The Federal Republic of Nigeria
Federal Ministry of Power and Steel (FMPS)
Federal Ministry of Science and Technology (FMST)
Energy Commission of Nigeria (ECN)
Rural Electrification Agency (REA)

The Master Plan Study for Utilization of Solar Energy in the Federal Republic of Nigeria

Final Report

Volume 5
Action Plan for Research and Development on Solar Energy

February, 2007

JAPAN INTERNATIONAL COOPERATION AGENCY
YACHIYO ENGINEERING CO., LTD.
RECS INTERNATIONAL INC.

THE MASTER PLAN STUDY FOR UTILIZATION OF SOLAR ENERGY IN THE FEDERAL REPUBLIC OF NIGERIA

FINAL REPORT

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PREFACE

In response to a request from the Federal Republic of Nigeria, the Government of Japan decided to conduct "The Master Plan Study for utilization of solar energy in the federal republic of Nigeria" and entrusted to the study to the Japan International Cooperation Agency (JICA).

JICA dispatched the study team headed by Mr. Mitsuhisa NISHIKAWA of Yachiyo Engineering Co., Ltd. and organized by Yachiyo Engineering Co., Ltd. and RECS International Inc. to Nigeria six times from June 2005 to February 2007.

The study team had a series of discussions with the officials concerned of the Government of Nigeria and conducted related field surveys at the study area. Upon returning to Japan, the study team conducted further studies and compiled the final results in this report.

I hope that this report will contribute to the promotion of the plan and to the enhancement of amity between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Government of Nigeria for their close cooperation throughout the study.

February 2007

Tadashi IZAWA
Vice President
Japan International Cooperation Agency

Mr. Tadashi IZAWA
Vice President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

February 2007

Dear Sir

It is my great pleasure to submit herewith the Final Report of "The Master Plan Study for Utilization of Solar Energy in the Federal Republic of Nigeria".

The Study Team that consists of Yachiyo Engineering Co., Ltd. and RECS International Inc. conducted field surveys including pilot projects in Nigeria over the period between June, 2005 and February, 2007 according to the contract with the Japan International Cooperation Agency (JICA).

The Study Team compiled this report, which proposes Master Plan and Action Plan for PV Rural Electrification, Action Plan for Research and Development of Solar Energy Technology, Action Plan for Awareness Raising of Solar Energy, etc, through close consultations with officials concerned of the Government of the Federal Republic of Nigeria and other authorities concerned.

On behalf of the Study Team, I would like to express my sincere appreciation to officials concerned of the Government of Nigeria and other authorities concerned for their cooperation, assistance, and heartfelt hospitality extended to the Study Team.

We are also deeply grateful to the Japan International Cooperation Agency, the Ministry of Foreign Affairs, the Ministry of Economy, Trade and Industry, and the Embassy of Japan in Nigeria for their valuable suggestions and assistance during the course of the Study.

Yours faithfully,

Mitsuhisa Nishikawa
Team Leader
The Master Plan Study for
Utilization of Solar Energy in the
Federal Republic of Nigeria

THE MASTER PLAN STUDY FOR UTILIZATION OF SOLAR ENERGY IN THE FEDERAL REPUBLIC OF NIGERIA

FINAL REPORT (VOLUME 5 ACTION PLAN FOR RESEARCH AND DEVELOPMENT ON SOLAR ENERGY)

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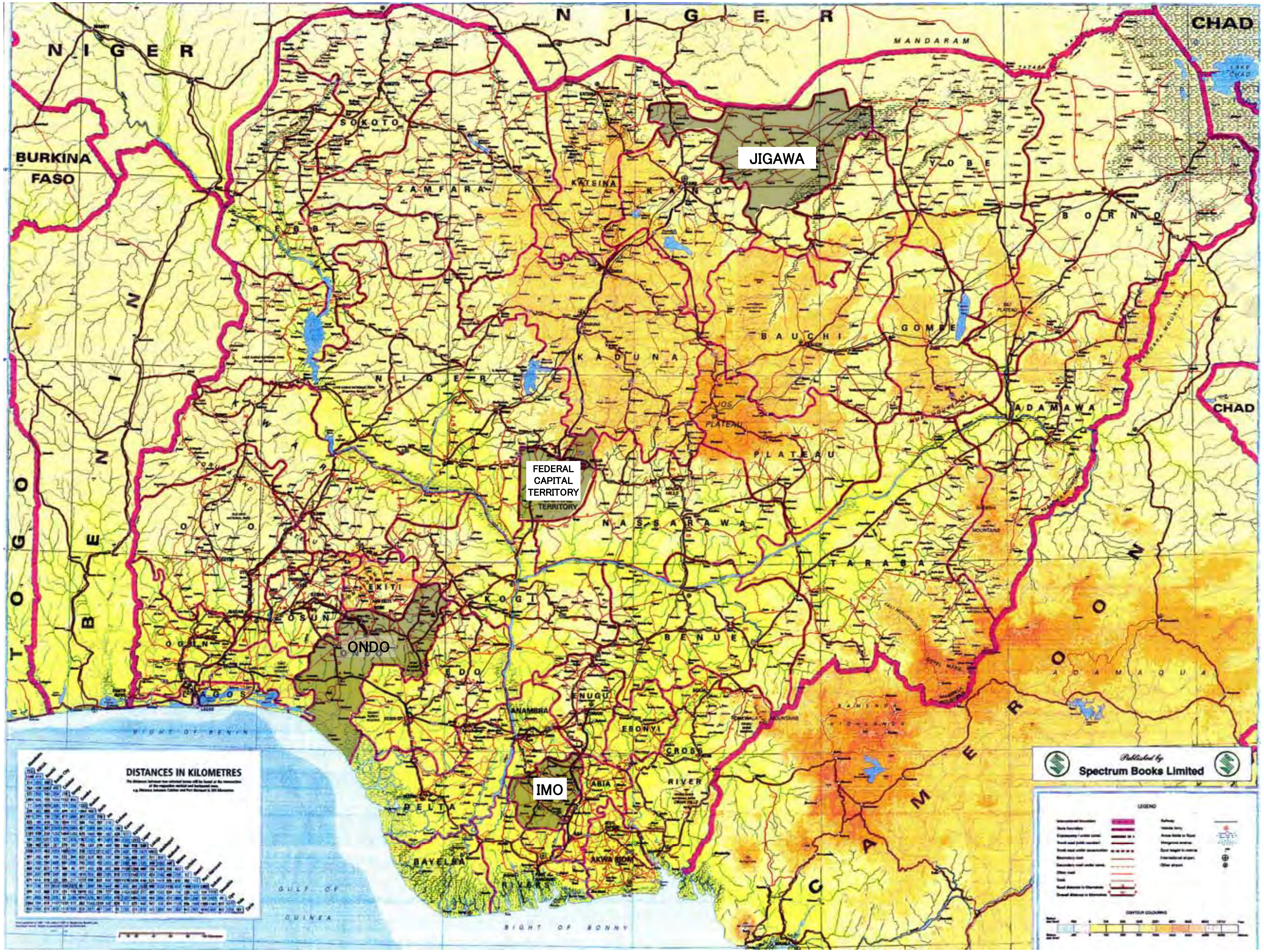

Study Area in the Federal Republic of Nigeria

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ABBREVIATION

B/C Ratio	Benefit/Cost ratio
BCS	Battery Charging Station
BPE	Bureau of Public Enterprises
CD	Capacity Development
ECN	Energy Commission of Nigeria
EIRR	Economic Internal Rate of Return
ENPV	Economic Net Present Value
FCT	Federal Capital Territory
FIRR	Financial Internal Rate of Return
ENPV	Economic Net Present Value
FNPV	Financial Net Present Value
FMPS	Federal Ministry of Power and Steel
FMST	Federal Ministry of Science and Technology
IEC	International Electrotechnical Commission
IPP	Independent Power Producer
ISO	International Organization for Standards
JAEF	Jigawa Alternative Energy Fund
JICA	Japan International Cooperation Agency
JIS	JAPANESE INDUSTRIAL STANDARD
JWG	Joint Work Group
LGA	Local Government Area
LWG	Local Work Group
NCERD	National Center for Energy Research and Development - University of Nigeria NSUKKA
NEDO	New Energy Development Organization
NEPA	National Electric Power Authority
NESCO	National Electricity Supply Corporation (Nigeria) Limited
NERC	National Electric Regulatory Committee
NIMET	Nigeria Meteorological Agency
NPC	National Planning Commission
O&M	Operation and Maintenance
OSEB	Ondo State Electricity Board
PDM	Project Design Matrix
PHCN	Power Holding Company of Nigeria
PURD	Imo State Ministry of Public Utilities and Rural Development
REA	Rural Electrification Agency
REF	Rural Electrification Fund
SELF	Solar Electric Light Fund
SERC	SOKOTO Energy Research Center
SHS	Solar Home System
USAID	United States Agency for International Development
UNIDO	United Nations Industrial Development Organization
WHO	World Health Organization

Chapter １ Present Conditions of Research and Development

This is an action plan proposed to the related organizations in Nigeria, which was prepared through the survey of present conditions and the implementation of technology transfer in the two (2) Energy Research Centers in Nigeria, as a part of the M/P Study for Utilization of Solar Energy in Nigeria.

1.1 Background

It was found that the use efficiency of the solar energy facilities, PV system, solar heat utilization equipments were not measured, and therefore, it was suggested that those efficiencies be measured and the efficiencies of the instruments be improved through technology instruction, in the report of the preparatory study of the M/P. Accordingly, the M/P Study Team took measurement devices to the Sokoto Energy Research Center, and instructed the way to use the devices and the way of system improvement.

1.2 Energy Research Centers

There are two (2) Energy Research Centers in Nigeria.

- Sokoto Energy Research Center：herein after SERC）
- National Center for Energy Research and Development—University of Nigeria Nsukka：herein after NCERD）

Both are established as substructures of the Energy Commission in Nigeria (ECN) under the FMST. The work of energy research and development is divided into two (2) regionally, north and south, and SERC covers the north, and NCERD the south. The purposes of the both centers are almost same. And they have common contents of work including kinds of trial products, time span of research, as well as common problems such as lack of measurement devices, budget and others. The scales of the two centers are almost the same, but the solar radiation is 5.92 kWh/m^2-day in Sokoto and 4.54 kWh/m^2-day in Nsukka. The SERC was selected main target center for technology instruction as it was found more appropriate because of its larger solar radiation and the counter parts recommended it.

1.3 Outline of the SERC

SERC is located in the University of Danfodiyo in Sokoto city of the Sokoto state. It was established in 1982 as a research organization attached to the university, but has become a subordinate organization of the Energy Commission of Nigeria (ECN) since 1988.

(1) Objectives of establishing the research centre

The research center pursues the following objectives of research and development:

1) Research on renewable energy as an economical and efficient alternative energy,
2) Design and development to allow the use of renewable energy for agricultural and industrial

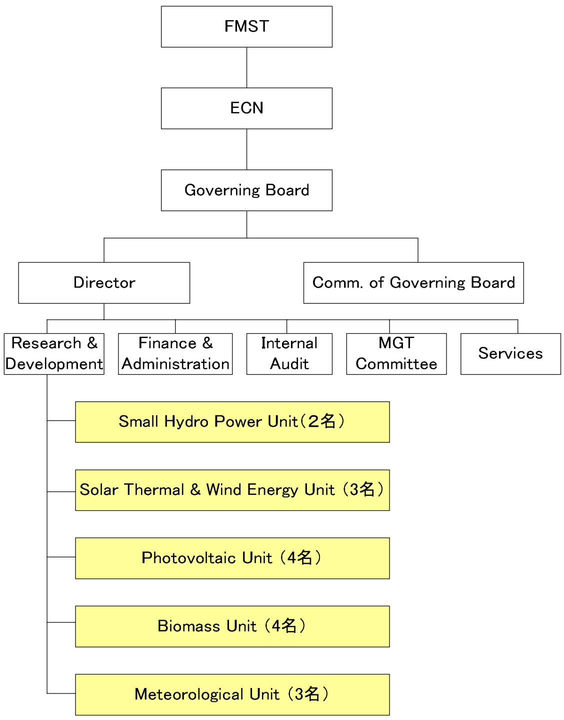
purposes,

3) Training of engineers for renewable energy technology,
4) Research on hybrid use of solar and other forms of energy, and
5) Improvement in efficiency of renewable energy use

(2) Organization of SERC

The director of the SERC, Prof. Dr. Zuru, is also working as a professor of the University of Danfodiyo, and there are 70 staff members. The work for research and development is in the five (5) units shown in Fig.1-1.

SERC does not have sufficient budget, and much of the budget is spent for salaries and it is difficult to allot the budget for research. Therefore, the measurement devices, which are out of order, are left as they are, and there is no measurement device available. The organization chart is shown in Fig.1-1.



Source: SERC

Fig.1-1 Organization chart of SERC

1.4 Outline of the NCERD

NCERD was established in the University of Nigeria, Nsukka, Enugu state, as a subordinate organization of the ECN in 1980, earlier than SERC. Nsukka city is located in savanna belt in the north of Enugu state.

(1) Objectives of establishing the research center

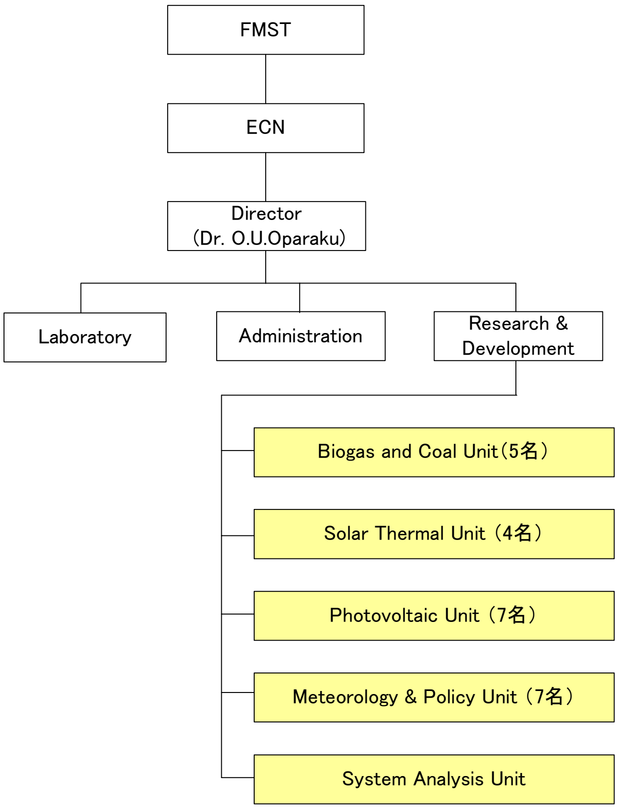
The research center pursues the following objectives of research and development:

1) Research on PV,
2) Development of solar heat equipments (dryers, water heaters, cookers, chicken incubators)

3) Development of biomass and biomass equipments
4) Development of briquettes equipment
5) Research on energy efficiency including energy saving technology

(2) Organization of NCERD

There are 65 staff members, out of which research staffs are 26, headed by the Director, Prof. O. U. Oparaku. The work for research and development is in the five (5) units shown in Fig.1-2. The research work is not done fully because of lack of the required equipments caused by insufficient budget. A meteorological data logger is working, but no other measurement devices exist. The measurement device for solar radiation is called a solar meter, which applies a solar battery, has not been calibrated for a long time, therefore, there is some doubt about its precision.



Source: NCERD

Fig.1-2 Organization chart of NCERD

1.5 Present Condition of SERC

1.5.1 Present conditions of the PV unit

The PV unit of SERC has 200W PV panels, a used controller and an inverter in the laboratory that is said to be for demonstration purposes. Since all the equipment for meteorological observations are out of order, even the data on solar radiation cannot be collected. Observed data at the airport are purchased and used when such meteorological data are necessary. Activities and experiments undertaken by the unit include the following:

1) Performance test of PV panels,
2) PV System development and
3) Monitoring of PV system

- Construction and operation of mini-grid system as part of rural electrification under ECN (it was stopped because NEPA extended the grid to the project area in 2005)
- Construction and operation of water pumps
- Construction of electricity source system for communication (backup source for a university communication facility)

They themselves want to manufacture PV related equipments such as controllers, inverters or PV panels. However, necessary measurement devices, research materials and tools are not enough because of insufficient budget, and they cannot conduct even basic research, and the three (3) researchers cannot have concrete future plan.

