
4-3	X-Y Recorder Quantity - 2 required	C	A_1		4,000	General use X-Y recorder to be used for solar cell and module current-voltage characterization	Hewlitt-Packard Company	1) Metric calibration 2) 1982 catalog price, p. 285
4-4	Hand held DMM	C	A_1		240	For general laboratory use or out-doors (LCD readout). Includes temperature measurement directly from K-type thermocouple	John Fluke Mfg Co., Inc.	October 1, 1981 catalog price
4-5	Lock-in Amplifier	C	A_1		6,000	For general laboratory use in any experiment requiring low-level signal recovery capability Model 124A	EG&G Princeton Applied Research	Provides a means to extract low amplitude signals from high noise levels
4-6	Preamplifier	C	B		875	For use with Item 4-5	Same as 4-5	
4-7	Solar Simulator	C	A_1		16,400	For testing individual solar cells; a 1,000 watt simulator; 6 x 6 inch beam, Model 81103	Oriel Corporation	Price does not include Xenon lamp
4-8	Xenon lamps (2 required)	C	A_1		900	1,000 watt ozone free; includes one as spare	Same as 4-7	
4-9	Air Mass- 1 Filter	C	A_1		425	For use with solar simulator to compensate for atmospheric absorption, Catalog #81004	Same as 407	

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
4-10	Reference Cell	C	A_1		150	Calibrated cell of the same material and similar process to those being manufactured and traceable to a standard	Solarex	
4-11	Monochromator	C	A_1		2,900	A quarter-meter monochromator to be used as a monochromatic illuminator or as a spectrometer in determining quantum yield of solar cells as well as other applications such as monochromatic light spot scanning. Instrument comes equipped with two 150 μ slits and two gratings mounted on an interchangeable, rotatable holder. Specify two gratings as follows: 1) 985-30-20-22 blazed for 500 μm 2) 985-30-30-30 blazed for 1.0 micron	Jarrell-Ash Division Fischer Scientific Company Model 82-410	Spectral region of interest for solar cells is 0.4 - 2 μm
4-12	Monochromator Light Source	C	A_1		470	Tungsten iodide lamp, Jarrel-Ash Model #45-542	Same as 4-11	
4-13	Spare lamp for Item 4-12	C	A_1		55	Spare lamp Catalog # 11330051	Same as 4-11	
4-14	Bipolar Power Supplies (2 required)	C	A_1		2,830	Power supplies for use with solar simulator cell test and for module test outdoors; bidirectional output stage must respond in either direction from zero.	Kepco, Inc. Model BOP 36-5M	Must have two; one for each dedicated application
4-15	Constant temperature	C	A_1		1,045	Refrigerated bath circulator for use with test block for cell test; temperature range -20°C to +100°C	Neslab Instruments, Inc. Model RTE-51	This model can be used for 230 volt, 50 Hz, 4.5 Amp operation

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
4-16	Test block	Q	A_1		900	Specially machined brass block, 6 x 6 inch with holes for vacuum hold-down and with provision for circulating fluid for adjusting and maintaining constant block temperature; 4 swivel probes for cell contact	Solarex	Solarex will supply drawings
4-17	Module test box	Q	A_1		200	Custom made test box with shunts and cables and terminals to be used for module test	Solarex	Solarex will supply drawings
4-18	4-Point Probe Test Fixture	C	A_1		665	Test probe fixture for measuring resistivity of wafers, ingots and diffused sheet resistance. To be used with 4 point probe of probe tip spacing of 0.025", made of tungsten carbide with tip radius = 0.002" and with spring pressure of 70 gms per tip (see model specification in 4-19)	Alessi Industries, Inc. Model ATP-1H	
4-19	4 pt probe assembly	C	A_1		435 (for 3)	See probe spacing, material and pressure in 4-18. Model A4P-25-T20-70	Same as 4-18	To be used with Item 4-18
4-20	Ellipsometer	C	C		10,000	For thickness measurement of oxide films and anti-reflective coatings; resolution capability for oxide films as thin as several angstroms	Gaertner Scientific Model L117	
4-21	Microscope	A	A_1		8,000	Trinocular microscope for later adaptation for camera attachment; 4 objective lenses for magnification to 1000X	Zeiss	

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
4-22	Microscope	Q	A_1		900	Zoom stereomicroscope with continuously variable magnification for lower power and large field of view applications	Bausch & Lomb	e.g., Model KVB-73 BL 31-26-39-73 $789 with Nicholas illuminator BL 31-33-05-01 66 / $855
4-23	Thermopile (radiometer)	C	A_1		900	For measurement of radiant energy from light sources such as the Monochromator (4-11). Circular type of $\sim$/cm^2 aperture	Eppley Laboratory	Includes window and low intensity calibration
4-24	Digital Nanovoltmeter	C	A_1		2,900	For use with thermopile (4-23). For very sensitive voltage measurement	Keithley Model 181	
4-25	Capitance Conductance Bridge	C	C		3,000	For analysis of pn junction profiles and solar cell conductance	General Radio	Estimated price
4-26	Spectrophotometer	Q	D			Beckman DK-2A Ratio Recording spectrophotometer	Beckman	Measure R&T as a function of wavelength
4027	Environmental Test Chamber	Q	A_1		20,000	Thermal cycle and humidity testing	Blue M Tenney Engineering Associated Env. Syst.	

