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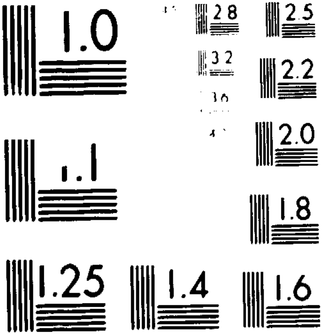

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MICRO HYDROPOWER DEVELOPMENT*

by

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The present day energy crises reflects that the technology for micro hydropower development as experienced by Japan, China, France, Germany etc. is an excellent example to follow for developing countries who are now making their best possible efforts for developing such micro hydropower. This is especially applicable in countries like Nepal where there are many isolated villages in hilly regions, or in Indonesia and the Philippines, where there are many small isolated islands. The development of micro hydropower can play a very significant role in raising the living standards of rural people.

Japan first started developing hydropower plants around 1890 and particularly between 1890 to 1925, Japan placed great emphasis on micro hydropower development, whileas in case of Nepal, hydropower development was first started around 1925. The total generating facilities of Japan is 103,791 MW (of which hydropower is approximately 24%) but in Nepal it is only 64.3 MW (of which hydropower is approximately 58%), as of 1976. The total hydropower potential of Japan is about 52 million kW and of Nepal is about 83 million kW. Per capita power consumption of Japan is roughly 1,470 kW while that of Nepal is only 10 kW.

I. Outline of Power Demand and Supply in Developing Countries

In most of the developing countries, the power supply network is concentrated in big cities. In these big cities, there are thermal power stations ranging from several thousand kW to several hundred thousand kW, or there are substations where power is transmitted to from very far distances. However, the power supply needed for nearby villages is not enough.

Generally speaking, there are small-scale diesel engine power plants in small cities scattered at various regions, and power is supplied mainly to some limited areas and centers. Like in the case of the big cities, power is supplied to towns nearby hydropower stations or nearby transmission lines which are extended to big cities from hydropower stations, but such towns are very few.

Presently, every country is making an effort for rural electrification and is expanding a transmission and distribution line network. World Bank and other financing agencies are providing loans for rural electrification. Small-scale diesel power plants are being replaced by transmission line terminal substations. However, not more than 10% of the overall households are being provided with a modern electric supply system.

The purpose of rural electrification is to provide electricity facilities in all the mountainous areas and isolated areas. But here, it seems that rural electrification aims to supply electricity only to towns, where there are district and regional head offices. Unlike the large cities where there are tall office buildings and large factories, the structure of power demand in small and medium cities in the various regions is mainly for lighting households. Eighty to ninety percent of the power is consumed by households, and yearly power consumption per household is barely 100 kWh. The remaining 10-20% of power is consumed by small factories, shops and district offices etc. and power consumed is about 1,000 kWh to 100,000 kWh per household. For example, let's look at the cases of Pokhara in Nepal, South Kalimantan in Indonesia and Catanduanes of the Philippines.

(1) Pokhara, Nepal

Pokhara is 130 km away from the capital city of Kathmandu and has a population of about 30 thousand.

There is a hydropower plant with a capacity of 1,000 kW near the town, and a micro hydropower plant with a capacity of 250 kW about 20 km away from the town. The power from the hydropower plant of 1,000 kW capacity is mainly consumed by local households district and regional offices, rice mills, oil mills etc. The power from the micro hydropower plant is transmitted to agriculture development centers within the region by a 7 km long transmission line of 11 kV and is used mainly for irrigation pumps, poultry farms and project offices.

(2) South Kali Mantan, Indonesia

There is a hydropower station in south Kali Mantan with a capacity of 20 thousand kW. This town has a population of _____ and is located almost 60 km away from the capital city. And from there, power is transmitted by 70 kV transmission lines and is supplied mainly to Bandjermasin and two other nearby cities. Bandjarmasin is famous as one of the centers of forest resources development of Kali Mantan and there is a paper mill having a load of 1,000 kW.

(3) Catanduanes Island, Philippines

This is a small island located to the south of Luzon island and it has a population of 175 thousand. There is a diesel engine power plant with a capacity of 1,000 kW in the capital city of Birak. The power is transmitted by 13.2 kV transmission lines of 130 km in length and is then distributed mainly to the southern part of the island. It is a rare case that an electrification system has developed in such an isolated island.