1.5.2 Present conditions of the solar thermal unit

The solar heat use and wind power unit have been installed for trial manufacturing of solar heat use equipment such as a water heater (with a straight pipe and spiral pipe), a drier, a large scale drier, a cooker and a water distiller. Those were made for trial about 10 years ago by a researcher who participated in training course in a solar energy institute in Lanzhou, China, but it has not been completed as merchandise because what is called P-D-C-A cycle for efficiency test, re-modeling and re-test was not applied. The unit has only the limited measurement devices just as the PV unit, and cannot conduct necessary tests of the trial products. The unit also does not have definite objective, method, schedule and target of research.

1.6 Issues for the SERC and NCERD

SERC and NCERD do not have enough capacity required for research centers. Efforts by related ministries and organizations are needed so as to make them work normally as research centers.

(1) Inadequate system for research

Direction and purposes of the research centers are not obvious. FMST, ECN and the research centers should consider the followings:

1) The purpose, kinds of research, objective, possible beneficiaries, dead line and other necessary points of the research should be decided so as to make the research direction clear.
2) FMST, ECN, SERC and NCERD are suggested to discuss target and measures of capacity building and budget for R&D, and make efforts to realize them.
3) FMST, ECN, SERC and NCERD are suggested to re-organize the organization of SERC and NCERD so as to promote the items mentioned above.

(2) Inadequate equipments and tools

There are few required equipments and tools such as measurement devices, equipment for trial, research materials, tools and facilities in SERC and NCERD, and it is impossible to continue research. Therefore, FMST, ECN, SERC and NCERD are suggested to prepare a list of the required equipments and tools and to get budget to purchase those.

(3) Inadequate experience of research staff

The research staff has neither experiences nor enough opportunities for training. FMST, ECN, SERC and NCERD are suggested to prepare a training plan including participation in trainings held in donor countries or aid agencies, and implement it.

(3) Inadequate research budget

FMST and ECN are suggested to organize a back-up system for budget for SERC and NCERD based on the purpose, research items and required time span.

1.6.1 Issues of PV unit

SERC and NCERD should deliberate what has to be done to improve the electrification rate in the rural area in Nigeria, and determine the purpose, research plan and research organization and obtain budget required for the research through FMST and ECN. FMST and ECN, which are policy decision makers, are required to prepare a long term plan considering the future of the energy research centers, and allot the budget properly.

1.6.2 Issues of solar thermal unit

The solar heat use unit made some trial equipments, which were done several years ago, but they have not improved or re-modeled them. The followings are required so as to improve them to be accepted as merchandises broadly.

1) To determine research system, purpose and schedule of development,
2) To make efforts toward the decided target of the models to be developed and improved,
3) To get budget to make models to be developed and improved,
4) To make the produced solar heat use equipments merchandise and establish sales route to spread them,
5) To prepare specifications for respective merchandises,
6) To increase the kinds of merchandises so as to satisfy users' needs,
7) To make efforts to get necessary budget (by FMST and ECN) and
8) To find companies that can produce and sell the developed merchandises.

Chapter 2 Technical Instructions

2.1 Concept of technical instructions

The concept of the technical instruction are 1) to train the staff to improve their measurement skill using the measurement devices that have been provided by JICA to SERC as the minimum requirement for research and development and 2)to make a suggestion to clarify the purpose, methods, schedule and others of the research to implement research and development.

2.2 Technical education

The staff members of SERC desire technical education. JICA study team conducted transferred technologies of the method how to measure and gather data using the measurement devices JICA provided, and trained them regarding the basic items for solar energy utilization including PV technology and electric wiring skill. The training items are as follows:

1) Method how to use the measurement devices
2) Data to be gathered and how to get them
3) Method of data collection and analysis
4) Technology of solar heat utilization and basic thermodynamic
5) PV electric generation
6) Basic experiment of PV module

2.3 Technology transfer to PV unit of SERC

JICA study team transferred technology of data to be gathered, the way of experiment, and the way of result analysis and others through the following experiments:

1) System outline (outward appearance)
2) Electric generation efficiency and system efficiency of solar batteries
3) Efficiency of an inverter
4) Relation between tilt angle and solar radiation
5) Measurement of FF(fill factor) and calculation method
6) Outline of solar battery technology
7) Battery technology

The concrete contents of the technology transfer to the PV unit are shown in Annex 2.

2.4 Technology transfer to solar thermal unit of SERC

They need to introduce the process of improvement for the trial products such as improvement of the trial products so that required data can be obtained from the products, data gathering, re-design and re-producing of the products, data gathering from the new products. And it is required to prepare the specifications as merchandises based on the re-design documents and to develop merchandises to be accepted by users.

JICA study team transferred technology of the following items through the experiments of water boiling tests and rice cooing tests for box cookers and parabolic cookers and dryers tests:

1) Experiments of heat transfer from the boxes to the open air and calculation method
2) Heat efficiency of a box cooker
3) Heat efficiency of a parabolic cooker
4) Improvement of a box cooker
5) Data analysis of a dryer
6) Comparative experiment method of dryers
7) Setting of measurement devices

The details of the technology transfer to the solar heat use unit are shown in Annex-3.

2.5 Measurement devices provided by JICA

JICA provided measurement devices to SERC to conduct the above instructions in January 2006. SERC can use them though they are JICA's property. The list of the devices is shown in Annex 1.

2.6 Technology transfer to NCERD

The technology transfer to NCERD was not included in the schedule of the Master Plan Study, but it was realized because of NCERD's strong desire. JICA study team visited NCERD to conduct survey and technology transfer during the 3rd field survey.

2.6.1 Technology transfer to PV unit

The technology of data gathering and analysis was transferred at the solar battery unit.

1) Tilt angle and generated electricity
2) Efficiency of inverters
3) Efficiency of PV system

2.6.2 Education plan to solar thermal unit

JICA study team transferred technology of the following items through the experiments of water boiling tests for box cookers and parabolic cookers:

1) Experiments of heat transfer from the boxes to the open air and calculation method
2) Heat efficiency of a box cooker
3) Heat efficiency of a parabolic cooker
4) Improvement of a box cooker

2.6.3 Education plan to NCERD

The concrete contents of the technology transfer to NCERD are shown in Annex 4.

Chapter 3 Technology for Solar Energy Utilization

3.1 Technology for solar energy utilization

The solar energy has been utilized in various forms all over the world. The sun light has been used as it is to dry farm products or other use in agriculture. Lighting system using sun light has been developed in Japan as one of the new utilization ways. They collect light and transfer it using glass fiber or reflectors to the lower floors of the buildings or houses among tall buildings in big cities. Research on use of sunlight by converting it to electricity or heat has been continued up to today.

3.2 Solar batteries

Solar battery system is of technique by which sunlight is converted to electricity and stored in storage batteries. Table 3-1 shows kinds of solar batteries.

Table 3-1 Kinds of Solar Batteries

Kind	Material	Type
Silicon	Crystallized silicon	Mono-crystallized silicon
		Poly-crystallized silicon
	Amorphous	a-Si, a–SiC, a-SiGe
Compound semiconductor	2—element	CDTe（Cadmium tellurium）
		CDS（Cadmium sulfide）
		GaAs（Gallium arsenic）
	3—element	CuInSe2（CIS: copper, indium- selenium） CIGS（copper –indium- gallium-selenium）
Organic semiconductor	Dye sensitive cell	DSC

Source: Solar energy utilization technology (in Japanese)

Solar batteries using silicon are manufactured corresponding to 1200MW all over the world in 2004, and the products are growing more from year to year. Grid connection system is introduced as individual PV system for households to reduce CO_2 emission in Japan and Germany. The price of solar batteries using silicon tends to rise recently because of demand increase and lack of silicon, though the cost for that has been decreasing for the past 20 years. Batteries of compound semiconductor type are utilized for special use such as satellites because of its high price. However, CIS and CIGS types of 3-element are going to be manufactured in large quantities for sale in Japan next year. Organic semiconductor (DSC) type is a battery that attracts attention lately as the product cost is cheap and silicon is not necessary. The material is titan oxide, pigment, iodine, and conductivity glass. Development of DSC with high conversion efficiency is being promoted in universities and enterprises all over the world. The present conversion efficiency in a laboratory is 5-7%.

3.3 Solar thermal utilization

Solar thermal utilization equipments used at present are classified according to the temperature of utilization in Table 3-2.

Table 3-2 Solar thermal utilization equipments

	Type	Temperature for use	Equipment
Solar heat collecting equipment	Light-condense	Low temperature normal～60 ℃	Hot water supply, heater, dryer, water distiller, incubator, Natural, force circulation system
		Middle temperature 50～130 ℃	Vacuum tube collector industrial water supply, heater, cooker, Absorption type cooler
	Non-light-condense	Middle-high temperature 300～500 ℃	Heliostat type solar generator Parabolic,凹 type generator
		High temperature 1000～3,000 ℃	Parabolic solar furnace Research new alloy

Source: Solar energy utilization technology (in Japanese)

(1) Equipment for low-middle temperature

SERC and NCERD are conducting research on the equipment for low-middle temperature use such as cookers, dryers, water heaters, water distillers and others. The examples that are used actually are limited except water heaters in OECD countries. Research on solar cookers was done aiming for its spread after the World War II in Japan, but it did not become popular because it is useless in the evening and during daytime without sunlight. Solar cookers are manufactured only for environmental education and recreation at present. Solar water heaters are common for bath and shower. Solar water heaters with 200～300ℓ contents for households are placed at the top of the roofs for their use.

(2) Equipment for middle-high temperature

Sunlight is gathered and the generated steam turns a turbine, and it is one of the potential ways of generating electricity in Africa, where the sunlight is abundant.

(3) Equipment for high temperature

Equipment for high temperature is used for research on an alloy of special metal and others in laboratories such as universities.

3.4 Basic concept for research on solar energy

It is indispensable to repeat the following four (4) steps for research and development of new products.

①Plan

②Do

③Check

④Action

The following cycle should be repeated to complete the research.

P→D→C→A → P→D→C→A → → → ・・・→Completion

(1) Plan

At the planning stage, the following should be done.

1) To conduct maker research of the item to be manufactured
2) To conduct survey on the possible purchase price by the users
3) To make decision of the target of the user based on the market research
4) To make decision of the specifications of the merchandise (for household or for companies, functions, size, weight, etc.)
5) To design equipment based on the specifications
6) To examine of materials and way of produce so that the selling price may be acceptable

②Do

1) Make the product based on the design

③Check

1) To examine the trial product from all the points of view
2) To measure the efficiency and the function of the trial product
3) To find out the problems

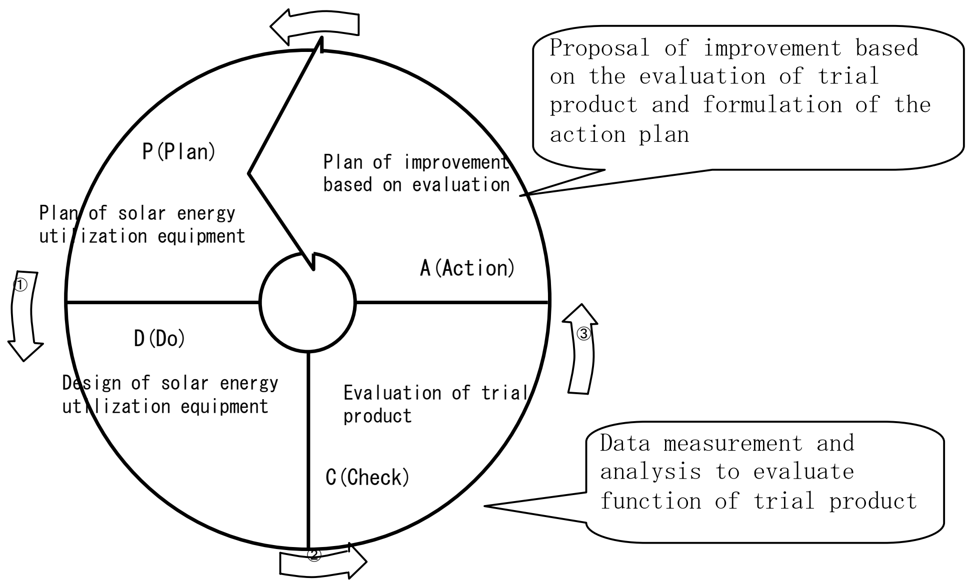
④Action

1) To find out the conditions for the improvement of the product
2) To raise the points to be corrected

⑤Plan (modification plan)

1) To re-design to modify the product

Then it is continued to the following steps.



Source: JICA study team

Fig.3-1 PDCA cycle for R&D of solar energy utilization

Chapter 4 Action Plan for PV Research and Development

A proposal was made on the objectives, organization, items, method, capacity development, funding and others as follows so that SERC and NCERD may conduct research and development (R&D) independently.

4.1 Objectives and process for R&D of the PV unit

The objectives of the PV unit are to develop low-cost PV system to contribute to the unelectrified areas in Nigeria by promoting electrification. The Nigeria government is aiming to supply electricity to 75% of the total population by 2020. It is proposed that 340,000 households are electrified by PV system by 2020, considering the above national aim, rural electrification policy by FMPS and the guideline on the renewable energy policy in the Master Plan. It is suggested that the PV module made in Nigeria be used in the part of the above electrification plan so as to promote electrification and contribute to raise the living standard. The development steps for the two research centers are shown in Fig. 4-1.

4.1.1 Research organization of SERC and NCERD

Both SERC and NCERD are required to decide concrete objectives, and prepare R&D plan, and finalize the plan after discussion with FMST and ECN. The plan should include the objectives, schedule (dead lines), number of staff members, methods, required equipments and devices and budget and others concretely and clearly. FMST and ECT should give them the uppermost support so as to make them to realize the plan after examination of the contents of the plan.

4.1.2 Objective of R&D

Both solar battery units are required to start with the R&D of the appurtenances of PV system, and then they establish a system by which they purchase PV modules and make SHS system with high efficiency (to raise the efficiencies of all the system including controllers and inverters).The ultimate objective is the R&D of PV module (SERC are supposed to import silicon crystal cells, and NCERD amorphous cells.).

4.1.3 Concrete contents and process for R&D

Accumulated basic data is indispensable for R&D of solar batteries. The solar battery units are requited to get the necessary measurement devices to obtain basic data, and to start the following R&D one by one.