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
5-1A	Solar Cells 2,500 ea	Q	A	18,750		Solder metalization 4" round	Solarex Solar Power Photowatt	
5-1B	Solar Cells 2,500 ea	Q	B	18,750			Same as Above	
5-2	Laminator - 1 ea	Q	A		50,000	Vacuum heat	Spire Solarex	Price variability from 25K - 80K depending on specifications.
5-3	Microscope - 1 ea	Q	C		10,000	Stereo for inspecting strings and panels		
5-4*	Bi-polar power supply - 2 ea	Q	A		5,660 (2,830 ea)	For panel I-V curves See 4-14	Kepco	Should be capable of handling 36 volts, 5 amps.
5-5*	Module test box	C	A		200	See 4-17	Solarex local fabrication	Needed to handle high current modules - Solarex's equipment is put together by Solarex people.
5-6*	X-Y recorder - 1 ea	Q	A		4,000	See 4-3	Hewlett-Packard	For measuring module I-V curves outside.
5-7	Light table - 1 ea	P	C		1,000	Local fabrication		For testing for panel continuity or shorts.
5-8	Frames for modules 20 ea	R	A	1,000		Same as our SX frames	Same as Solarex	Just enough to get started.

*Duplication

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
5-9	Frames for modules 100 ea	P	B A2	5,000		Local fabrication		
5-10	Lo-Iron glass 150 ea	C	B A2	750		1/8" x 18" x 42"	Hurdis Brothers	For panels
5-10A	Lo-Iron glass-100ea	C	A1	100		1/8" x 12" x 12"	Hurdis Brothers	For practice mini-panels
5-11	Craneglass - 1 roll	Q	A1	100		.005" random oriented scrim material	Electrolock	For air release aid in laminator (min order)
5-12	Soldering iron - 3 ea	P	A		200	Equivalent to Ungarmatic - Catalog no. 78 - Deanco Catalog	Deanco	Can be procured in Pakistan - get a variety of tips.
5-13	Solder paste	C-P	A1	100		ESP-6-564-350B	ESD - Mfr Deanco - Distr	Can be procured in Pakistan equivalent
5-14	Alignment fixture - 1 ea	P	A1		200	Local manufacturer		Needed to align cell string
5-15	Junction boxes and associated covers, terminals, etc.	P	A1	300		Aluminum box or equivalent	Local	
5-16	Multimeter*	C	A1		240	See 4-4	Fluke	Needed to check string continuity, resistance, etc.
5-17	Interconnect Material (15,000 ft)	R	A1	150		.002" x .078" of HC solder coated copper	Solarex stock	Connect - cell-to-cells.
5-18	Bus bar material (500 ft)	R	A1	100		.05" x .015" of HC solder coated copper	Solarex stock	End connections to outside module or groups of strings.

S/N	ITEM	PURCH RECOM	PRIORITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
5-19	EVA - 4,000 ft^2	C-R	A_1	1,400		18" wide .018" EVA (for PV encapsulation purposes)	Rowland Company	May have minimum order problems for encapsulation.
5-20	Tedlar	C	A_1	600		.004 white with 68040 DuPont primer	Dorrie Process	May have minimum order problem - for back surface of module.
5-21	Reference Cells 2 ea	C	A_1		300		Solarex	To provide standard reference for panel measurement.
5-22	Tanks - 2 ea	C-P	A_1		300	For holding flux neutralizer Locally fabricated spray tanks are a possibility	Local	For rinsing completed cell strings.
5-23	Tab pull machine	C	C		1,000		Ametek	To test metallization and tab pull strength
5-24	Flux neutralizer 5 gal	C	A_1	65		Goes with 5-22 - Alpha 2444		
5-25	Glass primer - 1 liter	C	A_1	20		Dow Corning Z6030/Z6020	Dow Corning General Electric	For EVA adherence to glass.
5-26	Wire - 500 ft	C	A✓	75		No. 12 wire for module output	Deanco Raychem	Suggest red and black mix.
5-27	Wire stripper - 3 ea	P	A	20		General purpose tool	Local	For general purpose wire work.
5-28	Tapes - 10 rolls	C	A_1	100		M-69	C - H - R	For insulating cell b. :ks to tabs or busses.
5-29	Carts - 2 ea	C-P	A✓		384	Cart - general purpose	Local	To hold, transport and store panels and strings.
5-30								

	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
[illegible]	Adhesive - 10 tubes	C-P	B	35		General Electric RTV-108, 102	General Electric	General purpose bonding
1	Insulating gloves 10 pair	P	B	92		Heavy gloves	Local	To protect hands from hot modules.
2	Scissors - 10 ea	P	B	75		Almost any kind acceptable	Local	To cut tabbing material and other small items.
3	Tweezers - 10 ea	P	B	75			Local	To handle individual cells-also needed in cell and wafer handling operations.
4	Isoprophyl Alcohol	P	B	40		For general purpose cleanup	Local	
5	Tabbing machine	Q	D		100,000 - 800,000	Depending on specification. Must have strong interface information.		