The demand structure is such areas is shown in Table 1 below.

As shown in the table, commercial, industrial and official demand almost match domestic demand. In case of commercial, industrial and official demand, load is concentrated in day time while in case of domestic demand load is concentrated in the evening time. The total load ratio is about 50% to 60%. In case of industrial purposes, power is consumed for driving motors. In case of commercial and official demand, power is consumed for lighting, heating and air conditioning purposes. In case of household demand, power is consumed for lighting purposes, and the consumption ratio is 100 W to 300 W per household. The power rate is quite high when compared to the income from power, and the use of heating equipment (cookers etc.) or air conditioners is not so widespread in such areas. Only very few of the wealthier households could own and use such equipment. In a country like Malaysia, where cookers, refrigerators television etc. are widely used, most power consumption per household is over 1 kW, and yearly energy consumption is about 1,000 kWh.

Table 1 An Example of Power Demand Structure

Demand Category	Pokhara Valley			Kali Mantan			Catanduanes		
	No. of Household	Total Power Consump.	Consump. per Household	No. of Household	Total Power Consump.	Consump. per Household	No. of Household	Total Power Consump.	Consump. per Household
					MWh	kWh		MWh	kWh
Domestic	2,209 (91%)	1,203,686 (51.1%)	545	9,612 (90.1%)	6,708 (64.4%)	698	3,831 (83.5%)	1,012 (46.9%)	264
Commercial	15 (0.6%)	221,714 (10.1%)	14,781	605 (5.7%)	1,021 (9.8%)	1,688	452 (9.8%)	528 (24.5%)	1,168
Industrial	32 (1.3%)	177,801 (8.1%)	5,556	42 (0.4%)	508 (4.9%)	12,095	9 (0.2%)	44 (2.0%)	4,889
Official		-	-	410 (3.8%)	2,169 (20.8%)	5,290	129 (2.8%)	506 (23.5%)	3,922
Street lights	170 (7.1%)	582,450 (26.2%)	3,246	-	-	-	169 (3.7%)	66 (3.1%)	390
Total	2,426 (100%)	2,285,651 (100%)	942	10,669 (100%)	10,406 (100%)	975	4,590 (100%)	2,155 (100%)	470

Note: In case of Nepal, officials is included in domestic.

II. Limit of Rural Electrification

As explained before, most of the developing countries have been making efforts for rural electrification and have invested huge amounts of money for expanding the power supply network.

However, unlike the power supply systems in big cities, the investment for expanding the power supply network to small cities scattered in vast regions, or villages scattered in remote areas, or i ated islands is not very effective. Moreover, since the major p on of power is consumed by domestic households, the capacity factor is very low and therefore, power income is not much in proportion to the cost of the generating facilities. Even if the project is constructed by foreign aid, there are some regions which then face a crisis in capital recovery.

Let us make a case study, wherein we propose that power is to be supplied to a town having a population, power consumption, etc. as listed below:

1. Total population of town = 5 - 6 thousand
2. Population per household = 5 - 6 persons
3. Total number of households = 1,000
4. Power consumption per household = 300 kWh
5. Annual power consumption = 500,000 kWh (including some commercial and industrial households)
6. Power transmission cost to this town = 10 - 20 U.S. mill/kWh
7. Transmission cost/year
   = 500,000 kWh x 10 - 20 U.S. mill/kWh
   = 5,000 - 10,000 US$/year.

Now, let's consider that the annual cost of transmission equipment (including capital recovery and operation & maintenance cost) is 7% of construction cost and that the loan used carries a very low interest, then the above transmission cost will be, (US$5,000 - 10,000)/0.07 = US$71,430 - 142,857. That is to say, the average construction cost will be about US$100,000. Thus, if the construction cost of the transmission line is about US$5,000/km, only 20 km can be covered.

The main problem is how to solve the transmission cost problem in mountainous areas like Nepal or in isolated islands in the Philippines. The construction cost of transmission lines in the hilly regions of Nepal will be higher than that of the Terai plains area. In proportion to this, the above limit of 20 km transmission line will be even greater, and therefore in such regions electrification by transmission line will not be feasible.