(1) To conduct R&D for a controller and an inverter and make trial products,
(2) To assemble SHS system using purchased PV modules and controllers and inverters of their own products so as to improve their technical skill,
(3) To prepare inspection standard, improve inspection skill aiming at improvement of production and assembly of equipments,

(4) Transfer the skill of production and assembly of SHS system to private companies,

(5) To entrust private companies with production of controllers, inverters, import of module and assembly and sale of SHS system,

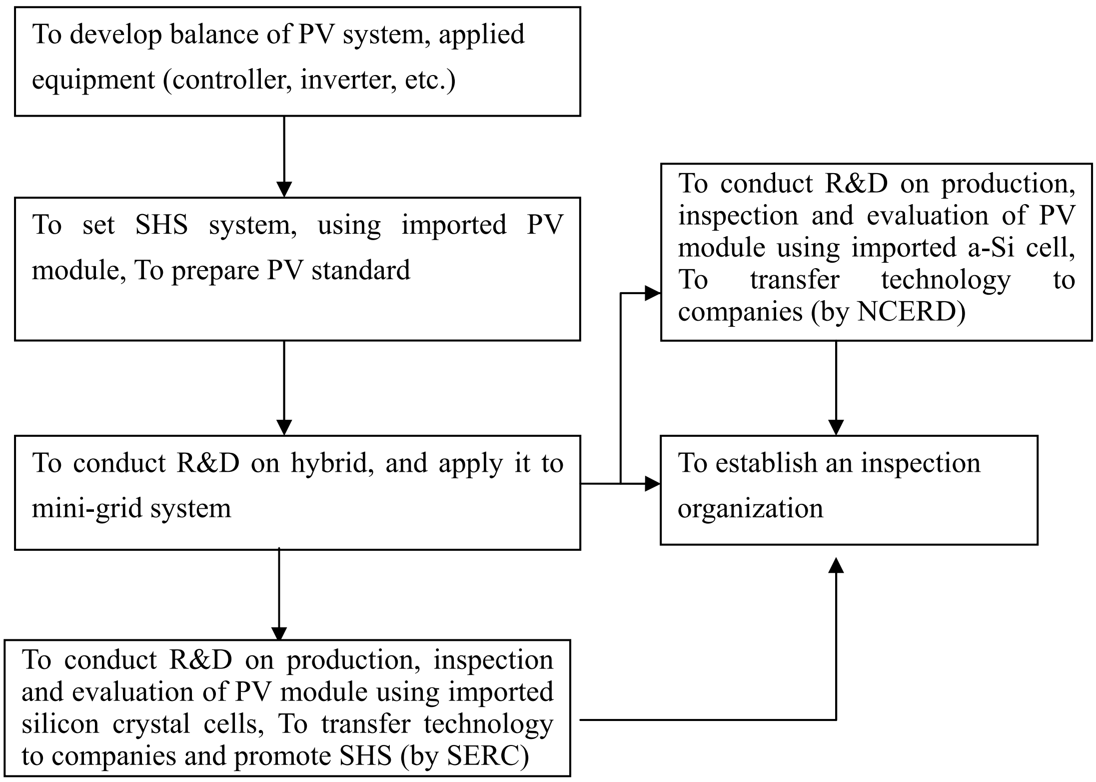
(6) To conduct R&D on hybrid with other renewable system and facilities for electric distribution aiming for practical use,

(7) To conduct R&D on production, inspection and evaluation of PV module using imported silicon crystal cells (by SERC),

(8) To conduct R&D on production, inspection and evaluation of PV module using amorphous solar battery module (by NCERD)

(9) To help to establish an organization for inspection and authorization.

The R&D flow is shown below.



Source : JICA study team

Fig. 4-1 R&D flow of solar battery units

4.1.4 R&D schedule for PV units

The schedule puts an end to the R&D period every 3 years (only the forth period has 5 years). The projects are divided into two groups: one is common for the two research centers and the other is undertaken separately.

(1) 2007-2009

1) To prepare data such as the relation between tilt angle and solar radiation, yearly radiation and generated electricity, etc.

2) To conduct R&D on controllers and inverters

(2) 2010-2012

1) To conduct R&D on SHS assembly using imported module

2) To conduct R&D on inspection and evaluation skill for SHS system

3) To help to prepare the standard on PV in Nigeria

4) To conduct R&D on hybrid with wind, micro hydro power, diesel generation

(3) 2013-2015

1) To continue R&D on inspection and evaluation skill for SHS system

2) To conduct R&D on module (from 2014)

R&D on silicon crystal module is done by SERC and R&D on amorphous module by NCERD. They both should discuss the contents prior to the R&D.

(4) 2016-2020

1) To continue R&D on module assembly

2) To continue R&D on inspection and evaluation skill for module

3) To transfer technology to private companies aiming at spread

(5) Through all the period

1) To prepare manuals on handling the measurement devices (way how to handle, measures to be taken in case of out of order, etc.) (by researchers).

2) To appoint the person in charge of the measurement devices, who will be responsible for the use of the devices, and record the users' name in a notebook (by researchers).

3) To educate engineers in other states (by researchers).

4) To prepare educational manuals (PV principle, way how to handle it, measures to be taken in case of out of order, way how to repair it, etc.)

The schedule is shown in Table 4-1.

Table 4-1 R&D schedule for PV units

year	1(2007 － 2009)	2(2010 － 2012)	3(2013 － 2015)	4(2016-)
Objective	R&D on balance of PV system	System composition by imported module	System composition	Technology Transfer to companies
Solar data	Tilt angle →	PV standard →		
Controller Inverter	Research on importer products →	* →	** →	→
Hybrid		wind/PV →	*** →	Promotion →
Si module research (SERC)			Research, experiment →	R&D →
Amorphous module research (NCERD)			Research, experiment →	R&D →

* Inspection and evaluation for PV system
** Inspection, evaluation and promotion
*** Hydropower/PV, Diesel/PV
Source: JICA study team

4.1.5 R&D plan for PV units

(1) Cost for R&D equipment

Costs for R&D equipment for SERC, NCERD are shown in Table 4-2.

Table 4-2 Purchase schedule for R&D equipment

	2007 – 2009			2010 – 2012			2013 – 2015			2016 – 2020		
Equipment	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)
Controller for research	30	250	7,500	30	250	7,500						
Inverter for research	30	300	9,000	30	300	9,000						
SHS *			0	30	104	3,320	30	104	3,320	100	104	10,400
Hybrid equipment			0	30	1,260	3,780	30	1,260,0	3,780	50	1,260,0	6,300
Module R&D material			0			0	30	28	840	170	28	4,760
Total amount(KN)	16,500-			23,600-			7,940-			21,460-		
Yearly amount(KN)	5,500-/y			7,870-/y			2,650-/y			4,300-/y		

*: including module, battery, controller, lamp, etc.
**: controller, inverter etc.
Source: JICA study team

(2) R&D Equipment and costs

Main R&D Equipments are shown in Table 4-3. Those are necessary for the R&D of modules.

Table 4-3 Purchase schedule of measurement devices for R&D

	2007 – 2009			2010 – 2012			2013 – 2015			2016 – 2020		
Equipment	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)
I=V meter				1	900	900						
Laminator							1	8,000	8,000			
Solar simulator for Cell							1	14,800	14,800			
Solar simulator for Module							1	20,000	20,000			
I-V meter for cell							1	6,000	6,000			
Spectroscope							1	4,500	4,500			
I-V meter for Module							1	5,000	5,000			
Thunder shock tester							1	10,000	10,000			
Meteorological meter	1		5,000									
Other small meters	1 lot		13,000									
Total amount(KN)	18,000-			900-			68,300-					
Yearly amount(KN)	6,000-/y			300-/y			22,870-/y					

Source: JICA study team

(3)Laboratory facilities

The laboratories of PV units of SERC, NCERD need preparation and maintenance. The required amount is shown in Table 4-4.

Table 4-4 Schedule for facility construction and operation

Equipment	2007 – 2009			2010 – 2012			2013 – 2015			2016 – 2020		
	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)	Quan-tity	Unit price (KN)	Amount (KN)
Laboratory equipment (100 ㎡)				1	8,000	8,000						
Equipment (including tools)	1 lot		4,000	1 lot		2,000	1 lot		1,000	1 lot		1,500
Expense for water, light and fuel	1 lot		1,500	1 lot		2,000	1 lot		2,500	1 lot		4,500
Stationeries	1 lot		1,400	1 lot		800	1 lot		1,300	1 lot		2,000
Total amount(KN)	6,900-			12,800-			4,800-			8,000-		
Yearly amount(KN)	2,300-/y			4,300-/y			1,600-/y			1,600-/y		

Source: JICA study team

(4) Schedule for staffing and payroll costs

Numbers of the present researchers and assistants are three and two respectively The staff members should be increased, and the schedule is shown in Table 4-5. The salaries of the researchers are very high, twice the amount of the ones of the staff of the federal ministries. Table 4-5 shows the schedule of staffing, which is based on the action plan, and payroll costs.

Table 4-5 Schedule for staffing and payroll costs

	Unit price	2007－2009	2010－2012	2013－2015	2016－2020
No. of reserchers	N170,000/month	4	5	7	10
Total payroll costs for reserchers	(KN)	24,480	30,600	42,840	102,000
No. of assistants	20,000/month	2	4	7	7
Total payroll costs for assistants	(KN)	1,440	2,820	5,040	8,400
Total payroll costs	(KN)	25,920	33,480	47,880	110,400
Yearly payroll costs	(KN)	8,640	11,160	15,860	22,080

Source: JICA study team

(5) Budget for R&D

Table 4-6 shows the required budget for R&D based on the action plan. FMST and ECN are required to get the required budget every year based on the budget schedule.

Table 4-6 Required budget for R&D

Cost item	2007 - 2009	2010 – 2012	2013 – 2015	2016 – 2020
R&D equipments	16,500,000	23,600,000	7,940,000	21,460,000
Measurement devices	18,000,000	900,000	68,300,000	0
Construction &maintenance	6,900,000	12,800,000	4,800,000	8,000,000
Payroll	25,920,000	33,480,000	47,880,000	110,400,000
Total	67,320,000	70,780,000	128,920,000	139,860,000
Total amount（for each center）	22,440,000	23,600,000	42,980,000	27,980,000
Yearly Total amount (total for SERC and NCERD)	44,880,000	47,200,000	85,960,000	55,960,000

Source: JICA study team

1) R&D of SERC (PV unit)

There will be no need to obtain N10 million for the R&D budget of SERC (PV unit) during 2007-2010 because they have already borrowed measurement devices from JICA.

2) R&D costs of NCERD (PV unit)

The R&D costs of NCERD (PV unit) are shown in Table 4-6**.**

The required costs for both research centers are between N20-30 million except 2013-2015, when measurement devices are scheduled to be purchased.

4.1.6 Budget procurement for R&D

Investment for R&D is not the one from which direct benefit can be expected, but the results can help people to enjoy improved life. The costs for R&D should be borne by national budget basically, but in case of developing countries, where their own budget is limited, support from international donors is common. Nigeria is relatively rich compared with other African countries blessed with oil and other natural resources. It is desirable that Nigeria by themselves will purchase the required facilities and equipments such as measurement and inspection devices, R&D materials and laboratory facilities. JICA let them use the measurement devices on the Annex 1 free of charge for SERC, but there are no such devices, which are minimum requirement, in NCERD. It is impossible to conduct R&D without those. Nigerian government, FMST and ECN, should be aware of this point.

4.2 Capacity development of PV units

Both energy centers need to train staff who can conduct R&D properly to attain the objectives. The both centers send one staff member in several years linking up with a university in the UK for capacity development, but this system has not helped partly because sometimes the staff member did not come back. Accordingly, the education program for the centers will include domestic training, OJT, Off-the job training, study abroad, training abroad, training by experts, training by senior volunteers, cooperation by international agencies, training by south-south cooperation, AICAD.

4.2.1 Capacity development of PV units

There are excellent energy research centers in China, India and Thailand. The one in Thailand has a lot of experiences, and it will be helpful to cooperate with the three universities below.

(1) ATT (Asian Institute of Technology)

ATT is promoting development and standardization of PV equipment with the surrounding countries. They also educate the engineers of those countries.

(2) SERT (School of Renewable Energy Technology)

SERT is conducting research on renewable energy in cooperation with the research centers in Mekong countries, Thailand, Vietnam, Cambodia, Laos, Yunnan in China. They receive many students from those countries and a conference on renewable energy is held every year, and participants are from India, Pakistan, Nepal, Bangladesh, Japan (NEDO) and GTZ.

(3) KMUTT (Mongkut University of Tec renewable energy Technology)

KMUTT conducts R&D on renewable energy and training for engineers.

Those universities are the center of the research, utilization of solar energy, and standardization, and also exchange information with NEDO, Japan. Training in Thailand will be useful for the research centers in Nigeria, because Thailand is similar to Nigeria in terms of the conditions of solar radiation and others and it has many experiences. If the research centers in Nigeria can participate in the conferences, report thesis and exchange information in collaboration with the Thai institute, it will be a great help for their research results.

4.2.2 Cooperation with AICAD (African Institute for Capacity Development)

AICAD is an organization which conducts research, training, information management, capacity development and others for national universities, research institutes, NGOs, small enterprises, residents groups in the three countries in east Africa (Kenya, Tanzania and Uganda), established by JICA. The headquarters is placed in Jomo Kenyatta University, Kenya. Research on renewable energy is one of the most important issues for them. Kenya is located relatively nearby, and its economy, culture, living conditions, natural conditions, etc are similar to Nigeria. The purpose of AICAD is to contribute to poverty alleviation and social economic activities. Therefore, the collaboration between the both energy centers in Nigeria and AICAD is one of the most important links. It is expected that the similar organization will be established in west Africa for mutual cooperation in the future.

4.2.3 Training by international donors

The international donors such as USAID, GTZ, SIDA, UNDP, GEF have training system for solar energy utilization. They hope that rural electrification using PV will be attained through education of PV engineers. FMST and ECN, upper organizations of the research centers, should understand the roles of the research centers. The staff members in charge may be required to participate in a training course such as domestic ones so as to study how the research should be done, research system, way of capacity development, fund raising, etc. as supervisors.

4.2.4 Training by JICA experts

SERC and NCERD need capacity development from basic stage at present. Therefore, it is suggested that they invite JICA experts in the future when they start higher research after they finish arrangement for basic research system through support by JICA senior volunteers or others.

4.2.5 Studying in Japan

The researchers in SERC and NCERD are eager in studying in Japan. Some have already had contacts with related organizations through JICA homepage. The Ministry of Foreign Affairs in Japan receives one or two students from Nigeria every year under their program, but it is very difficult to be the one under the program because the number of students to be invited will remain the same.

4.3 Research outline of the PV units

The both research centers do not conduct any substantial research. They only installed PV panels and conducted performance tests. It is recommended to start with R&D of BOS (balance of system: controller, inverter): to import modules, to assemble SHS using controllers made by themselves, and have experiences of inspection and evaluation. They will import cells, make PV module and cells, and conduct research on inspection and evaluation skill. They are scheduled to start research of module in 2014, to learn technology of produce, inspection and evaluation in 3-4 years, transfer the technology to private companies and spread the PV module made in Nigeria through the companies.

4.3.1 Data accumulation, R&D on system related equipment (controller, inverter)

Basic data (solar radiation and generation, tilt angle and solar radiation, etc.) will be accumulated in 2007-2009 as stated in 4.1.4, and R&D on system related equipment (controller, inverter) will be done. It is suggested that comparison among the products made in Japan, Europe, USA, China, India, etc, be done, and research be conducted aiming the best quality of those after evaluating respective qualities. SERC and NCERD are required to share the results through information exchange to promote the research efficiently.

(1) Way of R&D for system equipment

The way of R&D for system equipment is shown below. Several kinds of products from various makers will be prepared and used.

1) To make a measurement system, and set the controllers and inverters,
2) To check the movement of each part of the controllers and inverters, voltage, electric current, form of waves, etc.,
3) To check the efficiencies of the controllers and inverters,
4) To compare the controllers and inverters entirely,
5) To design them referring to the best controller and inverter
6) To purchase spare parts and develop the same product and check the voltage, electric current, form of waves, etc., after setting it,
7) To repeat the procedure of modification, test, examination, until the same performance is attained,
8) To calculate the cost after completion, continue research aiming for better product, and repeat modification, test, examination,
9) To complete controllers and inverters made in SERC and NCERD,
10) To promote of the development exchanging information (SERC and NCERD)

(2) Preparation of standard for PV inspection and evaluation

PV modules and related equipment should be checked for their functions. The countries which manufacture those have standard for inspection and evaluation, but Nigeria does not have this kind of standard. It is necessary to prepare the standard. The standard for PV inspection and evaluation to be referred is explained later.

(3) Preparation of PV system and promotion

SHS system will be made using imported PV module after completion of a controller and an inverter. The SHS system will be inspected and evaluated by the newly developed standard for PV inspection and evaluation. If the products without inspection are sold in the markets, there will be a lot of bad products in the markets and the reliance for PV will be failed. The technology will be transferred to companies after establishment of SHS system preparation and inspection skill, and instructions to promote high quality products will be made.