Non-Exp

① $\int A_2$ ② A_1 A_1 A_1

- Crystal growing
- Tabbing -
Sun simulator -
Diffusion -

10/8/82

10/8/82

S/N	ITEM	PURCH RECOM	PRIO-RITY CODE	PRICE EXP	PRICE NON-EXP	SPECIFICATION OR DESCRIPTION	POSSIBLE SUPPLIER	REMARKS
6-1	1.	Q	D		$75,000	Photovoltaic Systems 5KW for training and troubleshooting	Solarex	

APPENDIX D

UNIDO PURCHASE ORDER TO SOLAREX

Form/IO.52/Rev.1 (4.82)

F0000

A/c 5188-279

NOV 15 1982

UNIDO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

VIENNA INTERNATIONAL CENTRE

P.O. BOX 300, A-1400 VIENNA, AUSTRIA

TELEPHONE: 26 310 TELEGRAPHIC ADDRESS: UNIDO VIENNA TELEX: 131218

PURCHASE ORDER

No. 15-? K0911

IMPORTANT
ALL SHIPMENTS
ALL INVOICES
ALL CORRESPONDENCE
MUST SHOW THIS NUMBER

Date 3 November 1982

To: (Vendor)
Solarex Corporation
1335 Piccard Drive
Rockville
MD 20850
USA

Ship to: (Consignee)
Resident Representative
United Nations Development Programme
P.O. Box 1051, Islamabad
Pakistan FOR PROJECT: ST/PAK/80/T01

PLEASE SUPPLY THE FOLLOWING GOODS AND/OR SERVICES IN ACCORDANCE WITH REFERENCES OPPOSITE, SUBJECT TO THE UNIDO GENERAL CONDITIONS SHOWN OVERLEAF AND ANY SPECIAL CONDITIONS STATED.

UNIDO's reference: Enquiry
Dated: 25 August 1982

Vendor's reference: Quotation + telex
Dated 23 Sept+27 Oct. 1982

Delivery terms: 4 months

Shipping terms: C+F surface, Karachi

Payment terms: Net, on receipt of invoice, documents of despatch.

Item No.	Goods and/or services	Quantity	Unit	Unit price	Amount
	Project: ST/PAK/80/T01 - Development Centre for Silicon Technology Islamabad, Pakistan.				US $
9.	Diffusion furnace system - basic Thermo model 3103 furnace, all gas doping system - as per attached list of 1 page.	1	set		40,000.-
14.	Laminator for EVA type photovoltaic modules capable of laminating and curing 42" x 18" module.	1	pce		26,000.-
36.					13,640.-
37.					6,466.-
38.					2,900.-
39.	As per attached list of 3 pages.				6,873.-
40.					200.-
42.					1,945.-
43.					1,271.-
44.					10,000.-
46.					10,963.-
47.					1,725.-
48.					3,500.-
49.					1,700.-
50.					250.-
	Note: 1. Airfreight costs have been estimated only. Please invoice separately at cost.				127,433.-
		Est. shipping costs			7,000.-
	2. Kindly cable despatch details when known to UNDEVPRO, Islamabad, Pakistan.				
JRK/sr			C+F	Grand total	134,433.-

GENERAL INSTRUCTIONS

1. Please retain this Original and return the attached copy duly signed, acknowledging your acceptance of this order.
2. See Annex "A" for Forwarding and Invoicing Instructions.

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Signature: [signature]

Name D. Gardellin

Officer-in-Charge, Purchase & Contract Service (PAC)

1 ORIGINAL – to be retained by VENDOR

APPENDIX E

PURCHASE ORDER FROM SILICON TECHNOLOGY DEVELOPMENT CENTRE

SILICON TECHNOLOGY DEVELOPMENT CENTRE
15-B, Street 44, F 8/1
Islamabad, Pakistan

PURCHASE ORDER
NO.________________
DATE________________

TO: Solarex Corporation
1335 Piccard Drive
Rockville, MD 20850
U.S.A.

SHIP TO: STDC
Dr. A. Mufti, Director

Please supply the following goods and/or services

DELIVERY TERMS: 4 months

PAYMENT TERMS: 75 percent at the time of placing the order with Solarex, balance on receipt of invoice and documents of dispatch.

VENDOR'S REFERENCE: Package 82/2 items 15 through 35 excepting Item 22 as originally described in quotation to UNIDO, Vienna. Also Item 41 from 82/3 package.

ITEM NO.	GOODS AND/OR SERVICES	QUANTITY	UNIT PRICE	AMOUNT
15	Betascope	1		$ 7,088
16	PH Meter	1		451
17	Precision Laboratory Balance	1		1,613
18	Presco Model 462 Screen Printer	2	$11,800	23,600
19	Chemical Hood and Accessories	1		8,819
20	Silver Plating System	1		6,396
21	Laboratory Tanks (Assorted)	See Attached		12,915
23	Photolithographic System	1		33,423
24	Solder Fountain	1		2,289
25	Wafer Dicing Saw	1		22,727
27	Aircompressor	1		2,816
28	Digital Multimeter	1		589
29	Handheld Digital Multimeter	1		334
30	Lock-In Amplifier	1		10,767
31	Solar Simulator System	1		30,141
32	Quantum Yield System	1		11,169
33	Zoom Microscope	1		1,867
34	Module Test System	1		5,400
35	Module Preparation Station	1		1,500
41	Photolithography Supplies	See Attached		5,000
				$188,904
	Less 5% Consideration for Advanced Payment of 75%			9,445
				$179,459
	Estimated Crating and Shipping			4,000
				$183,459