III. Policy of Electrification in Isolated Areas

Power generation by diesel engine is the most common and simplest way to supply electric power in isolated areas like Nepal's mountain villages or Philippines' islands. In case of diesel engine power plants, output between 10 kW to 10,000 kW, can be selected of any choice, according to the need, and the construction cost therefore is around US$500 /kW to US$800/kW. The construction period is short and power plant can be installed easily. Fuel efficiency is also good, and fuel cost per kWh is U.S. cents 5 to 8.

This is the reason why most of the developing countries have been using diesel engine power plants.

However, there are some disadvantages of diesel engine power plants when compared to hydropower plants, such as:

a. It is necessary to supply fuel continuously.

b. It is necessary to have frequent maintenance and major overhaul of equipment every after 4-5 years.

c. Spare parts are not easily available and it is necessary to keep enough stocks of spare parts on hand to make repairs.

But, generally speaking, in isolated remote areas, problems of continuous supply of fuel and/or supply of spare parts cannot be solved easily.

And, since fuel cannot be supplied continuously and spare parts are not always available when needed, the power plant has to be shut down and continuous power supply is not possible.

Moreover, to employ skilled technicians for operation, repair and maintenance of diesel power plants is not so easy. Even if, such personnel are given educational training etc., they do not prefer to stay and work in remote and isolated areas, they leave the job and go to better areas. And when power plant is operated by non-skilled operators, there are such cases that diesel engine gets damaged within 2-3 years, spare parts are not properly stocked, maintenance work is not well done and the generator often ends up by getting scrapped. Besides these, there occurs some other problems such as a lower fuel efficiency causing the fuel cost to become 2-3 times that of normal operating conditions. In the case of diesel engine power plants, fuel costs occupies a major portion of the power cost, and when fuel costs rise, power costs rise automatically, and for this reason rural electrification in developing countries is not easily widely used.

The most common factor is that, the high rise in fuel prices causes the rise in power costs, and for non-oil producing countries, this is one of the most unfavorable conditions because it makes it not so feasible to install diesel engine power plants in isolated areas. Under such conditions, the developing countries are making efforts to establish micro hydropower plants for the following reasons:

a. The power cost gets to be cheaper when compared to long distance transmission lines, especially transmission lines through mountainous areas or submarine cables.

b. The reliability of micro hydropower is higher than that of diesel engine power plant and operation, maintenance and repair problem is simpler than in the case of diesel engine power plants.

c. There is no fuel that has to be continuously supplied.

d. The volume of imported oil can be reduced by using water, which is a clean and cheap natural resource.

Here, let's discuss the problem of feasibility in the case of micro hydropower development. The cost for micro hydropower development is comparatively high. Although the size of major equipment like turbines and generators is not large, the price of equipment cannot be reduced in proportion to its size, and moreover the price becomes higher for small size equipment. Also, the price of other ancilliary equipment such as governors, automatic oil pressure equipment, control pannels, etc. is comparatively higher when the sizes are small, and the size of such equipments has no relation with the capacity of the power plant.

For example, let's consider the price of a turbine, generator and other ancilliary equipment for a power station having head a of 30 m.

The price of the equipment is as follows.

Output (kW)	Price (US$) (all equipment)	Price of equipment/kW (US$)
250	400,000	1,600
500	500,000	1,000

The cost per kW of a micro hydropower plant with a capacity of 200-500 kW is assumed to be about US$3,500-5,000, when civil construction costs, transportation and installation cost of equipment, engineering cost etc. are all added together. When the capacity is less than 100 kW, the cost per kW will be around US$5,000-10,000.

Now, let's look at the cost per kWh of a micro hydropower plant whose cost/kW is US$7,500 (assumed) and which is operated at an annual load factor of 60%.

Annual Cost/kWh = US$7,500/(0.6 x 8,760 hrs.)/kW

= US$1.43/kWh

If the annual rate of cost is 8% of the total cost, the above cost/kWh will be 11.4 U.S. cents and if distribution and other costs are included, the total cost per kWh will be around 15 U.S. cents, and this cost cannot be borne by people of low income living in isolated areas. Therefore, small-scale micro hydropower is not economically feasible.

Micro hydropower is often developed in small rivers. In areas, where the dry and wet seasons are very distinct, there is almost no water in the river in dry season. To estimate the discharge of a river for micro hydropower, it is necessary to do a detailed study of the river flow for at least several months.