Instructions to the engineers of the local governments are also done for the operation and maintenance of the PV system. One of the most important problems is operation and maintenance. The researchers in the centers will prepare the manuals for inspection, quality control, education and others.

(4) Staffing plan

Staffing plan for PV groups is shown in Table 4-5.

4.3.2 Research on Hybrid

(1) Research on Hybrid

A hybrid circuit is a system by which one system is connected with other renewable energy system or other to complement the mutual weak points. It is effective, for example, for mini-grid system, which electrify all of a small village. SERC has PV system (2kW) and wind generation system (2kW), and SERC can conduct research on hybrid system and system connection using those two kinds of system. Required controller and inverter will be developed in the research centers. NCERD are supposed to develop hybrid system with micro hydro power and others.

(2) Hybrid circuit

An example of hybrid circuit is shown in Fig.4-2.

4.3.3 Research on silicon crystal PV module

Nigeria has abundant solar radiation and is one of the most suitable areas for solar power generation. The research should be started with a basic study for module (reform of laboratories, check for measurement devices, R&D equipments, supply sides of research materials, etc.)

(1) Research on module

1) Basic study

The basic study for module, includes products of silicon crystal, global price trend, global spread conditions of PV system and others.

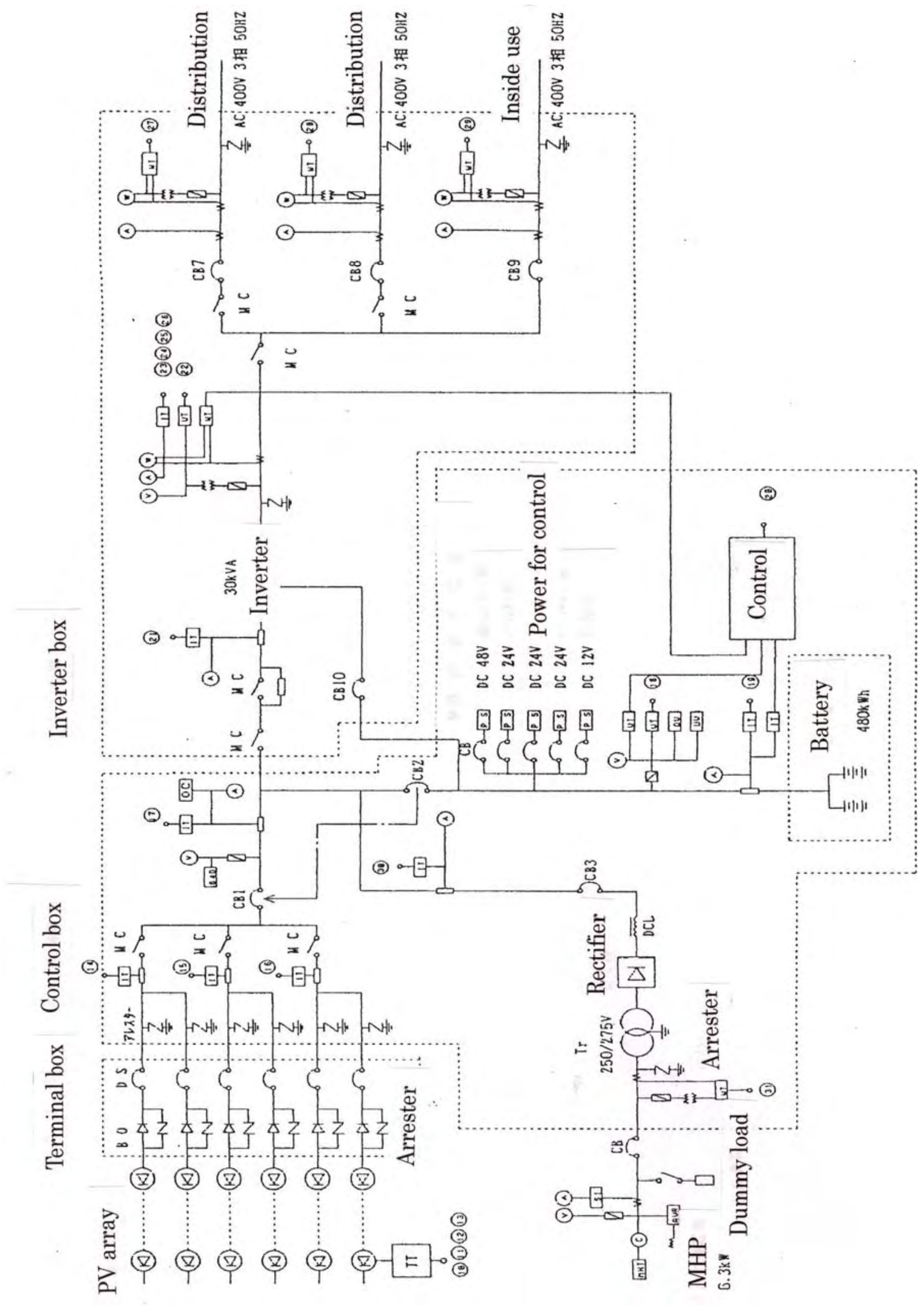
2) Preparation of laboratories

3) Preparation of laminator, measurement devices

4) Purchase of cell, R&D on assembly

5) Module inspection, R&D on evaluation skill

6) Technology transfer of skill for assembly, inspection and evaluation

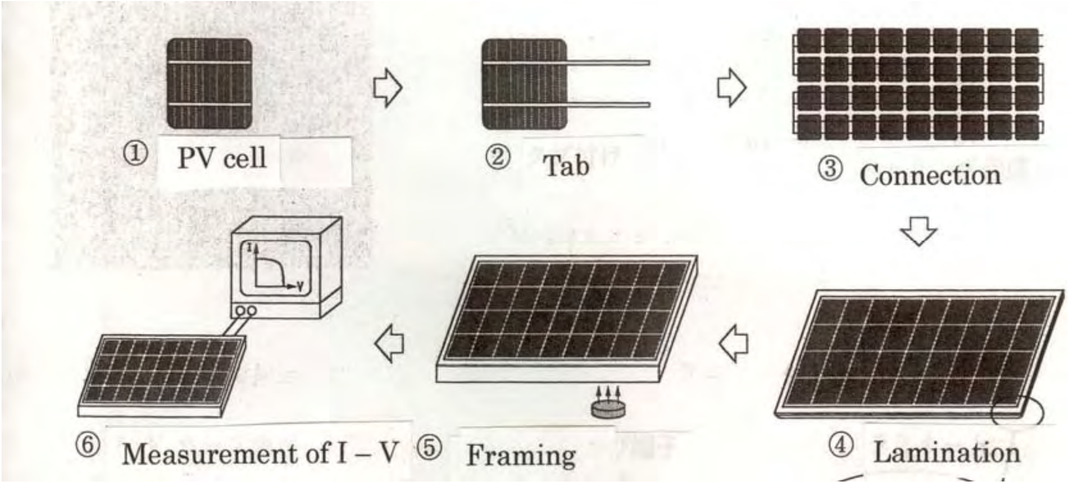


Source: JICA study team

Fig.4-2 Example of hybrid circuit

(2) Manufacturing process of solar battery module

Several kinds of process are necessary to manufacture solar battery modules.

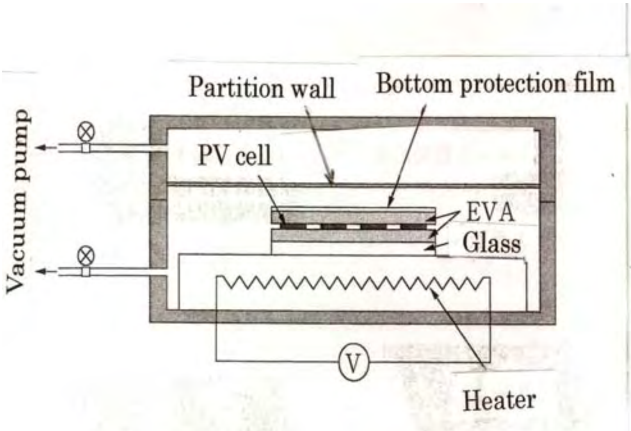


Source: 'Solar battery' (document in Japanese)

Fig. 4-3 Manufacturing process of PV module

(3) Laminating

A laminating device is shown in Fig.4-4 and Fig.4-5. PV cells are laminated in a device after connected.



Source: 'Solar battery' (document in Japanese)

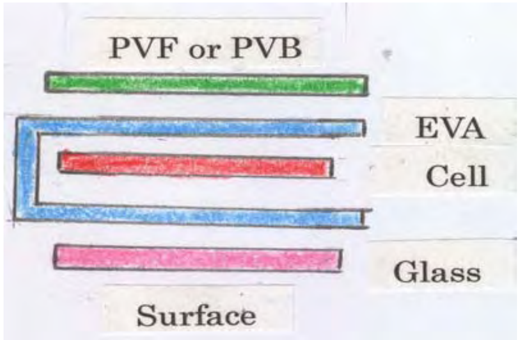
Fig. 4-4 Laminator

Source : JICA study team

Fig. 4-5 Laminator

(4) Laminating model

The positions of respective parts before laminating are shown in Fig. 4-6.



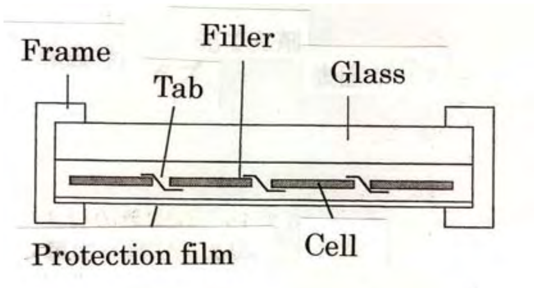
PVB : Poly Vinyl Buthyrol
PVF : Poly Vinyl Fluoride、
EVA : Ethylene Vinyl Acetate

Source : JICA study team

Fig. 4-6 Respective parts before laminating

(5) Structure of PV module

The structure of solar battery module is shown in Fig. 4-7. A frame and terminal are attached after laminating.



Source : JICA study team

Fig. 4-7 Structure of PV module

The required device for R&D of module is only a laminator, and other works will be done by manual, and devices are planned for installation to meet the minimum requirement. The required SHS (55W) is 94,000 sets, and the households to be PV electrified are 343,000, and it is meaningful to manufacture part of the large requirement in their own country. Establishment of new industry is expected in view of employment creation in Nigeria, and therefore, it is required for the federal, state and local government to support the business establishment of PV module manufacture.

(6) Technology transfer of module assembly skill to private companies

It is scheduled that module assembly skill will be transferred to private companies after the

R&D of assembly, inspection and evaluation for modules for 3-4 years. There are some companies which want to manufacture and sell modules. The followings are the ones.

- Juneco Nigeria Limited
- Prime Energy

4.4 Module inspection

The produced modules have to be inspected. It is desirable to use a inspection standard prepared in Nigeria, but it is recommendable to use international standard such as IEC, PV-GAP or other if there is no Nigerian standard. The standard is prescribed at JIS in Japan, and Japanese standard 'JIS C Standard for crystal solar battery' is shown for reference in Tables 4-7 and 4-8. The inspection items are:

1) Performance test by a solar simulator
2) Surface strength test
3) Insulation test
4) Voltage proof test
5) Temperature and humidity test
6) Cell test (done before manufacturing)
7) Temperature rising and humidity test with light

Nigeria is required to study the international standard such as IEC, PV-GAP or their own standard. Crystal solar battery module, measurement method and measurement devices are regulated by JIS shown in Table 4-7. Tests based on the standard are needed to sell the products.

Table 4-7 JIS standards for crystal solar battery module

Object	Mark	Item
Crystal solar battery module	JIS C 8917	Test method for conditions of crystal solar battery module, Test method for durability
	JIS C 8918	Crystal solar battery module
measurement method measurement devices	JIS C 8911	Second standard for crystal solar battery cell
	JIS C 8912	Solar simulation to measure crystal solar battery solar
	JIS C 8913	Measurement method for battery cell output
	JIS C 8914	Measurement method for crystal solar battery module output
	JIS C 8915	Measurement method for spectra sensitivity characteristics of crystal solar battery
	JIS C 8916	crystal solar battery cell/module output voltage
	JIS C 8919	Measurement method for temperature coefficient for output electric current
		Measurement method for crystal solar battery cell/module output

Source: JICA study team

The test methods for conditions of crystal solar battery module, and the one for durability are regulated by JIS C 8917 as shown below.

Table 4-8 JIS C 8917 tests for crystal PV module

	Item	Method
Strength	Wind pressure durability	Put the sample vertically, and put dry sand of 1422 N/ m^2 on it (simplified test)
	Twist test	Fix three corners of the sample, and add twist of 2% of length of a diagonal line. Do the same to the rest three corners.
	Hailstone test	Drop a steel ball with mass 227g, diameter 38 mm to the sample center located 1 m below(simplified test).
Conditions Test	Temperature cycle test	Repeat 200 times of a cycle of change from —40℃ to 90℃ (1cycle=6 hours)
	Temperature durability test	Keep the sample in 85℃ for 1000 hours.
	Humidity durability test	Keep the sample in 85℃ with humidity 90-93% for 1000 hours.
	Temperature/humidity cycle test	Repeat 10 times of a cycle of change from —40℃ to 85℃ with humidity 85%

Source: JICA study team

4.5 Establishment of inspection organization for PV module

Inspection organization for solar batteries is indispensable to spread PV system because the users can rely on the system through an official organization's approval for quality and functions. Some expensive devices are needed, therefore, it is recommended to establish only one (1) inspection organization, which covers all the Nigeria.

(1) Establishment of the organization

It may be efficient to establish it in the same premise of the existing inspection organization.

(2) Duty

Their duty is to conduct inspection of PV system, and issue certifications.

(3) Number of staff

Three (3) Electric engineers are necessary. They are required to participate in training course for basic knowledge for PV and inspection method in a country where inspection is already done or an inspection organization which provides the inspection devices.

(4) Management

They conduct inspection on clients' requests, issue certificates and charge fees to the clients. They manage the business by national budget.

(5) Announcement of the necessities

The necessities of the inspection for sale of PV modules and others by the governmental organization will be announced as a technical guideline from the competent Minister.

(6) Periodical correction

The organization will correct the measurement devices periodically.

(7) Inspection items

The items are stated in 4.5.

(8) Inspection devices and cost

Main inspection devices and prices are shown in Table 4-9. The prices are shown for reference as they are the costs in Japan.

Table 4-9 Main inspection devices and costs

Inspection device	Cost（N）
Solar simulator for cell	14,800,000
I-V inspection device for cell	15,200,000
Spectra sensitivity inspection device	50,600,000
Solar simulator for module	39,500,000
I-V inspection device for module	21,000,000
Test device for temperature and humidity cycle	63,000,000
Test device for voltage hit by thunder	9,900,000
Large scale irradiation simulator	94,100,000
Total	308,100,000

Source: JICA study team

(9) Fund raising for the organization establishment

It is required to purchase measurement devices and the inspection organization. The required amount is 308 million Naira. It is desirable to establish the organization as a national organization, and all the management costs are to be borne by the federal government.

Figures 4-8 and 4-9 are photos of solar simulators. The left one is an imitated solar light radiator, and the right is a device that receives light to the set module.