SILICON TECHNOLOGY DEVELOPMENT CENTRE

SIGNATURE: [signature]

NAME: A. Mufti
Director

Item #9 - Diffusion Furnace System

Cost Breakdown:	
3 Stack Furnaces	$ 29,768
Flow Meters	1,564
Regulators	2,471
Stainless Tubing	199
Plastic Panels & Tubing	92
Fittings, Valves	743
Quartzware	4,346
Packing & Shipping to Solarex	1,830
Assembly Labor	1,220
	$ 42,234

Package 82/2 - Items 15-35

Item #15 - Twin City Betascope with Voltage Regulator, Probe, Radiation Source	$ 7,088

Item #16 - PH Meter
Orion Model 301
or
Fisher Accumet 600
(with spare electrode) $ 451

Item #17 - Precision Laboratory Balance
0-300g not available

2 options: 1) Mettler H80 0-160g (precision of 0.01 mg)	$ 1,613
or	
2) Mettler H315 0-1000g (precision of o.1 mg)	4,444
	$ 1,613

Recommend Option #1

Item #18 - 2 Screen Printers $ 11,590 each

Presco Model 462 $ 16,775 each

DeHaart Model AOL-12

Solarex recommends purchase of 2 of the same type for redundancy, spare parts, etc. For Lab use Presco Model 462 adequate.

$ 23,600

Recommend 2 Presco Model 462

Item #19 - 1 Chemical Hood
Semifab SLFH/600

Tanks for Etch
4 Cole Parmer Model C-7206-80
4 Cole Parmer Model C-7207-80

Hot Water
4 Corning PC 351
2 Corning PC 101

$ 8,819

$ 6,396

Item #20 - Silver Plating System
with:
a) spray rinse tank & sink
b) Footswitch
c) Tank with stainless steel anode bars with lid
d) Filter housing & filter
e) 6-Plating racks for silver bars
f) 6-Plating racks for 9 4" wafers
g) 2 power supplies (0-20V) (0-3A) Lambda LP 521 FM
h) Tubing
i) Pump - Marathon S2P81366U
j) Exhaust Hood - Polypropylene

$ 12,915

Item #21 - Laboratory Tanks
2 each Fluoroware Model E 3201 Teflon Tanks
2 each Fluoroware Model E 3202 Teflon Covers
10 each Fluoroware Model PE 3201 Polypropylene Tanks
10 each Fluoroware Model PE 3203 Polypropylene Covers
6 each Fluoroware Model A 72408 Teflon Casettes
12 each Fluoroware Model PA 7240B Polypropylene Cassettes
6 each Fluoroware Model A027 Teflon Handles
12 each Fluoroware Model PA027 Polypropylene Handles
18 each Fluoroware Model A72-20-02 Teflon Lids
3 Cascade Rinse Tanks - Fluoroware Model E-64
2 FSI K/20 Spin Dryers

Item #22 - Deionizing Water System $ 41,620
1000 gallons per hour
8 Megohm Water

Item #23 - Photolithographic System $ 33,423

1 Oriel Photolithography Lamp #82230 &
84350 Controller
2 Branson ATH C10-6 Ultrasonic Cleaners
2 Blue M Bake Ovens POM9-256-1EFG
1 Headway Spinner Model EC101
with CB 15 Substrate Bowl, 2 E220-3 5/16"
Chucks and 1 E216G Chuck
4 Vacuum Pumps - 0522-7103-C18DX

Item #24 - Solder Fountain $ 2,289
Electrovert Model WDCHT
with 5" x 2" Nozzle

Item #25 - Wafer Dicing Saw $ 22,727
Tempress 602-B2-220V
plus 18 spare blades

Item #27 - Aircompressor $ 2,816
Dayton Speed Air #72501

Item #28 - Digital Multimeter $ 589
Fluke Model 8050A-01

Item #29 - Handheld Digital Multimeter $ 334
Fluke Model 8024-B

Item #30 - Lock-In Amplifier $ 10,767

Item #31 - Solar Simulator System Including: $ 30,141

a) 1000 Watt Xenon Simulator Model 81103
by Oriel for 6"x6" area

b) 2 x-y Recorders
HP-7035 B
(Redundant with Item #34 - only include one here)

c) 2 Spare Xenon Lamps

d) Air Mass 1 Filter for Oriel Simulator

e) 1 Solarex AMI reference cell

Item #31 - Continued

f) 2 Kepco Bipolar Power Suppliers BOP 36-5M
(Redundant with Item #34 - only include one in price)

g) 1 Neslab Constant Temperature Refrigerator Unit
RTE-5B

h) Test Block - Solarex Design

i) 4 Point ~~Probe~~ Test Fixture
Alessi ATP-1M

j) 3 Spare 4 point Probe Heads
Model #A4P625T270 for Alessi System

Item #32 - Quantum Yield System, Including:	$ 11,169

a) Quarter Wave monochromator
Jarrell-Ash 82-415
with additional grating

b) Monochromator Light Source -
Tungsten Iodide Model 45-542
with 4 spare lamps

c) Epply Thermopile

d) Digital Nanovoltmeter
Keithley Model 181

e) Housing & Sample Mount

Item #33 - Zoom Microscope	$ 1,867

Burton Instrument
Model 33-5-12

Item #34 - Module Test System	$ 5,400

Includes:
a) Module Test Box
b) 2 Kepco Bipolar Power Suppliers
(redundant with 2 listed on Item #31 - only include one in price)
c) X-Y Recorder
HP-7035B
d) 2 Solarex Reference Paddles

