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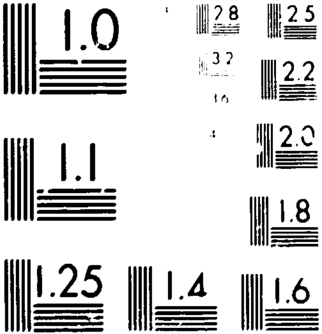
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Seminar-Workshop on the Exchange of Experiences and Technology Transfer on Mini Hydro Electric Generation Units

Kathmandu, Nepal, 10-14 September 1979

UNIDO ISSUE PAPER*

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GENERAL ISSUE

- UNIDO's assistance in a general nature or specific cases
- Disuse of MHG and its renewal
- Training (study tour/inplant training)
- Survey of local capabilities/capacities
- Advisory services
- Financial assistance

I. Introduction

This short document is intended to be an expanded agenda for this Seminar Workshop. It is intended to spell out and organize the issues that have appeared most relevant during our preparation work. Those issues are grouped into three main catagories: technical, economic and institutional. This meeting is intended to be essentially practical. It is hoped that on September 14 the participants will go home with a better understanding of what those issues involve, so that they will be better equipped to make decisions concerning the possible development of MHG in their own country.

At the end of the meeting some of those issues may still be unclear, or new issues may have come up from the discussion, and for which no satisfactory answer was provided. UNIDO will be available for further assistance, whether those issues are of a general nature or whether they pertain to specific cases.

Micro hydro generation, usually referred to as MGH, is the generation of electricity by means of small turbines and generators with a connected power of a few kilowatts to about 200 kilowatts. Mini hydro generation on the other hand would cover larger installations, from 200 kilowatts to 5,000 kilowatts. Such small hydro electro power plants have found wide applications in all developed countries, where the technology has reached a high level of sophistication in certain cases. For economic and institutional reasons however, many of those units have fallen into disuse when the national grid reached the areas served by those installations. Only in recent years has there been a renewed interest in MHG in developed countries, since most large hydro electric sites have been utilized and because of the world oil situation. At the same time, a number of developing countries such as China, to name only the most prolific MHG builder, have demonstrated the viability of local manufacture and installation of MHG.

UNIDO has recently engaged in a number of MHG-related programmes. A study tour of MHG units was recently conducted in China, at the invitation of the Chinese government. OLADE, the organization of Latin American States for Energy Development, has specifically requested UNIDO's assistance in the field of MHG, and a programme of assistance has been initiated to that effect. Several experts from different countries have come to UNIDO and offered to co-operate in MHG related programmes. Our Factory Establishment and Management Section has an on-going programme of assistance to Panama which includes the transfer of technology between a firm from a developed country and a Panamian firm for the manufacture of small turbines. Last, but not least, the present workshop seminar was primarily requested by the ESCAP Regional Centre for Technology Transfer, and the very enthusiastic response that followed its announcement led us to extend invitations to a much wider circle of interested countries.

In preparation for this meeting we sent a technical questionnaire to all the UNIDO Senior Industrial Development Field Advisers, and we received 20 answers from developing countries. The results are tabulated in Table I. Clearly, MHG represents a tiny portion of the electricity generation capacity of the developing countries. China is the only known exception, but their questionnaire has not been received at the time of the preparation of this document. Further development is contingent upon the completion of the hydrological survey in most cases, and upon technical and economic assistance. The development of MHG programmes is only one element of national industrial development plans.

TABLE I. Analysis of the questionnaire received from 20 developing countries.