Source: JICA study team

Fig.4-8 Light of a solar simulator

Source: JICA study team

Fig.4-9Light receiving device of a solar simulator

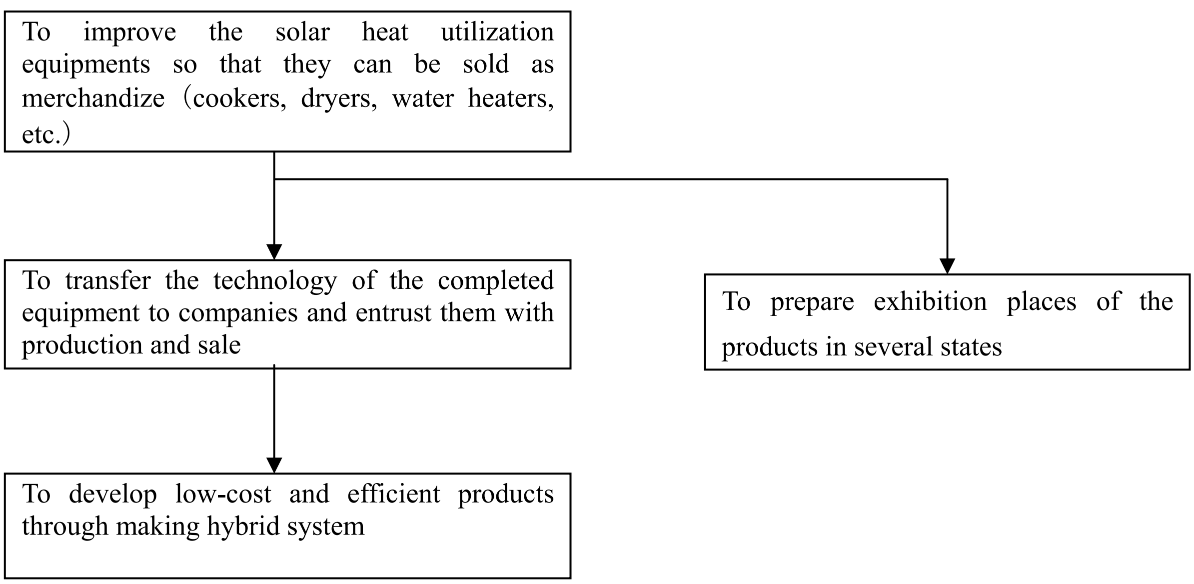
Chapter 5 Action Plan for R&D for Solar Thermal Unit

Many of the solar heat utilization technologies are developed in OECD countries. Heat utilization of renewable energy, with low-density of energy, had not been developed during the period when the oil price was low partly because it is easy to handle. However, the oil price is about 60-70/bbl now, and there is higher possibility they study the heat utilization of renewable energy in OECD countries.

In the dry area north in Nigeria, desertification is moving forward in a speed of 2km/year, but the people get firewood from the shrubs, and it causes forest degradation. It is considered that solar cookers and dryers which the energy research centers are making can contribute to reduce the quantity of the firewood consumption. A proposal has been made for the research of the solar heat utilization units regarding system, objectives, methods, capacity development, fund raising, etc. as follows:

5.1 Research plan of solar thermal units

The purposes of those units are improvement of living standards, reduction of firewood use, and decrease of oil consumption through development of cheap solar heat utilization equipments. Accordingly, it is indispensable to make the equipment diffuse broadly, and to let the people recognize the solar thermal utilization equipments.



Source: JICA study team

Fig.5-1 Development objectives of solar thermal units

Accumulation of basic data of solar power is indispensable for R&D. SERC is required to obtain basic data using the introduced measurement devices and to start the following R&D.

1) R&D for a parabolic cooker
2) R&D for a dryer
3) R&D for a water heater
4) R&D for a distiller
5) R&D for an incubator
6) R&D for a brooder
7) R&D for hybrid solar heat use equipments

5.1.1 R&D schedule of solar thermal units

The units need to clarify the ultimate purpose, time and duration of R&D prior to the start of the research. The schedule puts an end to the R&D period every 3 years. The schedule is shown in Table 5-1.

Table 5-1 Schedule for R&D on solar thermal unit

	2007 – 2009	2010 – 2012	2013 – 2015	2016– 2020
Parabolic cooker	R&D	R&D	R&D and TT	
Dryer	R for I	TT	R&D and TT	
Water heater	R for I	TT	R&D and TT	
Distiller		R for I	R&D and TT	
Incubator	R for I	R&D and TT	R&D and TT	
Brooder	R for I	R&D and TT	R&D and TT	
Hybrid equipment			R&D	R&D and TT

R for I: Research for improvement TT: Technology transfer
Source: JICA study team

5.1.2 R&D equipments procurement plan

(1) R&D equipments costs

The R&D Equipments procurement plan is shown in Tables 5-2 and 5-3. R&D on small equipments will be done from 2007-to 2012. The procurement plans are shown in Table 5-2.

Table 5-2 R&D plan for solar thermal unit (1)

Equipment	Unit price (N)	2007-2009		2010-2012		Remark
		No.	Amount (N)	No.	Amount (N)	
Cooker	30,000	15	450,000	45	1,350,000	Small parabolic
Dryer	110,000	20	2,200,000	45	4,950,000	Small dryer
Water heater	95,000	30	2,850,000	45	4,275,000	Small water heater
Distiller	85,000	5	425,000	45	3,825,000	Small distiller
Incubator	130,000	30	3,900,000	45	5,850,000	For 700 eggs
Brooder	100,000	30	3,000,000	45	4,500,000	For 100 eggs
Hybrid equipment	150,000	0		0		
Total			12,825,000		24,750,000	
Yearly amount(N)			4,275,000		8,250,000	

Source: JICA study team

It is scheduled that R&D on medium and large equipments for cottage industries or farming will be started in 2013. Table 5-3 shows the R&D costs for those equipments.

Table 5-3 R&D plan for solar thermal unit (2)

Equipment	Unit price (N)	2013-2015		2016-2020		Remark
		No.	Cost（N）	No.	Cost（N）	
Cooker	40,000	30	1,200,000	50	2,000,000	Medium parabolic
Dryer	150,000	30	4,500,000	50	7,500,000	Large dryer
Water heater	150,000	30	4,500,000	50	7,500,000	Medium water heater
Distiller	100,000	30	3,000,000	50	5,000,000	Medium（1 m3）distiller
Incubator	180,000	30	5,400,000	50	9,000,000	For 1000 eggs
Brooder	400,000	30	1,200,000	50	20,000,000	7 m2
Hybrid equipment	150,000	30	4,500,000	50	7,500,000	Eg. distiller & water heater
Total			24,300,000		58,500,000	
Yearly amount(N)			8,100,000		11,700,000	

Source: JICA study team

(2) R&D equipments procurement plan

The required R&D Equipments are shown in Tables 5-4.

Table 5-4 Required R&D equipments

Device	Amount (N)	2007-2009		2010-2012		2013- 2015		2016-2020	
		No.	Amount (KN)	No.	Amount (KN)	No.	Amount (KN)	No.	Amount (KN)
Weather meter	5,000,000	1	5,000					1	5,000
Phyranometer	500,000	2	1,000					2	1,000
Portable Phyranometer	300,000	3	900					3	900
Spectrometer	3,500,000	1	3,500					1	3,500
Recorder	700,000	3	2,100					3	2,100
Logger	300,000	2	600					3	900
Thermometers			1,000						1,000
Precision scale	200,000	3	600					3	600
Other meters			1,500						1,500
Total			16,200						16,500
Yearly amount(N)			5,500						3,300

Source: JICA study team

(3) Schedule for operation and maintenance expense

Schedule for operation and maintenance expense for R&D is shown in Table 5-5.

Table 5-5 Schedule for operation and maintenance expense for R&D

	2007 – 2009			2010 – 2012			2013 – 2015			2016 – 2020		
Purchase of equipment	No.	Unit price (KN)	Amount (KN)	No.	Unit price (KN)	Amount (KN)	No.	Unit price (KN)	Amount (KN)	No.	Unit price (KN)	Amount (KN)
Office furniture (including tools)	1 lot		2,400	1 lot		2,200	1 lot		2,400	1 lot		6,000
Costs for water, light and fuel	1 lot		1,200	1 lot		2,000	1 lot		1,200	1 lot		1,500
Costs for stationeries and others	1 lot		1,200	1 lot		1,100	1 lot		1,200	1 lot		2,000
Total	4,800			5,300			4,800-			9,500		
Yearly amount(N)	1,600/y			2,300/y			1,600/y			1,900/y		

Source: JICA study team

(4) Costs for construction and operation of exhibition places

Two (2) exhibition places of the solar heat utilization equipments will be prepared in respective six (6) geo-political zones. The schedule and costs are shown in Table 5-6.

Table 5-6 Schedule and costs for preparation and operation of exhibition places

(unit: N)

	2007-2009	2010-2012	2013-2015	2015－2020
Cost for preparation		21,600,000		
Cost for operation		11,520,000	17,280,000	28,800,000
Total		33,120,000	17,280,000	28,800,000
Yearly amount(N)		11,040,000	5,760,000	5,760,000

Source: JICA study team

(5) Costs for construction and operation of exhibition places

The staff members of the research centers are scheduled to be increased as the research goes ahead. The schedule is shown in Table 5-7.

Table 5-7 Research staff and payroll costs

item	Average salary (N/month)	2007－2009	2010－2012	2013－2015	2016－2020
No. of researchers		4	5	5	6
Increased No. of researchers		0	1	1	2
No. of assistants		2	3	3	4
Increased No. of assistants		0	1	1	2
Total staff		6	8	8	10
Payroll costs for researchers（N）	170,000	24,480,000	30,600,000	30,600,000	61,200,000
Payroll costs for assistants（N）	20,000	1,440,000	2,160,000	2,160,000	4,800,000

Source: JICA study team

5.1.3 Expense schedule of R&D

The expense schedule for R&D for the solar heat utilization units based on the action plan is shown in Table 5-8. FMST and ECN are required to obtain fund for SERC and NCERD based on the expense schedule.

Table 5-8 Expense schedule of R&D

(Unit：N)

	2007 - 2009	2010 – 2012	2013 – 2015	2016 – 2020
Purchase of R&D equipment	12,525,000	24,300,000	35,100,000	17,500,000
Purchase of measurement devices	16,200,000	0	0	16,500,000
Construction & maintenance costs	4,800,000	5,300,000	4,800,000	9,500,000
Costs for exhibition places		33,120,000	17,280,000	28,800,000
Payroll	25,920,000	32,760,000	32,760,000	66,000,000
Total	59,445,000	95,489,000	89,940,000	138,300,000
Total amount (for each center)	19,815,000	31,829,700	29,980,000	27,660,000
Yearly total amount (Total for SERC,NCERD)	39,630,000	44,869,000	54,200,000	49,560,000

Source: JICA study team

5.2 Capacity development of solar thermal unit

The energy research centers are required to conduct capacity development for the staff to that they can attain the research purposes. The contents of this section are the same as the one for the solar battery units.

5.2.1 Training in energy institutes in Thailand

It is already stated that participating in training or conference in the energy institutes in Thailand is considered to be meaningful in 4.2.1. See 4.2.1.

5.2.2 Cooperation with AICAD

It is already stated that cooperation with AICAD is meaningful in 4.2.2. See 4.2.2.

5.2.3 Training by international donors

It is already stated that international donors such as USAID、GTZ、SIDA、UNDP、GEF have various kinds of training courses in 4.2.3. See 4.2.3.

5.2.4 Training by JICA senior experts

It is desirable to invite JICA senior expert when the solar heat utilization units are going to conduct a high standard of research such as treatment of organic waste/waste water or environmentally friendly energy using solar heat.

5.2.5 Studying in Japan

See 4.2.5.

5.3 Outline of solar thermal units

SERC and NCERD are now making trial products such as a water heater, a distiller, an incubator, a brooder. No equipments have been actually used so far except a water heater for a hospital by SERC and an incubator by NCERD, both of which are not used at present. The present condition of the trial products is 'C' of the P-D-C-A cycle, and it is required to decide whether research on those trial products is going to be continued or not, after immediate evaluation.

JICA study team conducted an evaluation of a box cooker, and it was found unsuitable for cooking. It is necessary to change it to a parabolic one and conduct evaluation. Table 5-9 shows the research items by the solar heat utilization group. The priority for trial products should be put by respective research centers, but JICA Study team prepare a plan based on the order of a water heater, an incubator, a dryer, a cooker, and a distiller.

Table 5-9 Research items by the solar thermal unit

Equipment	Type	Remarks	Research center
Cooker	Box type Parabolic type	Consideration needed because of its inefficiency Trial, check and research for commercialization	both
Dryer	Public, industrial	Research for commercialization for vegetable, grain, fruits and fish	both
Water heater	Public Industrial	-For households, for hospitals -For washing for fiber industries, preparation of design, specification, and research for commercialization	both
Distiller	Public, industrial	Research for commercialization as battery water and potable water	both
Incubator	Public, industrial	brooders	both
Brooder	Public, industrial	brooders	both
Hybrid equipment	Public, industrial	Eg. combination of water heater and distiller	both

Source: JICA study team

5.3.1 R&D for cookers, dryers, water heaters, incubators and brooders

The numbers of the staff both research centers are limited, and they cannot start the R&D for all of those equipments. Therefore, it is recommended to conduct R&D based on the priority decided by themselves, and complete research one after another. They are supposed to transfer the technology to private companies after heightening the level of the products for commercialization. The priority recommended by JICA team is shown in Table 5-9 for reference. It is suggested both research centers share the R&D work to improve the efficiency. It is indispensable to select suitable materials, to develop suitable design, make efforts to reduce the production costs.

(1) R&D on cookers

It was found that a box cooker was not practical because of its inefficiency, and therefore, the research should be concentrated on a parabolic cooker. A parabolic cooker made in Japan is designed so that women also can handle and carry it easily, and many women researchers wanted to use it as a trial user. It is suggested that they produced it in a low cost, after improvement if necessary based on the trial users' opinions. It is necessary to conduct research aiming at mass production and broad production. It is suggested to make it refer the one made in Japan, which was given by JICA study team.

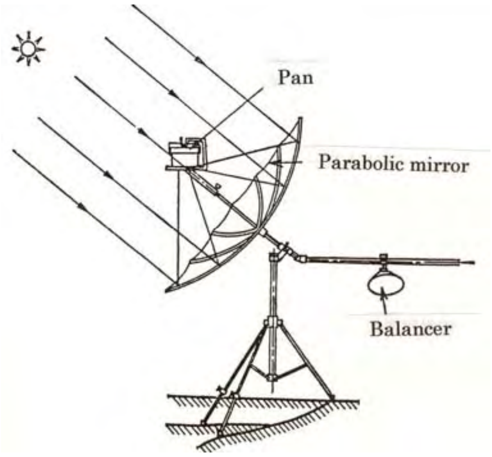
1) Data collection

It is necessary to accumulate data such as test result on solar radiation and water boiling after finishing the R&D of parabolic cookers. If enough data is accumulated, change of specifications can be done easily.

2) Parabolic mirror

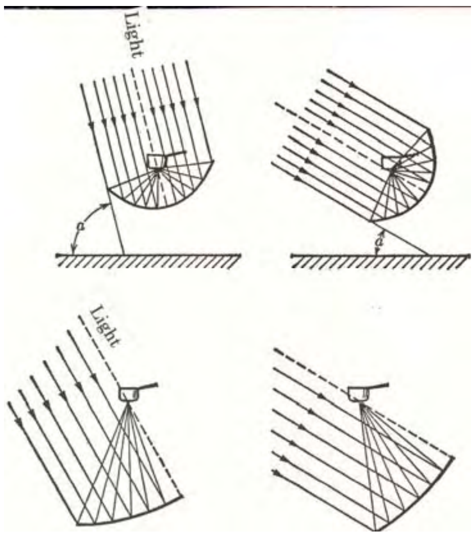
Fig.5-3 shows how to set parabolic mirrors. Attention should be paid to the place to put the mirror if its focus is out of the mirror because it may cause fire if the focus is on combustibles.

It should be put on a place where there is not solar light.