Item #35 - Module Preparation Station	$ 1,500

Includes:
a) Alignment Fixture
b) 2 Tanks for holding Flux
c) 2 General Purpose Carts
C&H Catalog No. 52-281/3D

Package 82/2 Items 15-35 TOTAL:	$ 225,524

Package 82/3 Items 36-50

$ 27,280

Item #36 - 300 Kg of Semiconductor
Grade Polysilicon
(Less than 0.2 PPBA of B)

$ 6,466

Item #37 - Gases Include
a) 3 tanks of UHP Ar
b) 3 tanks of UHP He
c) 1 tank of UHP O_2
d) 3 tanks of UHP N_2
e) 1 tank of 1% PH_3 in N_2
f) 1 tank of 1% PH_3 in He
g) 1 tank of 1% PH_3 in Ar

$ 2,900

Item #38 - Screens Include
1) Artwork for BSF paste screen
2) Artwork for 4" front Mettalization Pattern
3) 5 each copies of above
4) 5 gallons of screen cleaner

$ 5,673

Item #39 - Silver Anodes
32 silver bars 2"x.125"x11"

$ 1,200

Item #39 (Continued) - Silver Solution Components
a) 160 oz Potassium Cyanide
b) 40 oz Potassium Carbonate
c) 70 Tr oz Metallic Silver
d) 110 oz Free Cyanide

$ 200

Item #40 - Dionizing Water Chemicals
10 gallons HCl
1 Drum NaOH
Starting Lot - Remainder to be bought in Pakistan

$ 5,000

Item #41 - Photolithography Supplies
Includes:
a) Artwork for 2 front patterns
b) 2 Prints Each of Above
c) 20 Chrome Blocks 5"x5"
d) 2 gallons Shipley AZ-2400 resist
e) 4 gallons Shipley AZ-2401 developer