Country	Number of MHG Plants up to 1 MW		Hydrological Survey	Assistance Required
	Installed	Planned		
1. Afghanistan	22	23	done	MHG needed in isolated mountain villages. Technical and Economic
2. Bangladesh	0	0	started	Technical and Economic
3. Cameroon	2	0	started	Technical and Economic
4. Chile	0	1	started	Technical and Economic
5. Cook Islands	0	2	started	Information on availability and supplies of alternaters and Turbines up to 10 kv.
6. Ethiopia	6	0	started	Technical and Economic
7. Fiji	1	several	started	Technical and Economic
8. India	85	25	started	Technical and Economic
9. Kenya	0	0	started	Technical and Economic
10. Malaysia	21	1	to be done	Technical and Economic
11. Paraguay	0	0	done	Technical and Economic
12. Peru	1	2	to be done	Technical and Economic
13. Philippines	3	10 annually	done	Technical and Economic
14. Sierra Leone	0	1	started	Technical and Economic
15. Sri Lanka	0	0	to be done	Technical and Economic
16. Trust Territory Pacific Islands	0	1	started	Technical and Economic
17. Turkey	123	0	done	Technical and Economic
18. Uruguay	0	0	to be done	Technical and Economic
19. Zaire	0	3 (pilot)	started	Technical and Economic
20. Zambia	3	0	to be done	Technical and Economic

ISSUE ON TECHNOLOGICAL ASPECT

- MHG technology is a mature technology
- The technology is widely available
- Selection of site
- Appropriate choice of turbine/generator/control panel/ distribution system
- Feasibility study and design
- Technology transfer means and conditions
- Industrial infrastructure availability
- Possibilities for local manufacture (reliability/ social and economic advantage)
- Safety factor
- Standardization (civil works/turbine/generator/transformer etc.)