It is not beneficial to make electrification plans for isolated areas based on the principles of a modern power supply system. There are three things to be considered when planning rural electrification by micro hydropower plants:

a. Consider using the maximum level of intake water.

b. Consider that the operation of the power station may have to be periodically stopped for several days.

c. Consider installing small-scale diesel engine power plants in parallel with the micro hydropower plants.

From the above points, we see that development of micro hydropower plants should be considered very seriously and, it is necessary to make detailed feasibility studies concerning how to develop micro hydropower plants.

Only after a detailed study has been completed, can it be determined whether money should be invested for implementation.

IV. Selection of Sites for Micro Hydropower Plant

For the development of hydropower, head of water is available from one of the following:

a. Use the natural head like that of waterfall.

b. Use an intake dam and canal so that the gradient of the river can provide an effective head.

c. Make use of head by raising the elevation of a river by building a dam.

In the case of micro hydropower, to get head the above method mentioned in c. is not feasible, because it will be too costly.

We recently had an experience of constructing a micro hydropower plant by making use of head from a waterfall. In this case the head was 35 m and the output was 200 kW.

Roughly speaking, the cost of a turbine for this type of plant is 1/3 of the construction cost which was US$7,500. From this above example, it is seen that 40 - 50 % of the construction cost is strongly affected by the discharge used. Since, the output of power plant is the product of discharge and head it is better to get a high head by making use of a waterfall, and in the case of micro hydropower, the price of head to construction cost is very much.

For example,

Let's assume that the lower limit of a micro hydropower plant is 120 kWh with an overall efficiency of 80 % (including water way loss, machine efficiency etc.)

$\therefore P = Q \times g \times H \times \eta$, or $Q \times H = \dfrac{P}{g \times \eta}$

where, $P = 120$ kWh

$\eta = 80$ %

$g = 9.8 \text{ m/sec}^2$

Q = Discharge (m^3/s)

H = Head (m)

Thus,

$$Q \times H = \frac{120\ kW}{9.8 \times 0.8} = 15 \quad ..... (1)$$

Also, let's assume:

Annual rainfall = 2,500 mm

Flow coefficient = 0.7

Catchment area = A km^2

Discharge Q = 1/3 of average discharge

The relation between A and Q is given by the formula,

$0.7 \times 2.5 \times A \times 10^6 = Q \times 3 \times 31,536,000$

$\therefore A = 54Q$ ..... (2)

The relation between equations (1) and (2) is shown in the following table:

H (m)	15	30	45	60
Q (m^3/s)	1.00	0.50	0.33	0.25
A (km^2)	54	27	18	13.5

There are not so many small rivers having catchment areas between 2 km^2 to 30 km^2, so from the above table it is clear that the head will be more than 30 m. This shows that many economical problems arise in the case of micro hydropower development.

But in case of Nepal where a glacier can be used as a reservoir, and in the case of islands in the Philippines or Indonesia where there is enough rainfall with dry seasons and wet seasons not being distinct, micro hydropower can be developed at sites under conditions other the those given in the above table.

Now, when an intake dam, intake canal etc. are large, the civil works volume is also large and in such cases, output must be large in proportion to the intake dam and intake canal. Thus, small-scale hydropower is not possible and thus a large-scale micro hydropower project is necessary. In such cases, an intake dam located upstream may work as a reservoir, depending on the landscape. (ref: Report of Chu-o-kaihatsu Co., March 1978)

In case of an intake canal, an open type is preferred to be constructed along a mountain side and some portion of it may have to be a tunnel. But the tunnel should not be a major portion, because most of the developing countries do not have the technology needed for tunnel construction. The gradient of the river should be about 5 % of the total length of intake canal. For example, when the length of intake canal is 2,000 m, the river gradient will provide a 100 m head. If a 100 m head is available, then 800 kW output can be obtained with a discharge of 1 m^3/s.