APPENDIX F

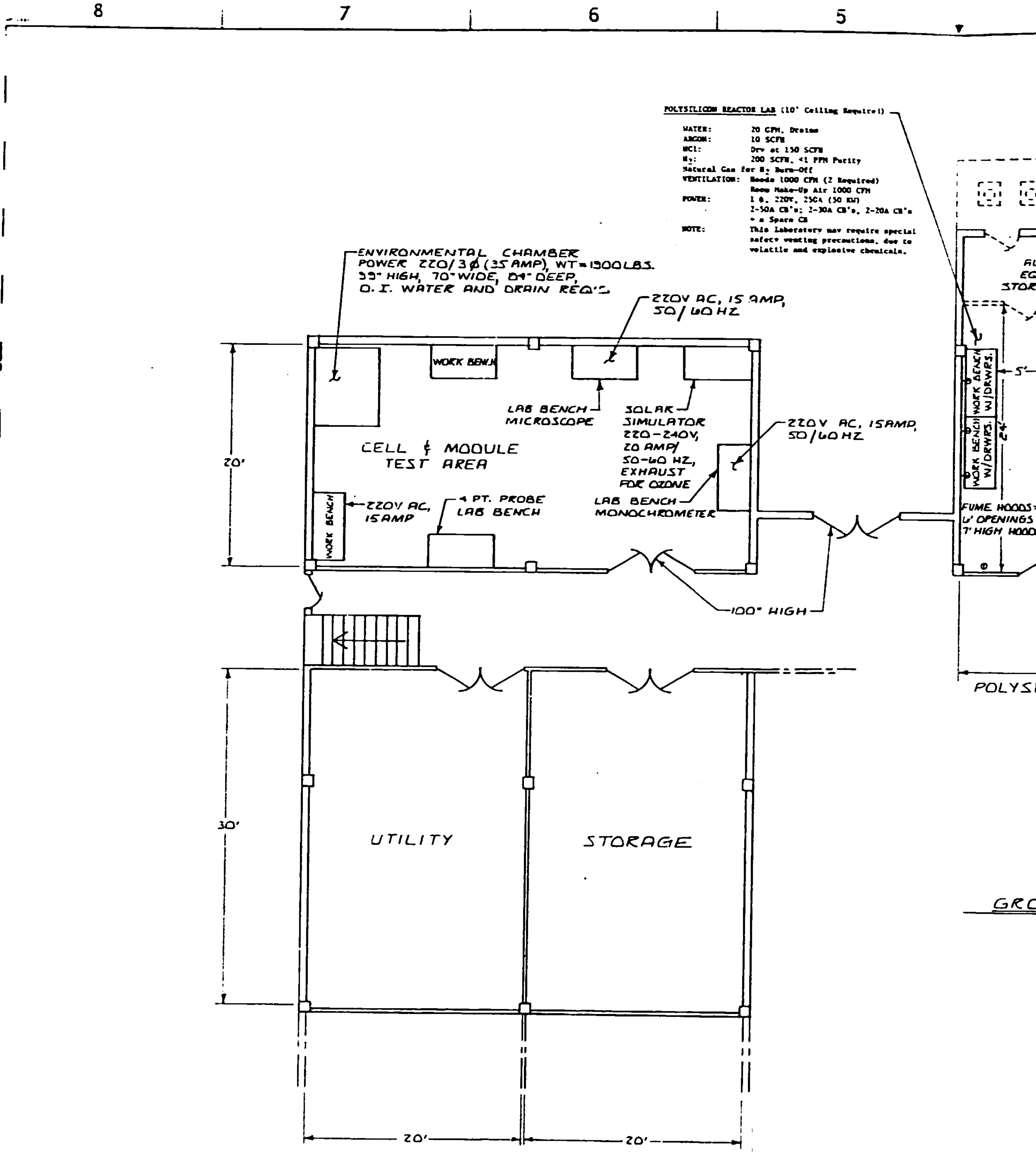
BATTELLE REPORT TO BE FURNISHED LATER

APPENDIX G

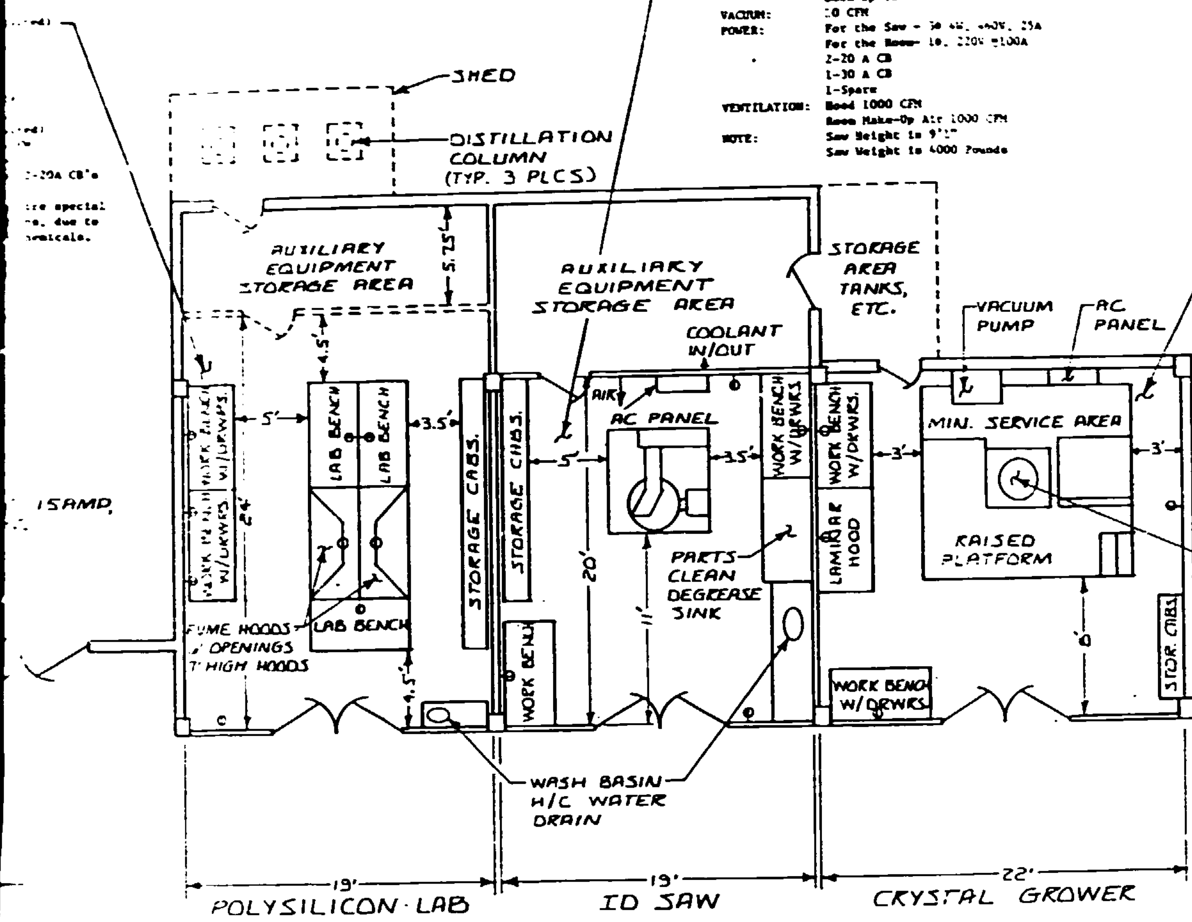
STDC LABORATORY BUILDING

SOLAREX DRAWING #1299

TWO SHEETS


8
7
6
5
POLYSILICON REACTOR LAB (10' Ceiling Required)
WATER: 20 GPM, Drains
ARGON: 10 SCFH
HCl: Dry at 150 SCFH
H2: 200 SCFH, <1 PPM Purity
Natural Gas for H2 Burn-Off
VENTILATION: Hoods 1000 CFM (2 Required)
Room Make-Up Air 1000 CFM
POWER: 1 Φ, 220V, 250A (50 KW)
2-50A CB's; 2-30A CB's, 2-20A CB's + a Space CB
NOTE: This Laboratory may require special safety venting precautions, due to volatile and explosive chemicals.
ENVIRONMENTAL CHAMBER POWER 220/3Φ (35 AMP), WT=1300 LBS. 39" HIGH, 70" WIDE, 84" DEEP, D.I. WATER AND DRAIN REQ'S.
220V AC, 15 AMP, 50/60 HZ
WORK BENCH
LAB BENCH MICROSCOPE
SOLAR SIMULATOR 220-240V, 20 AMP/ 50-60 HZ, EXHAUST FOR OZONE
220V AC, 15AMP, 50/60 HZ
CELL & MODULE TEST AREA
20'
WORK BENCH
220V AC, 15AMP
4 PT. PROBE LAB BENCH
LAB BENCH MONOCHROMETER
100" HIGH
WORK BENCH W/DRWRS.
WORK BENCH W/DRWRS.
5'
24'
FUME HOODS
6' OPENINGS
7' HIGH HOOD
30'
UTILITY
STORAGE
20'
20'

SECTION 1



ID SAW ROOM

WATER:	Hyd. System 1.1 GPM
	Blade Coolant 0.1 GPM
	Both Require Drains
AIR:	21 CFM at 70 PSI (Refrigerated)