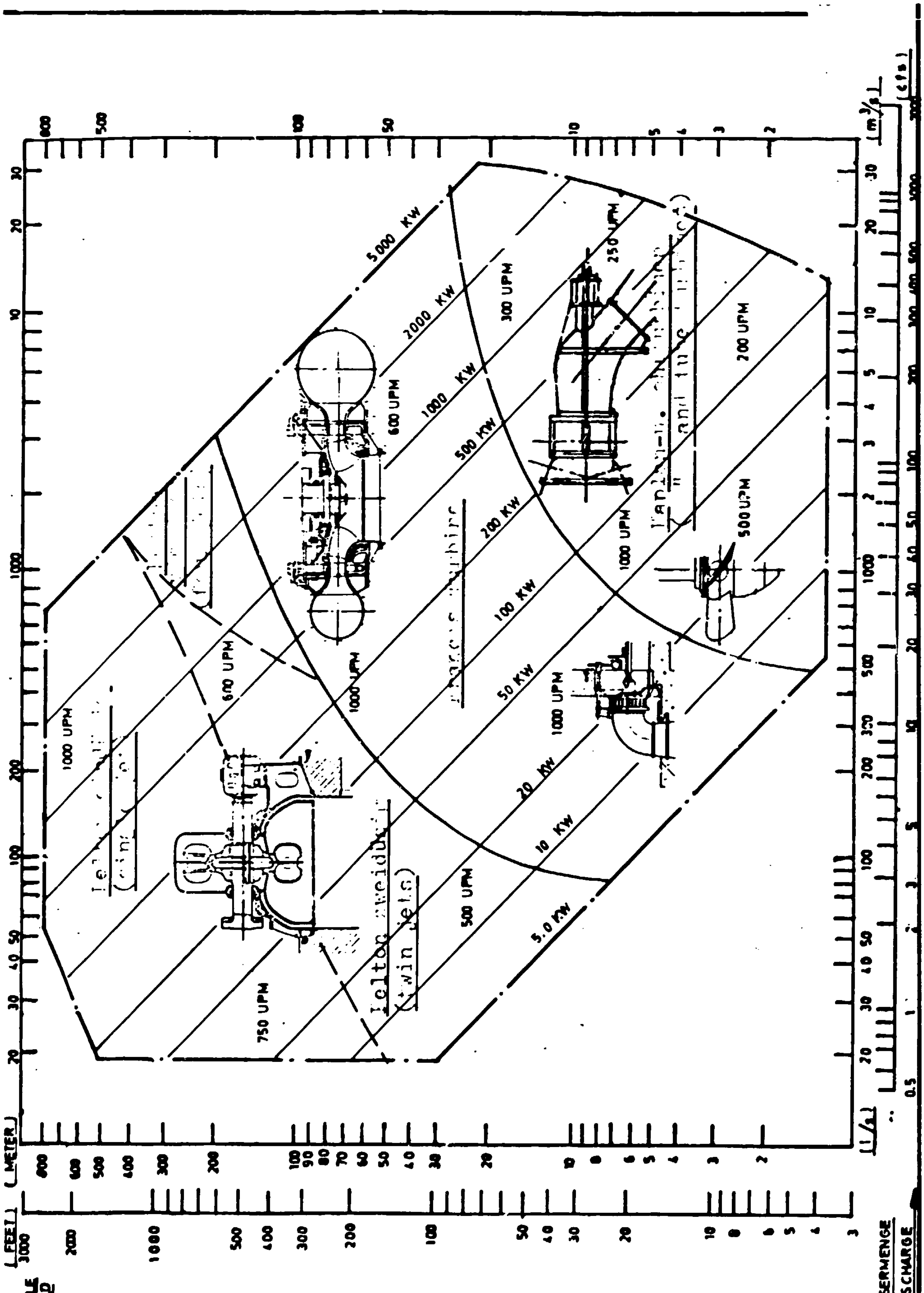
II. Technological Review

MHG technology is a mature technology. All the basic patents have long fallen into the public domain. This is not to say that the state of the art is not progressing, but one must emphasize that progress is slow and that no breakthrough is expected in the near future in the technology of any of the components that constitute a MHG plant. The technology is widely available in many countries. Propriety aspects usually concern small improvements over the basic configuration. In particular the choice of the type of turbine, generator, regulation and distribution equipment is in fact very narrow once the present and projected demand, the possibilities of the proposed sides and the financial capabilities of the sponsors are known.

High efficiency turbines belong to three generic families, and their domain of application is schematically shown on Exhibit I. The choice depends only upon the available head and flow rate. Less efficient, cheaper turbines such as the Mitchell-Banki type can be substituted in the case of lower power installations. The alternator is usually three phase, 50 or 60 Hz, 220-380 volts of the brushless syncronous type for small powers, asynchronous for high powers. Most of the available literature actually covers in great detail the description and technical characteristics of commercially available equipment. The precise choice of the technology adopted for the electro-mechanical equipment is economic in nature.

Technology transfer, therefore, is less a matter of licensing rights and royalties than a problem of fair conditions of know-how transfer. One main issue is to match the technology withthe available industrial infrastructure under the most economic conditions. For instance, a country equipped with casting and forging facilities as well as relatively sophisticated metal fabricating equipment is able to absorb a much wider range of MHG technological capabilities than a country deprived of such facilities. A MHG programme alone usually does not warrant the establishment of that type of infrastructure. On the other hand the development of such infrastructure, although lengthy, is a necessary part of a harmonious industrial development. While conceiving a MHG development programme, it is therefore best to keep in mind the overall foreseeable development of the industrial infrastructure of the country,

EXHIBIT I. Domain of Application of High-Efficiency Turbines.



Source: Kössler Ges.m.b.H. Maschinenfabrik, A-3151 St. Pölten - St. Georgen, Austria.

so as to co-ordinate the choice of technology with the present and planned possibilities for local manufacture.

Local fabrication has taken a variety of forms and degrees in the countries that have implemented it. At one end of the scale is China where over 85,000 units have been built entirely in the country. The turbines and civil engineering are done by the communities who will operate the MHG set for their own use, the know-how being brought by members of other communes who have engaged in the same activity. The generators and transformers are usually built in regional plants. Extensive use is made of existing irrigation structures, and standardization of the MHG units in a small number of models permits a relatively easy flow of know-how. The efficiency of some of those homemade units is probably low, but the reliability of the equipment does not seem to be a problem. Latin American countries such as Peru or Panama have adopted intermediate solutions, whereby part of the equipment is imported and part of it is developed and fabricated locally. In Peru, the design is simplified to avoid casting and forging: the result is 30% less efficient, several times cheaper installations. Finally in some very remote areas where reliability is crucial and where the infrastructure required for local fabrication is totally inexistent, the entire equipment is imported. The cost is very high, but the equipment is more dependable and the kWh is cheaper than in the case of a diesel generation set for which the fuel would have to be flown in. One example of such a situation is the Namche Bazar Project in the high mountains of Nepal. To summarize, local fabrication usually implies simplified designs and consequently lower efficiency, which means that a number of social and economic advantage are traded against the fact that the potential of the water fall for electricity generation will not be fully utilized.