V. Application of Multipurpose Dam

Developing countries have been making efforts for development of hydropower in other areas by utilizing multipurpose dams or irrigation dams. The characteristics of hydropower by an irrigation dam is that, generally the head is low and the output varies by large ranges. In order to adjust to this phenomenon, currently most of the turbine manufacturers have developed a variabie low-head type turbine, and the design is being standardized. An example of a standardized type of burbine is given below.

a) Alischalmers Co., U.S.A. - Tube Turbine

Head: 2 - 15 m; Discharge: 2 - 46 m^3/s; Max. output: [illegible] - 5,000 kW

b) Fuji Electric Co., Japan - Bulb Turbine

Head: 5 - 18 m; Discharge: 8 - 27 m^3/s; Max. output: 40.0 - 4,000 kW

The disadvantages of a hydropower station incorporated with an irrigation dam is that during the irrigation season the tailwater becomes zero because the discharge for the power station is decided by the volume of water to be used for irrigation purpose and almost all the water is used for irrigation, the power station has to be shut down. So on the other hand, the advantage of such a hydropower station is that, it does not have a peak value (kW - value), and the benefit of its energy value (kWh - value) can be compared with the fuel cost of a thermal power plant. The major cost of the irrigation dams is for the civil work, and the cost of turbine generators is comparatively high because of the variable low head; therefore, it is not economically feasible when compared only to kWh - value.

However, for non-oil producing countries, in order to save outflow of foreign currency due to the high rise in oil prices, from a long-term viewpoint it is more beneficial to use the foreign currency for buying low-head turbines and generators. Although it may not be economically feasible when compared to the kWh value, from an energy saving viewpoint the development of hydropower incorporated with a multipurpose irrigation dam seems to be more encouraging.

Moreovec, if a hydropower station incorporated with multipurpose dam is installed, it is necessary to have support from a thermal power, because when the tail water is used for irrigation purpose, the total outpu of power station will fall considerably. In such case, the kW-value of a multipurpose irrigation dam can also be considered, when a supplement termal power plant is installed.

From the above discussion, we can conclude that, for the development of an isolated area, the first thing to be considered is to develop micro hydropower projects using the effective head of a natural waterfall. And also to develop multipurpose dams both for hydropower generation and irrigation, because in the dry season the tail water can be used for irrigation purpose.

VI. Hydropower Potential in Developing Countries

The hydropower potenatial of Japan is 52 thousand MW, in China it is 540 thousand MW, in the Philippines it is 8.4 thousand and in Nepal it is 83 thousand MW.

Among the developing countries, Nepal and the Philippines have taken special interest for micro hydropower development, and lot of surveys works have been carried out. In Nepal the dry and wet seasons are very distinct, but its glaciers provide natural reservoirs, so there is great prospect for development of micro hydropower in Nepal. In the case of the Philippines, there are many isolated islands where there is lot of steady rainfall, so there is also a great prospect for development of micro hydropower there. Each of these potentialities is discussed as follows.

a. Micro Hydropower Survey in Nepal

In Nepal, a "Micro Hydropower Development Board" was established in 1974-75. Since then, Nepal has been playing an active role in the development of micro hydropower. There is a factory in Balajyu, Kathmandu which manufactures turbines for micro hydropower plants, but an integrated plan for micro hydropower development covering all the potential sites throughout Nepal has not been formulated. The survey of micro hydropower projects in Nepal is based on demand. There are several micro hydropower stations constructed in Namche Bazaar, Dhankuta, Pokhara, Nepalganj, Surkhet etc., and there are 17 - 18 potential sites already surveyed.

b. Micro Hydropower Survey in the Philippines

In August 1978, the Philippines published a booklet entitled "Preliminary Evaluation of Mini-Hydro Potentitals in the Philippines". This is a joint publication of the National Electric Power Corporation, Electricity Department and Irrigation Department of the Government of the Philippines. According to this report, there are 4,500 potential sites for micro hydropower development in the Philippines, and among these, 474 sites are said to be feasible sites. There are 316 sites to be surveyed in datail during next 10 years. A breakdown of this is shown below.

Table Feasible sites for Micro Hydropower Development

Region	Site No.		Potential (MW)	
Luzon	271	(159)	520.0	(143.1)
Bisaya	132	(93)	135.4	(64.8)
Mindanao	71	(64)	88.9	(58.8)
Total	474	(316)	794.3	(262.7)

Note: The figures in brackets include those that are to be surveyed during the next 10 years.

VII. Transfer of Technology

Although we have already discussed in detail the necessity of small-scale hydropower plants, there has been no explanation as to how to satisfy the necessity for power demand in isolated areas.

Therefore, we will consider this matter in the following paragraphs given below, explaining the method of transfer of technology, properly and effectively.

In general, it is said, that developing countries do not have the technology about small-scale hydropower development.