	Back Up Tank Recommended
VACUUM:	10 CFM
POWER:	For the Saw - 3φ 4W, 440V, 25A
	For the Room- 1φ, 220V ±100A
	2-20 A CB
	1-30 A CB
	1-Spare
VENTILATION:	Hood 1000 CFM
	Room Make-Up Air 1000 CFM
NOTE:	Saw Height is 9'2"
	Saw Weight is 4000 Pounds

ROOM ENVIRONMENT: For the Crystal Puller Room

AMBIENT:	30°C
HUMIDITY:	60% Maximum
VENTILATION:	Hood - 1000 CFM
	Room Make-Up Air - 1000 CFM
NOTE:	Weight of crystal puller is 5000 lbs. Floor loading is 8000 lbs/ft². Height is approximately 15 ft.

POWER: For the Crystal Puller Room
1φ, 220V, ±100A
2-20A CB
1-30A CB
1 Spare "X" CB

CRYSTAL PULLER

COOLANT:	30 GPM at 27-35 PSI
	Back-up tank recommended for emergency use
DRAIN:	<8 PSI Back Pressure
AIR:	5 CFH at 50 PSIG
ARGON:	60-80 CFH at 50 PSIG.

POWER: For the Crystal Puller
3φ 4W, 460V, 300A

GROUND FLOOR

SECTION 2

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED

NO.	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MANUFACTURER

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE
FRACTIONS ± DECIMALS XX ± XXX ± ANGLES ±
MATERIAL
FINISH
NEXT ASSY | USED ON
APPLICATION
DO NOT SCALE DRAWING
CONTRACT NO

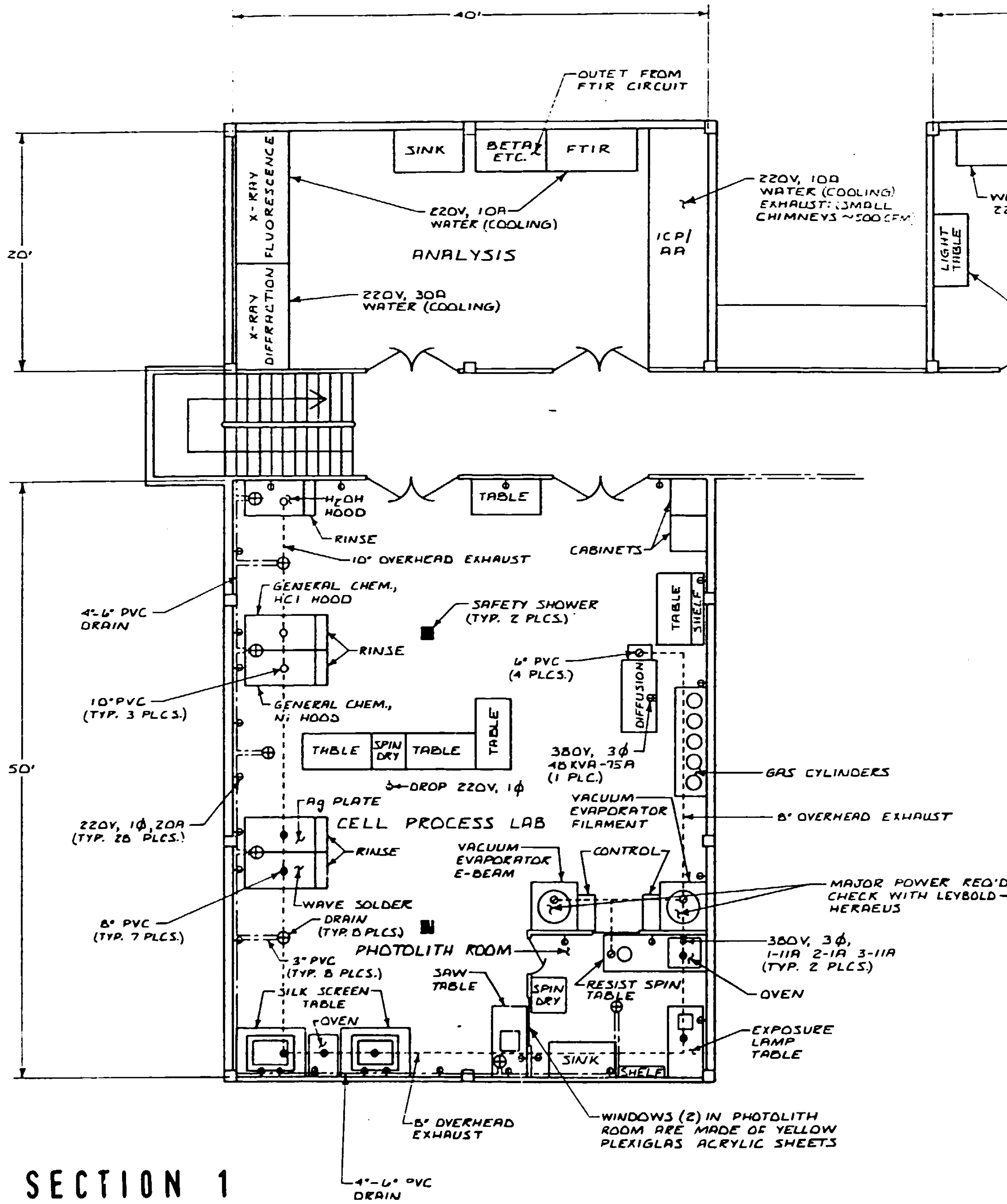
APPROVALS		DATE
DRAWN	T. KELLER	11-23-82
CHECKED		