Source: Solar energy book (in Japanese)

Fig. 5-2 An example of parabolic cooker



Source: Solar energy book (in Japanese)

Fig. 5-3 An example of parabolic mirrors

Source: JICA study team

Fig. 5-4 Parabolic cooker (at SERC)

Source: JICA study team

Fig. 5-5 Banana dryer (at SRET, Thailand)

(2) R&D on dryers

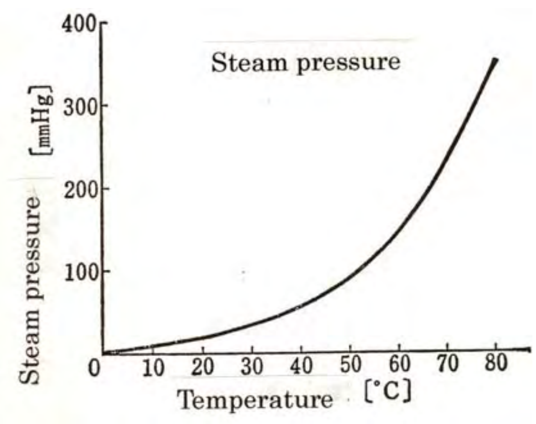
Dryers for households are indispensable to preserve vegetables and fruiters in rural area, where no refrigerators are available. They are very important especially housewives, who take care of health of family members. Storing dried food in their houses can help save time to prepare meals and supply meals with balanced nutrition. Dried fruits are eaten as they are, so dryers are especially important to keep away insects such as flies. Foods can be preserved for a long time because bacteria, enzyme and mold can not propagate in foods with reduced moisture by drying. They are producing dried foods such as dried bananas using large dryers. Fig. 5-5 shows a dryer in SERT.

It is recommended to repeat experiments and check the function: to compare drying conditions by solar dryers and sun-drying and to obtain data of tilt angle of dryers and drying extent. It is necessary to obtain meteorological data such as solar radiation and data on relation between tilt angle of dryers and drying extent.

1) Data collection

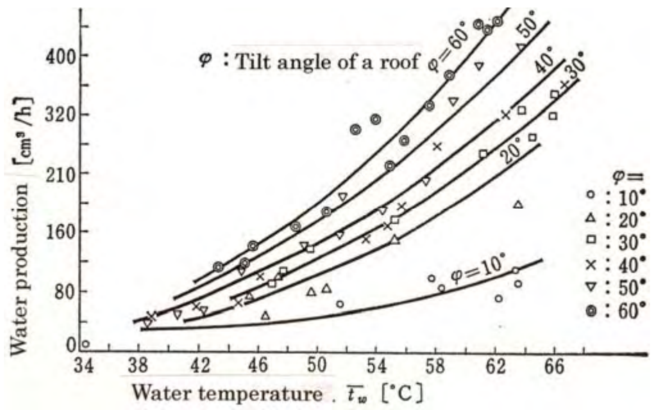
It is necessary to obtain data of solar radiation and produced distilled water after completion of the distiller. The data samples of distiller in Japan. are shown in Fig 5-6, 5-7 and 5-8.

It is suggested similar data be obtained referring those data, and aim at more improvement of the produced distiller. Fig. 5-7 shows a steam pressure curve of water.



Source: Solar energy book (in Japanese)

Fig. 5-6 Water temperature and steam pressure

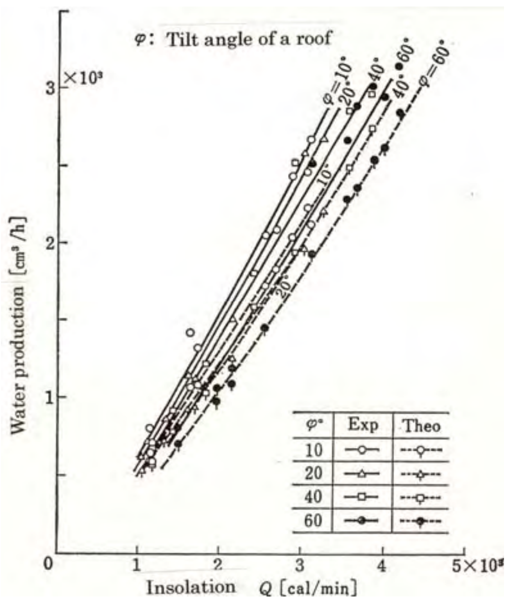


Source: Solar energy book (in Japanese)

Fig. 5-7 Water production and tilt angle of a roof

2) **Water production and tilt angle of a roof**

Figs. 5-7 and 5-8 show experimental data in Japan on water production and tilt angle of a roof. The larger the tilt angle is, the more the water production is and at the same time the smaller the irradiation is. Both research centers are required to conduct similar experiments and obtain data referring to those

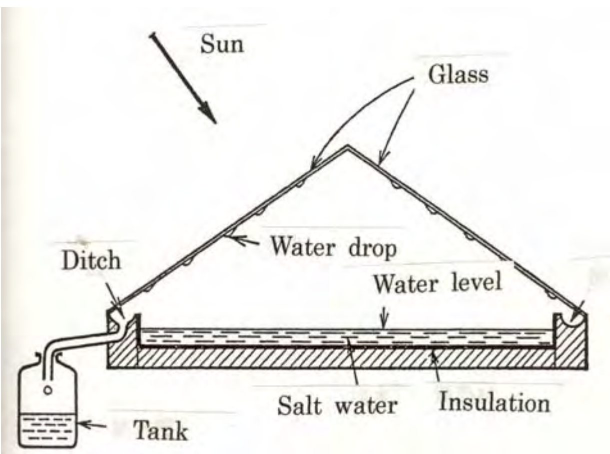


Source: Solar energy book (in Japanese)

Fig. 5-8 Insolation and water production

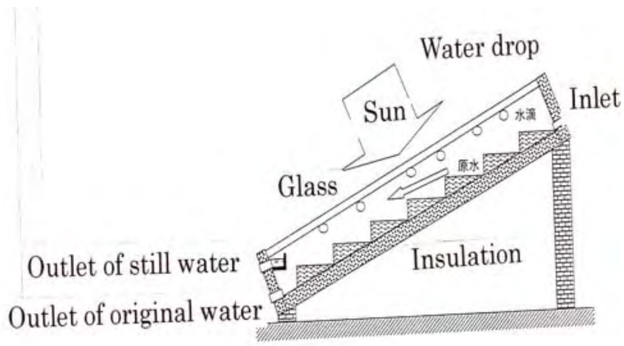
3) **Most suitable tilt angle of a roof**

It has been found the most suitable tilt angle is 15-30 in Japan and both centers are suggested to conduct research on the most suitable angle in Nigeria.



Source: Solar energy book (in Japanese)

Fig. 5-9 Water distiller



Source: Solar energy handbook (in Japanese)

Fig. 5-10 Water distiller using treys in steps shape

4) **Inside treatment of the glass**

The surface of the glass should be treated with caustic soda so that the water drops may slip on the glass surface and fall in the ditch. It is found recently that treatment with titan dioxide has sterilizing properties.

5) **Improvement of equipment**

Fig. 5-10 shows a water distiller using trays in steps shape, one of the various developed water distillers. Combination of this distiller and water heater will be an efficient distiller. It is suggested both research centers make trial products referring to those ones.

6) **R&D on incubator**

Chicken incubators are put to practical use in NCERD, and it is required to improve the equipment so that it may be commercialized.

7) R&D on hybrid equipment

The trial products in SERC and NCERD work as single equipment in most cases. It is recommended to conduct R&D on combination of a water heater and a dryer, a water heater and a distiller, warm breeze equipment and a dryer aiming at production with high efficiency.

5.3.2 Recommendation on products spread

Construction of twelve (12) exhibition places, 2 places in respective six (6) geo-political zones, is recommended to let the people acknowledge the completed products such as cookers, dryers, water heaters, distillers, incubator and others. All of the products, prepared to be used for public and industrial use, should be exhibited. It is also recommended that the research centers will conduct research on efficiency, inspection and evaluation of the products so that the technology can be transferred to private companies. Four (4) exhibition places will be constructed every year from 2010 to 2012. The equipments to be exhibited are shown in Table 5-10.

Table 5-10 Equipments to be exhibited

Equipment	Specifications (for 1 set)		No. of sets	Remark
Cooker	For 4 persons	For 7 persons	12	Parabolic one
Dryer	For household	Cottage industry	12	For vegetables &fruits
Water heater	For household	For industrial use	12	
Distiller	For household	For batteries	12	
Incubator	For 500 eggs	For 1000 eggs	12	
Brooder	For 100chickens	For 200chickens	12	
Hybrid equipment	A dryer	A distiller	12	

Source: JICA study team

Annex of Volume 5

Research & Development on Solar Energy

Annex-1 List of the measurement devices provided by JICA

1. For experiments in RERC

1）Phyranometer
2）Portable Phyranometer
3）Logger
4）Multi meter
5）DC current、voltage、AC current、voltage meter
6）Thermometer
7）Mega tester
8）Thermocouple meter & sensor
9）Compass
10）Tilt angle meter
11）Earth tester
12）Oscilloscope
13）Personal computer
14）Transformer
15）Weather meter
16）Multi meter (AC / DC current clump)
17）Current check tester
18）Power tester (3 phase)
19）Infrared thermo meter（500℃）
20）PH tester
21）Thermo-Anemometer
22）Spectrometer
23）Hygrothermo meter
24）Graduated cylinder
25）Alcohol thermometer
26）Specific gravity tester
27）Scale cup
28）Digital scale

* JICA study team told them to share those equipments among all the staff members in the research center.

2. Provided by JICA study team

1）Parabolic cooker

Annex 2 Technology Transfer to SERC PV Unit

1 Exterior Appearance Inspection

The following points of exterior appearance, setting condition and environment of PV unit have been inspected and advices were given.

(1) Surface of solar panels to be maintained properly
(2) Trees and building not to cast shadows on the solar panels
(3) Solar panels to face right direction
(4) Tilt angle
(5) Temperature and condition of ventilation of battery room
(6) Condition of battery terminal
(7) Condition of measuring instruments
(8) Condition and size of wiring

2 Efficiency of 2kW System

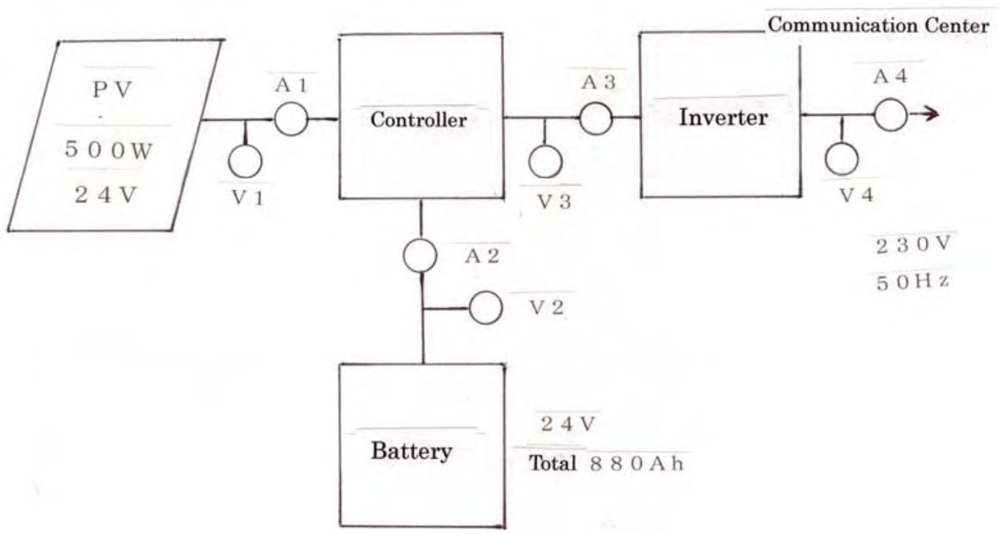
(1) Fitting of Measuring Instruments to the Communication System

The university had installed 2kW PV system to university's communication center as a backup power supply for computer. Measuring instruments brought from Japan were installed to the system. On-site training for measurement and parameter determination for data collection was provided.

(2) Instructions on Measuring Instruments Installation

The installation took long time because SERC did not have proper tools such as screw drivers and spanners.

(3) Circuit Diagram of Measuring Instruments Installation



Source: Study Team

Fig. 1 Circuit Diagram of Measuring Instruments Installation
(A1-A4: Ammeter, V1-V4: Voltmeter)

2kW system of the university consists of eight blocks of 12v, 500W unit. Two units are connected in series and four sets of this series pair are connected in parallel to get 24V, 2kW. Meters are installed to one of the 500W block.

(4) Data Collection

The Study Team collected data by using a pyranometer, thermometer and electric equipment brought from Japan. The PV panel surfaces which had not been cleaned until the measurement were covered on surface with dust. Moreover, trees had grown to cast large shade on the panels. The system stayed almost in dormant condition because of no load connected. As the communication center did not use the power from PV system, a coffee maker (900W) was used as a dummy resistance. Table 2-1 is an extract from data collected on 23 January 2006.

Table 1 Data of 2kW System (Study Team)

(System Configuration: 500W x 4 sets = 2kW, 24V)

(V1-V3, A1-A3: Measurements from 1 bock, A4, V4: Measurements of the system)

	Time/Unit	10:30	11:30	12:30	13:30	14:30
Insolation	W/m^2	668	813	902	891	775
Air Temperature	℃	33.1	35	35.2	39.3	36.3
Panel Temperature	℃	40.1	48.5	53.1	54.2	52.4
V1	V	25	25	25	25	24
A1	A	9	9.5	9.5	9	6
V2	V	24	25	25	25	24
A2	A	20	15	12	11	7.5
V3	V	22.5	24	24	24	23
A3	A	10	9.5	9.5	7.5	9
V4 （AC）	V	230	230	230	230	230
A4 （AC）	A	3	3.5	3.5	3	3.5

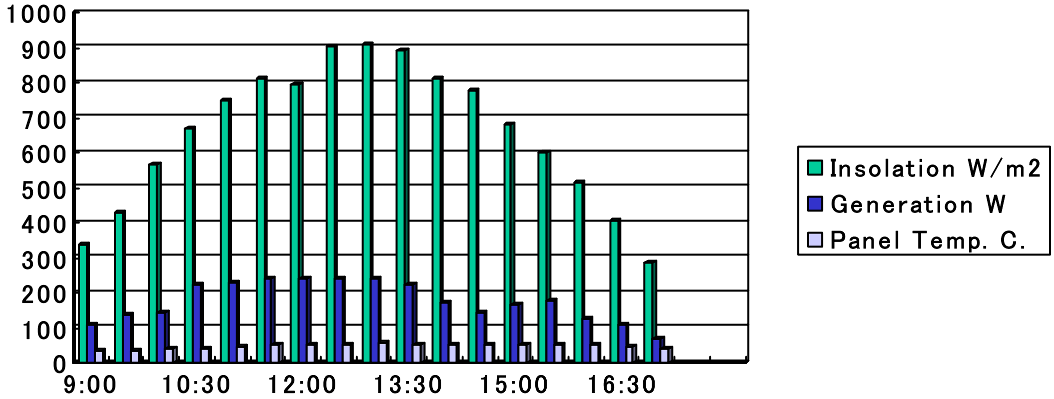
Source: Study Team

1) Generation efficiency

As shown in Table 1, the generation efficiency was about 60%. This is corresponding to the solar radiation of 902W/m^2 and the panel temperature of 53.1℃. The dust on the panel surface had large influence on the measurement results.

2) Load efficiency

The use efficiency with the dummy resistance has been tabulated. The actual load was less than 5% of the capacity. Fig. 2 shows solar radiation and power generation in Sokoto (unit: W).



Source: Study Team

Fig. 2 Solar Radiation and Power Generation

(5) Results and Findings

After the measurements, the followings have been identified.

1) System maintenance is inadequate
2) Batteries are not charged uniformly
3) Generation efficiency is low
4) Panel cleaning is insufficient
5) System is almost dormant (no load)

(6) Training and education for researchers and engineers

The following points for the maintenance have been explained.

1) Effect of panel temperature rise

The panel performance specified in the catalog corresponds to the panel temperature of 25℃. As the temperature rises by 1℃, the power output decreases by 0.45%.

2) Effect of solar radiation

The generated power changes almost in proportion to the solar radiation. The performance specified in the catalog corresponds to the solar radiation of 1kW/m^2.