Even if this is a fact, it is not clear what the technology of a small-scale hydropower plant actually means. This is discussed as follows.

a. Various Types of Technology

We have divided the technology into five different categories as given below:

1) Technology of Planning.

This includes the collection of such fundamental data as exploration of the areas, the amount of rainfall, the river's discharge capacity, site selection, and make a study of each project including a pre-feasibility study and a feasibility study.

It also means that, the overall basic principles of micro hydropower for example preparation of master plan, site selection, consideration of priority project and finding a model project etc. is included in this category.

The most important matter concerning this kind of technology is that most of the developing countries don't have enough basic data about rainfall and the discharge capacity of rivers.

That is why it is necessary to start collecting annual information and also to set up equipment and an organization for the necessary observation and research works.

2) Engineering Technology

This includes detailed planning from the beginning to the completion of the engineering construction. And, such engineering construction needs very special and solid planning.

For example, make use of an open waterway as a rule, and never go to the expense of building a tunnel waterway.

3) Manufacturing Technology (manufacture of equipment for small-scale hydropower)

In order to manufacture such equipment, we need the proper combination of casting techniques, machining techniques. electronic techniques etc.

The model of the equipment varies according to the general conditions of the project. Idealistically, it is hoped that the developing countries will eventually be able to manufacture the equipment by themselves, however, very few countries currently have the technology to manufacture it. Therefore, they should begin manufacturing simple equipment which can be made by using whatever technology the developing countries has as of this time. Even in the case of Japan, she did the same thing at the early stages of development as mentioned before.

The next step is for the developed countries to help the developing countries to improve the quality of technology and make more effective hydropower facilities.

4) Operation and Maintenance Technology

When compared with other types of power plants, hydropower plants have the least complicated and expensive system for operation and maintenance. However, such plants cannot be left alone without any type of care. For example, if there is sand or dirt mixed in water, it damages the vanes of a turbine and then the output of the plant is greatly reduced. Thus, it is very important that much attention is given to ensure proper operation and maintenance work is performed.

5) Management Technology

Concerning economic feasibility, it is necessary to carefully analyze a project before it is implemented.

In developing countries, the management system and aftercare of the project is usually quite poor, so there is often a lot of loss. It is well known that this tendency is even more pronounced in the case of public projects.

We have briefly examined five different technologies giving the relationship between developed countries and developing countries. The problem is how to transfer these technologies from the developed countries to the developing countries. This is covered in the following paragraphs.

b. Technical Cooperation and Transfer of Technology

1) Types and Patterns of Technical Cooperation

Japan International Cooperation Agency (JICA) has the following program:

a) Dispatching experts from Japan to developing countries.

b) Inviting engineers including government officers of developing countries to Japan where they can participate in training programs.

c) Cooperating with professionals of developing countries for preparing feasibility studies, etc.

d) Providing grants and aid to developing countries.

These patterns of cooperation have been done separately. Presently, Japan has more different types of cooperation, because there are now more complicated projects.

2) Transfer to Technology

The dispatching of experts is also a source of transfer of technology and it can be done by sending very capable people from developed countries to developing countries, and asking them to work with the local people.

Training of engineers is usually done by inviting selected persons of developing countries to Japan and giving them appropriate training.

When people are needed for a special project, they are sent to particular firms and trained there in the most effective manner.

Cooperation for survey and study is done by sending consultants from Japan to make master plan and prepare a feasibility study.

The effectiveness of technology transfer is obtained by joint cooperation of the local staff and consultants from both developed and developing countries.

The impact of grants and aid has been realized recently by all parties concerned. It is expected that such activity will be used more widely in the future.

Until now, we cannot expect much effect of the transfer of technology directly; however, we can improve it by joint cooperation and working together.

In summary, we should emphasize that it is necessary to use different kinds of technology cooperation to successfully carry out the installation work of micro hydropower plant project and only that way can we make technology transfer possible and more effective.

The following are the matrices of four kinds of technical cooperation and five kinds of technology from the point of view of technology transfer.

Table

Technology / Items	Planning Technology	Engineering Technology	Manufacturing Technology	Operation and Maintenance Technology	Management Technology
Dispatch of Experts	0	0	0	0	0
Cooperation for Training		0	0		
Research Cooperation	0				
Grants & Aid			0		