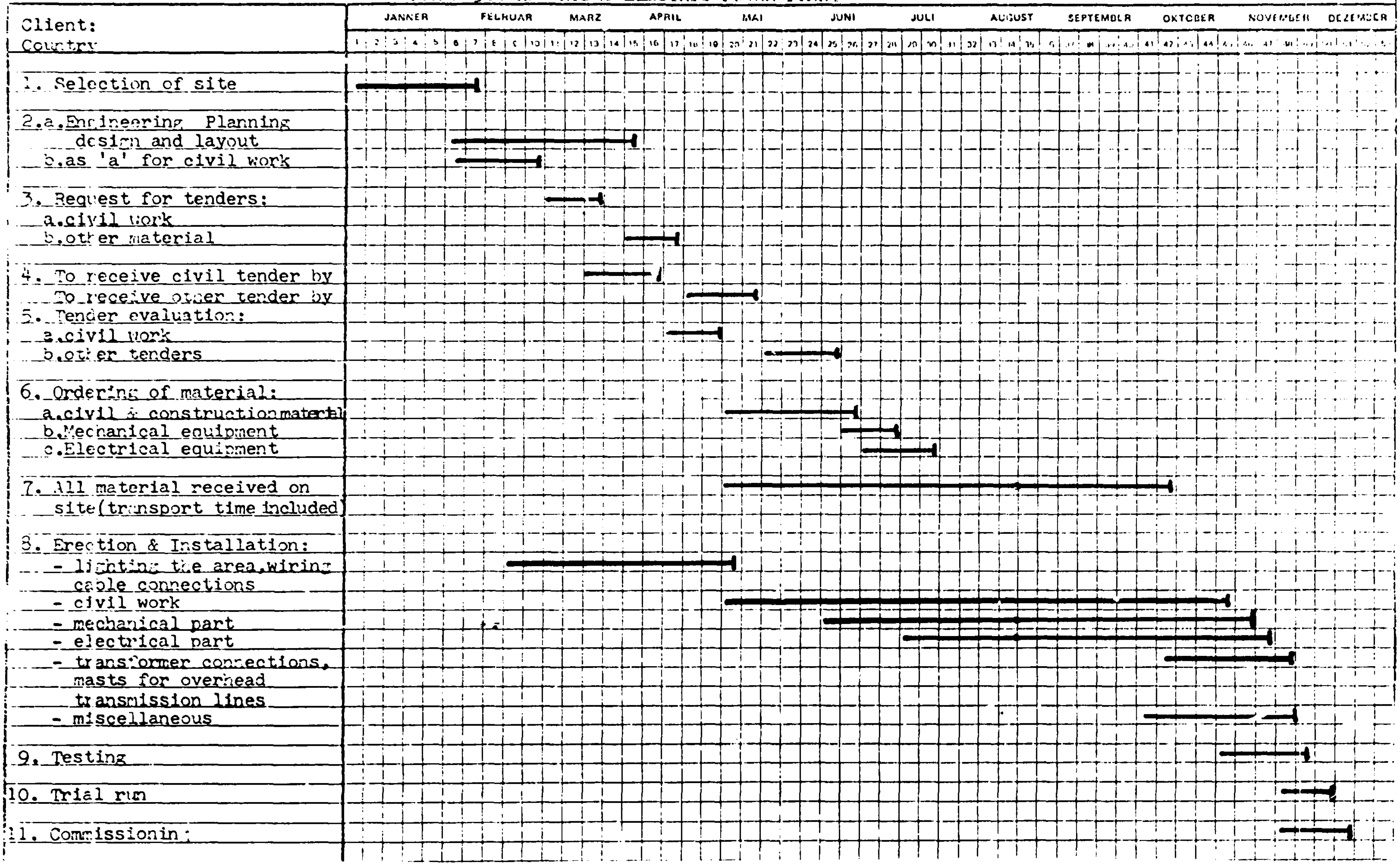
Safety is a major technical issue in the field of hydro power generation in general and MHG in particular. The concern for keeping the costs down and to involve local labour and expertise at the expense of some higher degree of technical sophistication should never lead to the point where amateurism endangers human lives. First and foremost, the dam construction, if any, must be able to far outlive the rest of the installation. It must be able to sustain very adverse weather conditions and provisions must be made for qualified experts to check on the soundness of the structure at regular intervals. According to one source 1/; this is not always sufficiently the case in developing countries. Second, the generation and distribution of the electric current must be designed so as to minimize the risks for electrocution. This involves the installation of safety devices, good quality insulators and proper wiring equipment and practice: it also involves extensive operator and user information campaigne since, presumably, the community served by the MHG is confronted with a new and dangerous source of energy readily available in their own homes and places of work.