3) Dust on panel surface

The generated power drops by dust on the panel surface as the solar radiation cannot effectively penetrate. This effect is significant in Sokoto. Before the cleaning, the surface had been fully covered with dust.

4) Tilt Angle

Sokoto is located at latitude N13°, and the tilt angle was set to 15°. Effect of tilt angle on solar radiation was examined during the 3rd field study.

5) Full Charging of Battery

When batteries are not charged uniformly, batteries are to be charged fully once in a month.

6) Efficiency calculation of the inverter

2.1 Evaluation of 2kW PV System

2kW PV system was tested between February and May 2006 by the PV Unit of SERC.

(1) Results

Data was collected every month on around 23rd as well as on the previous day and on the following day. According to the data collected, generated power and load were same as the measurements done by the study team. Data of February and March clearly showed that batteries had problems. Therefore battery acid was replaced totally and batteries were fully charged. As a result of this, data of April and May showed normal figures. Table 2 is an extract from the data collected on 2nd May after the battery maintenance.

Table 2 Data of 2kW System (SERC PV Group)

(System Configuration: 500W x 4 sets = 2kW, 24V)

(V1-V3, A1-A3: Measurements from 1 bock, A4, V4: Measurements of the system)

	Time/Unit	10:00	11:00	12:00	13:00	14:00
Insolation	W/m^2	806	910	1014	923	923
Air Temperature	℃	37.5	39.5	41.3	42.2	43
Panel Temperature	℃	44.8	51.2	52.4	60.3	55.4
V1	V	25	25	25	25	25
A1	A	10	10	10	10	10
V2	V	25	25	25	25	25
A2	A	20	15	15	15	15
V3	V	24	24	24	24	24
A3	A	10	10	10	10	10
V4（AC）	V	230	230	230	230	230
A4（AC）	A	4	4	4	4	4

Source: Study Team

(2) Data Evaluation and Advices

Data collected by SERC PV Unit was evaluated and following advices were given.

1) Replacement of system ammeter

System ammeter was not functioning and to be replaced or repaired.

2) Full battery charge

In order to charge each cell evenly, batteries are to be fully charged once in a month.

3) Prevention of stratification of electrolyte

If operation rate of batteries remain at low level for long time, electrolyte stratifies. In order to prevent this, batteries are to be shaken once in a month to stir the acid inside.

3 Effect of Tilt Angle on Solar Radiation

(1) Measurement of Solar Radiation with Different Tilt Angles

During the 3rd field study, amount of solar radiation was measured against different tilt angles. Since Sokoto is located at latitude N13°, four tilt angles (15°, 13°, 10° and 0°) were selected to compare. Table 3 shows the results. Since the position of the sun is in North of

Sokoto in May, the solar radiation is higher with less tilt angle. The result showed maximum radiation at 5°. Tilt angle's influence on the radiation was explained.

Table 3 Tilt Angle and Solar Radiation (Unit: W/m^2)

Tilt angle	0°	10°	13°	15°
5/06/2006		753.2	738.1	
6/06/2006			813.6	810.1
7/06/2006	780.5		726.2	

Source: Study Team

Generally tilt angle is set to latitude plus 2° or 3° taking easiness of surface cleaning and rain water flow into consideration. Due to the condition of sandstorm in Sokoto, there is no big difference between the amount of dust piled on the surface with tilt angles of 15° and 0°. Therefore it is advisable that tilt angle is to be set mainly considering the demands for the system.

(2) Continuous Measurement of Relationship between Solar Radiation and Tilt Angles

Continuous measurement of relationship between solar radiation and tilt angles was recommended. Tilt angles are to be 15° South and 0°. As shown in table 4, the sun moves towards North and South and solar radiation changes with tilt angle. Therefore it is recommended that SERC is to decide appropriate tilt angle taking PV demand period, cleaning method and weather into consideration after taking the data through the year.

Table 4 Movement of the Sun

	latitude (°)	Passing Date	Passing Date	Remarks
Tropic of Cancer	N23	23/6		Towards North
Sokoto	N13	23/5	18/8	Towards North
Nsukka	N7	20/4	27/8	
Equator	0	23/3	23/9	Towards South
Tropic of Capricorn	S23	23/12		Towards South

Source: Study Team

(3) After the data collection, tilt angle is to be fixed taking the following factors into account.
1) Period when maximum PV generation is required
2) Possibility of panel cleaning (to consider panel installation height)
3) Weather condition (possibility of abnormal weather, hailstorm, etc.)
4) Security against theft

(4) Data to be collected
1) Solar Radiation
2) Generated Power (using 55W module, ammeter and voltmeter)

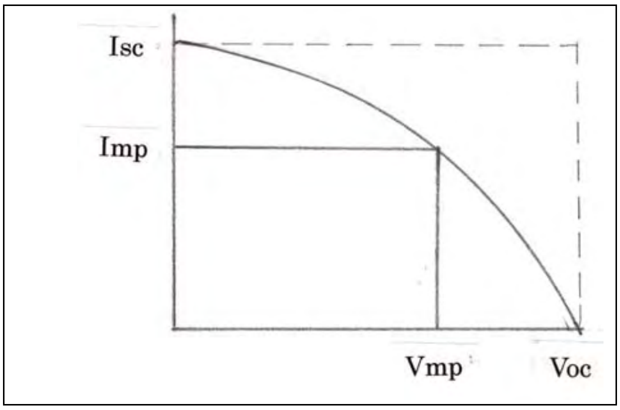
3) Weather condition (temperature, humidity, wind velocity)
4) Panel Temperature

4 Measurement and Calculation of Fill Factor (FF)

Methods of measuring and calculation of FF were instructed. FF is given by the following formula.

$$FF = (Vmp \times Imp) / (Voc \times Isc)$$

Generally FF ranges from 0.6 to 0.8 although it varies with panel. Fig. 3 shows the I-V curve of PV module.



Source: Study Team

Fig. 3 I-V Curve of PV Module

(1) Measurement Method

Voc and Isc of the module were measured. Vmp and Imp were worked out from comparison of figures given in the catalogue.

(2) Results

Table 5 shows the results.

Table 5 FF of the Module (Siemens make of 1990)

Tilt angle 13°	Catalogue Value	Measured Value
Voc	21.7	18.14
Vmp	17.4	13.84
V（Voc – Vmp）	4.3	4.3
Isc	3.45	2.83
Imp	3.15	2.58
K（Imp / Isc）	0.913	0.913
FF	0.73	0.7

Source: Study Team

Annex 3 Technology Transfer to SERC Solar Thermal Unit

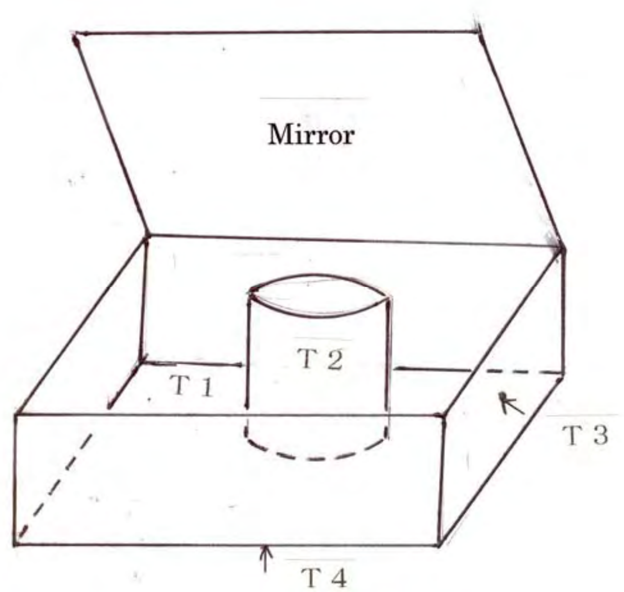
1 Exterior Appearance Inspection

Test site of SERC has prototypes of solar cooker, solar drier, solar water heater and solar distiller. Each piece of equipment is made of wooden box and galvanized iron sheet. Iron sheet of the distiller was rusted. Based on the discussion with the SERC, it was decided that the box-type solar cooker would be studied at first. The cooker had the wooden box with galvanized iron sheets spread inside and a reflector as shown in Figure 1. At the beginning, the condition of cooker did not suit the measurement. Therefore the study team gave advices and instructions to repair the cooker before the measurement.

2 Method of Data Collection on Box-Type Solar Cooker

The pyranometer, thermometer, automatic temperature recorder and meteorological meter were used. Several thermo sensors were fixed to the cooker to measure T1 through T4 as shown in Figure 1. The following data were collected.

(1) Solar radiation – measured in mV and converted to W/m^2
(Conversion ratio : 7.69 mV/7.69x1,000)
(2) Air temperature and humidity
(3) Wind velocity
(4) Temperature inside the box-type cooker: T1
(5) Temperature of the water in the pot: T2
(6) Temperature on the right surface of the box: T3
(7) Temperature at the bottom of the box: T4



Source: Study Team

Figure 1 Box Type Cooker and Temperature Measurement

2.1 Result of Experiment

The data were collected as described below. Measurement and calculation of heat transfer from the box, solar radiation and temperature rise of cooker, water boiling test, and rice cooking test were done. Extract data of water boiling test is shown in Table 1 and extract data of rice cooking test is shown in Table 2.

Table 1 Extract Data of Water Boiling Test

	Unit / Time	12:10	12:30	12:50	13:10	Average
Insolation	W/m^2	827	709	810	819	791
Air Temperature	°C	41.4	40.4	39.9	40.6	41.0
Humidity	%	7.6	8.0	9.8	6.9	8.0
Wind Velocity	m/h	2.1	2.8	1.8	1.5	2.0
T1 (box inside)	°C	84	90	94	97	
T2 (pot inside)	°C	31			84	
T3 (box side)	°C	43.6	45.0	42.6	43.7	
T4 (box bottom)	°C	42.2	42.0	41.2	42.0	

Source: Study Team

Table 2 Extract Data of Rice Cooking Test

	Unit / Time	10:20	11:00	11:20	12:00	12:20	13:00	13:20	13:40
Insolation	W /m2	637	749	787	858	874	908	880	871
Air Temperature	°C	29.1	31.4	32.8	35.1	38.4	41.2	37.6	37.6
Humidity	%								
Wind Velocity	m/h								
T1 (box inside)	°C	28	91	97	110	111	124	129	131
T2 (pot inside)	°C	27	37.1	46.4	69.5	78.9	90.8	99.2	101
T3 (box side)	°C								
T4 (box bottom)	°C								

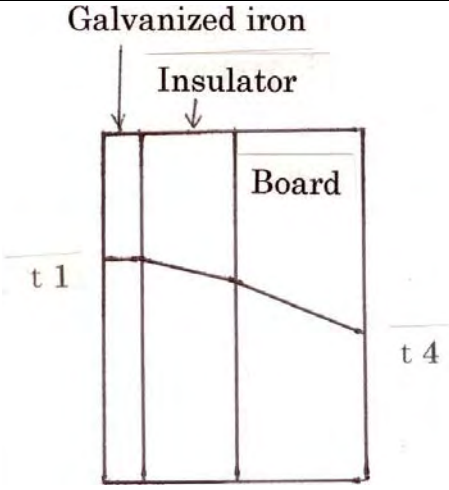
Source: Study Team

3 Heat Transfer Calculation

Test results show that the heat transfer from high temperature side to low temperature side is small, indicating no problem with heat retention and insulation. The Study Team explained the method of calculation for heat transfer so that the researchers can do it by themselves.

(1) Heat Transfer Diagram

Figure 2 is the heat transfer diagram.



Source: Study Team

Figure 2 Heat Transfer at Bottom of Cooker

(2) Thermal Conductivity and Thickness of Various Materials of the Box

Thermal conductivity and thickness of various materials of the box are summarized in Table 3.

Table 3 Thermal Conductivity and Thickness of Various Materials

Material	Symbol	Unit	Galvanized iron	Insulation	Wooden plate
Thermal Conductivity	k	W/mk	50	0.08	0.14 – 0.18
Thickness	b	Mm	1	51	13

Source: Study Team

(3) Heat Transfer Calculation

The following formula was used for heat transfer.

$q = (t1 - t4) / \{(b1 / k1) + (b2 / k2) + (b3 / k3)\}$ result: $q = 82.3$ W/m^2

3.1 Water Boiling Test and Efficiency Calculation

It took three hours for the water to boil on the day of the test. The time depends on the solar radiation. The study team calculated and explained the relationship between solar radiation and water temperature. Calculation method is shown below.

The following calculation shows the time required for heating up 1 ℓ of water from 31°C to 84°C. The result was compared with the actual time shown in Table 1.

(1) Area receiving solar radiation

Bottom 0.25 x 0.35 = 0.0875 m^2

Side 1 0.146 x 0.425 x 2 = 0.124 m^2

Side 2 0.146 x 0.335 x 2 = 0.0978 m^2

Mirror 0.42 x 0.5 = 0.21 m^2

Total 0.432 m^2

(2) Basic Conversion Rate

1 kW/m^2 = 1 kJ/m^2

1 kcal = 4.186 kJ

(3) Heat Calculation (Efficiency Calculation)

Average sun radiation from 12:10 to 13:10 :	791 W/m^2s
Water temperature rise :	84 – 31 = 53 °C
Required Energy :	53 x 1 (L) = 53 kcal
Sun radiation conversion:	0.791 W/m^2=0.189 kcal/m^2
Received energy by cooker :	0.189 kcal/m^2s x 0.432 m^2 = 0.082 kcal/s
Required time to receive 53 kcal :	53 kcal / 0.082 kcal/s = 646.3 sec.
	→ 10.8 minutes

It took 60 minutes to raise the temperature of 1ℓ water from 31°C to 84°C. Temperature rose rapidly up to about 80°C. However temperature rising from 84°C to 100°C slowed down and this dropped the total efficiency.

Efficiency up to 84℃ ： 10. 8/60 = 0. 18 → 18%

3.2 Rice Cooking Test

3.2.1 Test of Original Cooker

The result of test is shown in Table 2. It took more than three hours to cook rice on the day of the test. Box-type cooker managed to cook rice but it took long time. On another day when sun radiation was stronger, it still took about two hours to cook 500 g of rice with 1 ℓ of water. Naturally required time also depends on the amount of rice and water.

3.2.2 Defects of Original Cooker

Original box-type cooker had the following problems and hence was not suitable for cooking.

(1) It too long time to boil water. Heat collection was not effective.
(2) Opening cover during the cooking dropped the temperature.
(3) Steam from the pot obstructed solar radiation to the cooker.
(4) It was unusable in the afternoon.

3.2.3 Modified Cooker

The cooker was modified by increasing reflector mirrors from one to four which cover four sides of the box. This modified cooker was tested.

In the morning it took 100 minutes to heat up 0.5 ℓ of water from 36 °C to boiling as shown in Table 4. In the similar experiment after exposing the cooker to the sunshine to raise the inside temperature, water of 42 °C boiled after 42 minutes as shown in Table 5. Warming up the cooker by the sunshine before use was effective.

Table 4 Modified Cooker : 1st Boiling Test

Amount of water：0.5 L

Sun Radiation Receiving Area：0.63 m^2

	Unit	10:20	10:40	11:00	11:20	11:40	12:00	Average
Sun Radiation	W/m^2	752	766	830	895	888	895	838
Air Temperature	°C		31.3	33.6	33.9	34.2	35	
Inside Temperature	°C	64	111	125	131	136	140	
Pot Temperature	°C	36	58.2	79.2	93.6	98.6	100	

Source: Study Team

Table 5 Modified Cooker : 2nd Boiling Test

Amount of water：0.5 L

Sun Radiation Receiving Area：0.63 m^2

	Unit	12:20	12:40	13:00	13:08	Average
Sun Radiation	W/m^2	898	912	902	908	905
Air Temperature	°C	32.9	34.1	35.8	36.6	
Inside Temperature	°C	150	135	138	143	
Pot Temperature	°C	42.1	74.6	95.1	100	

Source: Study Team

3.2.4 Efficiency Calculation of Modified Cooker

Efficiency was worked out from the results of the 2nd test as shown in Table 5.