SOLAREX CORPORATION
1335 PICCARD DRIVE ROCKVILLE, MD 20850 ☐ 301 948 0202

REVISED STDC LABORATORY BUILDING

SIZE	CODE IDENT NO	DRAWING NO
D		1293

SCALE | SHEET 1 OF 2

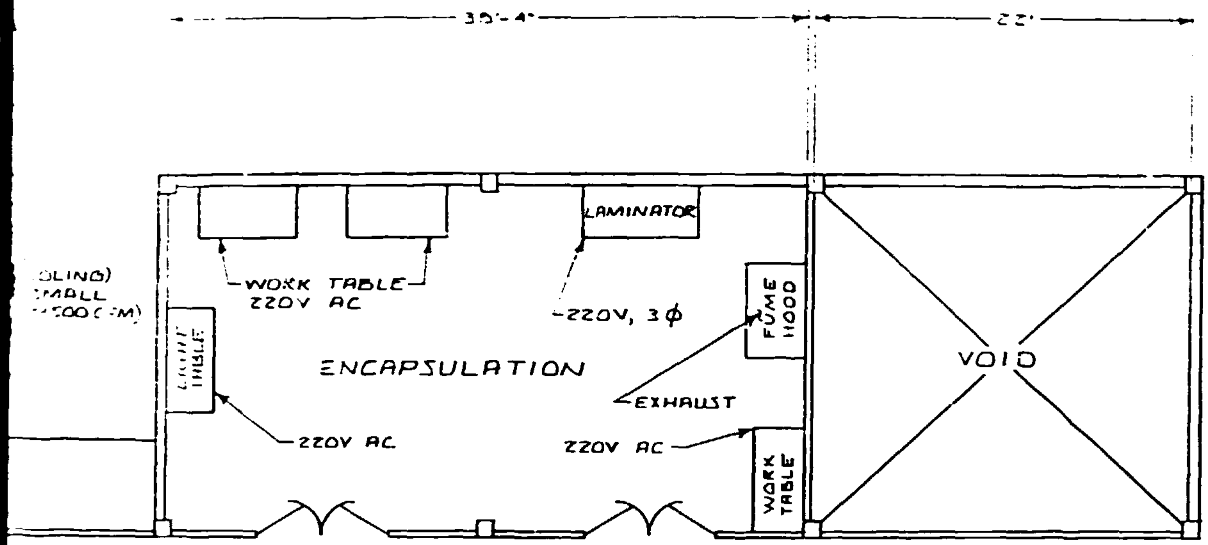


SECTION 1

8 7 6 5

ZONE	LTR	DESCRIPTION	DATE	APPROVED

REVISIONS



FIRST FLOOR

-UDERS

-EAD EXHAUST

-AJOR POWER REQ'D
-ECK WITH LEYBOLD-
-RAEUS

3-11A
CS)

SECTION 2

NO.	QTY REQD	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MANUFACTURER

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS XX ± XXX ± ANGLES ±

MATERIAL

FINISH

CONTRACT NO

APPROVALS		DATE
DRAWN	J. KELLER	11-24-82
CHECKED	M. Gulian	11-24-82

SOLAREX CORPORATION
1335 PICCARD DRIVE ROCKVILLE, MD 20850 □ 301 948 0202

REVISED
STDC LABORATORY
BUILDING

SIZE	CODE IDENT NO	DRAWING NO
D		1299

SCALE — SHEET 2 OF 2

NEXT ASSY	USED ON
APPLICATION	

DO NOT SCALE DRAWING