(1) Calculation 1

Temperature rise of water : 100 – 42.1 = 57.9
Required energy : 57.9 x 0.5 L = 28.95 kcal
Energy from the sun: 905 w/m^2s = 0.216 $kcal/ m^2s$
Heat Receiving area 0.635 m^2
Received calories per 1 sec: 0.635 x 0.216 = 0.136 kcal/s = 8.16 kcal/minutes
Time required if 100% efficiency :
28.95 / 8.16 = 3.55 minutes
Actual time : 48 minutes
Efficiency : 3.55 / 48 = 7.4 %

(2) Calculation 2

Actual time : 48 minutes x 60 = 2,880 sec.
Received calories per 1 sec: 0.635 x 0.216 = 0.136 kcal/s
Total received energy : 2,880 x 0.136 = 391.68 kcal
Total output heat: 57.9 x 0.5 L = 28.95 kcal
Efficiency : 28.95 / 391.68 = 7.4 %

Efficiency was 7.4%. Efficiency improvement by adding three booster mirrors was not significant. Probably this is because reflection rate of aluminum foil used for the mirrors was low.

3.2.5 Rice Cooking Test of Modified Cooker

Table 6 shows the result of rice cooking test of the modified cooker.

Table 6 Modified Cooker : Rice Cooking Test

Condition： Rice 300 g , Water 900cc
Direction： North East
Insolation receiving area 0.635 m^2

	Unit	10:20	10:40	11:00	11:20	11:40	12:00	12:20	12:40	Ave.
Sun Radiation	W/m^2	681	711	766	769	811	827	844	841	781
Air Temperature	°C		36	36	37	37	38	39	39	
Inside Temperature	°C		90	109	110	120	123	125	125	
Pot Temperature	°C	38.3	48.6	58.7	67.5	79	86	92.7	97.2	

Source: Study Team

It took 120 minutes on the day of experiment when sun radiation was not so strong.

3.2.6 Additional Modification to Modified Cooker

Test is to be done after replacing reflector's aluminum foil with better reflection foil.

4 Parabolic Cooker

4.1 Water Boiling Test of Parabolic Cooker

Table 7 is the result of parabolic cooker brought from Japan.

Table 7 Water Boiling Test of Parabolic Cooker

Amount of water：0.5 ℓ
Sun Radiation Receiving Area：0.47 m^2 (diameter of parabola : 0.8 m)

		11:00	11:20	11:40	12:00	Ave.
Sun Radiation	W/m^2	830	895	888		874
Air Temperature	°C	33.6	33.9	34.2		
Pot Temperature	°C	37	90.1	96.8		
		Start		Finish		

Source: Study Team

As temperature rose, the cooker became sensitive to disturbance by wind and pace of temperature rise dropped. It took 20 minutes for heating up water from 53 °C to 90 °C, and another 20 minutes from 90 °C to 96 °C. After this point, temperature started dropping due to the wind.

4.2 Efficiency Calculation of Parabolic Cooker

(1) Calculation 1 (Efficiency from 37 °C to 96 °C)

Heating time : :	40 minute×60=2,400 s
Amount of heat / m^2s :	874 W/4.186=0.208 kcal/m^2s
Heat received / s:	0.47×0.208=0.0977 kcal/s
Total received heat :	0.0977×2,400＝234.48 kcal
Temperature rise :	96.8－37 = 59.8
Amount of heat output :	59.8×0.5=29.9 kcal
Efficiency :	29.9/234.5=0.1275=12.75 %

(2) Calculation 2 (Efficiency from 37 °C to 90 °C)

Heating time : :	20 minute×60=1,200 s
Amount of heat / m^2s :	862 W/4.186=0.206 kcal/m^2s
Heat received / s:	0.47×0.206=0.0968 kcal/s
Total received heat :	0.0968×1,200＝116.2 kcal
Temperature rise :	90.1－37=53.1
Amount of heat output :	53.1×0.5=26.55 kcal
Efficiency :	26.55/116.2=0.228=22.8 %

As shown in the above example, efficiency rates up to 90 °C and 96 °C are 22.8 % and 12.75 % respectively. The efficiency is higher than that of box-type cooker. Since the parabolic cooker is sensitive to wind disturbance, the cooker should be placed in a place to avoid wind.

4.3 Rice Cooking Test of Parabolic Cooker

Table 8 Rice Cooking Test of Parabolic Cooker

Amount of rice : 300 g, Amount of water : 0.5 L

Sun Radiation Receiving Area：0.47 m^2 (diameter of parabola : 0.8 m)

		12:20	12:40	13:00		Ave.
Sun Radiation	W/m^2	898	912	902		904
Air Temperature	°C	32.9	34.1	35.8		
Pot Temperature	°C	37.2	78.8	91.1		

Source: Study Team

Rice was cooked in 40 minutes. Test was stopped when pot temperature reached 91 °C because it was windy on the day of test.

4.3.1 Monitoring Use of Parabolic Cooker

This parabolic cooker is designed to be handy for housewives. Adjustment of tilt angle and facing direction is easy. Its handiness and high performance made it very popular among female researches. Therefore many female researches were interested in its monitoring use. The cooker will be improved taking their monitoring result into consideration.

5 Training and Technology Transfer to Technician and Researchers

As described already, the following points were explained.

(1) Data collection method of cooker
(2) Data analysis method
 · Heat transfer calculation
 · Heat conductivity
 · Solar energy calculation method
 · Cooker's efficiency calculation method
(3) Defects of box-type cooker
(4) Modification of box-type cooker
(5) Assembling and testing method of parabolic cooker

5.1 Summary of Cooker

Efficiency of the box-type cooker was lower than that of parabolic cooker, although it was improved after adding booster mirrors to cover four sides of the box. After testing the modified box-type cooker, production of parabolic cooker was recommended.

6 Solar Drier Test

SERC Solar Thermal Unit tested solar drier by themselves. Drying test of vegetables (tomato, okra and pepper) was conducted. The summary result is shown in Table 9.

Table 9 Summary of Vegetable Drying Test

		1st Day	2nd Day	3rd Day	Total Time	Water Evaporation
Measuring Time		13:30–14:50	10:00–15:00	10:00–12:20		
Ave. Insolation	W/m^2	813	918.5	875		
Tomato	kg	3	1.2		25 h 30 m	1.8 ℓ
Okra	kg	2		1.35	46 h 50 m	0.65 ℓ
Pepper	kg	2		1.42	46 h 50 m	0.58 ℓ

Source: Study Team

The above table is the summary of data collected. Number of data collected in a day was few and the weight of vegetables was measured only at the beginning and the end of test. Starting test by using measuring instruments provided by JICA is appreciated, although amount of data was insufficient.

6.1 Method of Drier Test

Method of test and data to be collected was instructed.

Annex 4 Technology Transfer to NCERD

Originally there was no technology transfer plan to NCERD. In response to the request from NCERD, the study team member visited and gave advices and proposals to NCERD during the field studies. The following is the summary result of the visit.

1 NCERD PV Unit

1.1 Tilt Angles and Power Output

NCERD PV Unit had installed solar panels on the roof of the center for computer back-up power supply, street lighting, battery charging and comparison experiment. PV panels are installed facing south and with five tilt angles (8□, 15□, 16□, 18□, 22°)without specific reasons. We tried to study the effect of tilt angle on generated power. Unfortunately data collection was not sufficiently done due to the rainy season. We could not get sufficient solar radiation due to the cloud. We could not measure the amount of solar radiation due to lack of pyranometer. Although the data was insufficient, the difference caused by the different tilt angles was confirmed.

1.2 Efficiency of Inverter in Ikeakpa Awka village

We visited PV system of meeting hall in Ikeakpa Awka village. Efficiency of the inverter was calculated based on the data collected in the village. The result showed a big loss in the inverter.

Capacity:	550 W (24V)
Inverter:	220 V 50 Hz
Load:	Lights and TV of meeting hall
Load capacity:	220 V, 0.3 A
DC input:	24 V, 8A
DC power input:	24 x 8 = 192 W
Output power:	VI cosθ = 220 x 0.33 = 66 W (assuming cosθ = 1)
Efficiency:	66/192 = 0.344 (34.4 %)

The efficiency with the current load condition was 34.4 %.

1.3 Proposals and Advices to NCERD PV Unit

(1) Tilt Angle Setting

There is no problem with NCERD to set a tilt angle with specific objective. However for practical PV system it was advised that tilt angle should be such angle that maximizes the power output after studying the relationship between the tilt angle and the generated power.

(2) Measurement of System Efficiency

System efficiency should be measured. Unfortunately it was impossible due to a lack of measuring equipment.

(3) Measurement of Inverter Efficiency

It was advised to measure efficiency of the inverter of the system. It should be checked if the capacity of the inverter is suitable for the system.

2 NCERD Solar Thermal Unit

(1) Water Boiling Test of Box-Type Cooker

In the morning hours on the day of test, it took 90 minutes to heat up 0.5 ℓ of water from 31.3 ℃to 91.5 ℃. After the cooker is warmed up, it took 40 minutes to heat up 0.5 ℓ of water from 39 C to 70.1 C. Solar radiation was unstable due to the rainy season when we visited. We stopped the test and explained method of efficiency calculation.

Table 1 is the result of 1st test and Table 2 is the result of 2nd test.

Table 1 Extract Result of 1st Water Boiling Test

Amount of Water: 0.5 L

Radiation Receiving Area: 1.28 m^2

	Unit	11:00	11.20	11:40	12:00	12:10	12:20	12:30	Ave.
Sun Radiation	W/m^2	296	706	384	953	1009	957	1057	766
Air Temperature	℃	27	29	27	29	31	30	31	
Inside Temperature	℃	35	51	53	68	88	94	100	
Pot Temperature	℃	31.3	41.4	48.2	66.8	74.2	83.6	91.5	

Source: Study Team

Table 2 Extract Result of 2nd Water Boiling Test

Amount of Water: 1 L

Radiation Receiving Area: 1.28 m^2

	Unit	12:50	13:00	13:10	13:20	13:30	Total	Ave.
Sun Radiation	W/m^2	749	811	802	913	427	3,207	740
Air Temperature	℃	30	30	30	31	30		
Inside Temperature	℃	43	80		90	91		
Pot Temperature	℃	39	46.7	54.4	62.5	70.1		

Source: Study Team

(2) Egg Boiling Test of Box-Type Cooker

Egg boiling test of box-type cooker was done. Due to cloudy days data collection was not sufficient. It took two hours to prepare soft-boiling eggs due to low solar radiation. Table 3 shows the result.

Table 3 Extract Result of Egg Boiling Test

Amount of Water: 1 L with 10 eggs

Radiation Receiving Area: 1.28 m^2

	Unit	10:20	10:40	11:00	11:20	11:40	12:00	12:20	12:40	Ave.
Sun Radiation	W/m^2	371	468.5	407.8	930	343.2	346	376.7	358.9	450.2
Air Temperature	℃	28	26	27	27	27	28	28	27	
Inside Temperature	℃	45	55	63	68	72	66	66	65	
Pot Temperature	℃	37	40.6	48.4	54.3	59.7	60.6	60.6	62.8	

3 Efficiency Calculation of Box-Type Cooker

Efficiency was calculated from 2nd water boiling test result.

(1) Calculation 1

Water Temperature Rise:	70.1 – 39 = 31.1
Calories Required:	31.1 x 1 L = 31.1 kcal
Received Energy/m^3s:	740 W/m^2s = 0.176 kcal/ m^2s
Receiving Area:	1.28 m^2
Calories per second:	1.28 x 0.176 = 0.225 kcal/s = 13.5 kcal/minute
Time if 100 % efficiency:	31.1 / 13.5 = 2.3 minutes
Actual Time:	40 minutes
Efficiency:	2.3 / 40 = 0.0575 = 5.75 %

(2) Calculation 2

Heat Input Time:	40 minutes x 60 = 2,400 s
Calories per second:	1.28 x 0.176 = 0.225 kcal/s
Heat Input:	2,400 x 0.225 = 540 kcal
Heat Output:	31.1 x 1 L = 31.1 kcal
Efficiency:	31.1 / 540 = 0.0575 = 5.75 %

As shown above, heat efficiency of this box-type is 5.75 %. This efficiency is relatively low among this type of cookers.

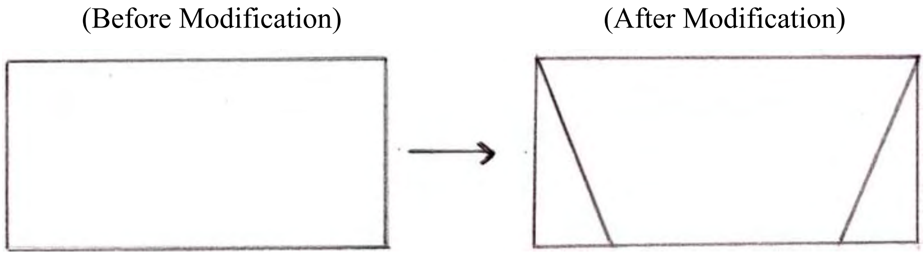
4 Assembling Parabolic Cooker and Testing

A parabolic solar cooker was brought from Japan and tested in NCERD just like in SERC. This cooker is handy and easy to use for women. Some female researchers proposed to purchase.

5 Proposals and Advices to Solar Thermal Unit

To improve efficiency of the box-type cooker, the following proposals were made.

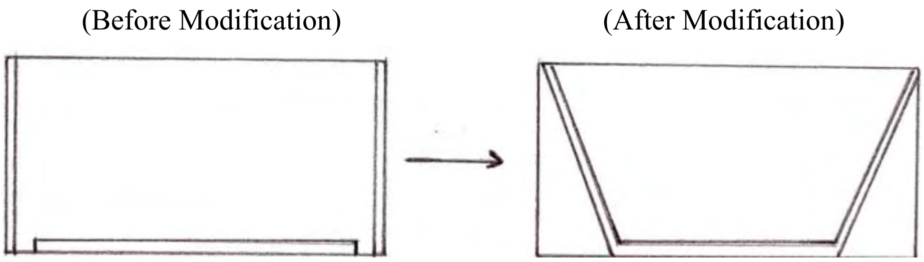
(1) The side walls of the cooker can not receive solar radiation because the side walls are perpendicular to the bottom. It was proposed that the walls incline outward as shown in Figure 1 in order to receive solar radiation.



Source: Study Team

Figure 1 Proposed Modification of the Side Walls

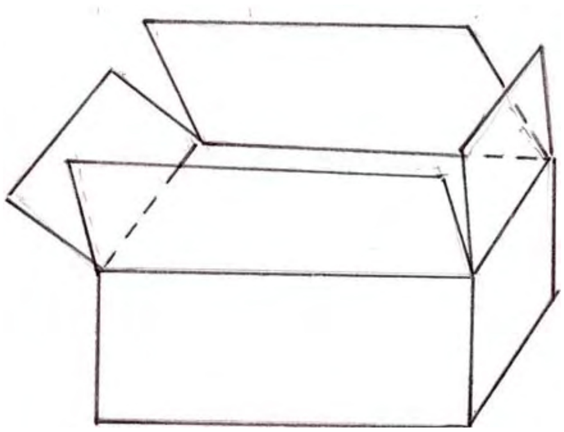
(2) In order to transfer heat received by the side walls to a pot placed on the bottom, side walls and bottom (black galvanized iron) are to be touched as shown in Figure 2.



Source: Study Team

Figure 2 Proposed Modification of the Side Walls and the Bottom

(3) Increase the number of booster reflectors to four and make them foldable as shown in Figure 3.



Source: Study Team

Figure 3 Proposed Modification of the Booster Mirrors

(4) The cooker is to be designed and manufactured in the manner that it will be more efficient, light and handy.

(5) For the rural population, the researchers in NCERD are proposed to teach the method of manufacturing clay kitchen stoves.