Standardization and equipment compatibility are important not only to save time and money at the installation stage but also to simplify repair and maintenance in the future. The establishment of norms and standards usually is the responsibility of a National Bureau of Standards, which is part of the technical services of the government. For memory we should mention that the metric system is a must for a developing country, that the 50 Hz frequency is the most common (with the exception of 60 Hx in the United States), that the standard low voltage generation is usually 220-380 volts, and that it is best for a developing country to adopt early on standards for local distribution (10 or 15 kv) and long distance transportation voltages. While turbines are difficult to standardize, the generators, transformers and associated regulating equipment can be limited to the descrete number of standard sizes. In all cases the equipment design should be viewed by a specialist of methods preferably closely associated with the National Bureau of Standards for simplification purposes: minor modifications to the engineer's design can permit the use of numerous identical parts, the reduction in the total number and complexity of the parts which results in reductions in the costs of making those parts and also makes future maintenance easier and cheaper.

While the planning of a MHG programme at the national level may take three to four years, it is generally accepted that the total time span between the decision to exploit a micro hydro site and the start up of the equipment is of the order of one year. Exhibit II is an example of such a schedule provided by a commercial company.

1/ Prof. S. Radler, Vienna - Private communication.

WORKPLAN - PROGRESS CHART
FOR A 500 KW HYDRO-ELECTRIC POWER PLANT



ISSUE ON ECONOMIC ASPECT

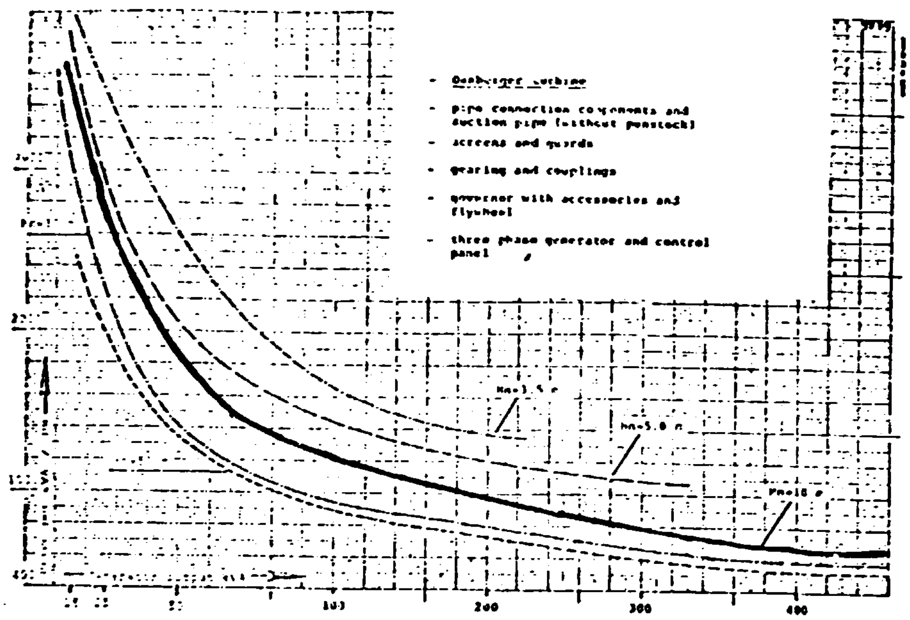
- Total cost breakdown of different MHG systems (land/building/civil works/hardware/software/operating costs etc.)
  Ex. medium-head power station: civil works 60%/mechanical parts 26%/electrical parts 14%
- Economic comparison of different system of electricity generation (initial investment and operating cost)
  Ex. MHG - Diesel
- Cost reduction scheme (simplified system and design/local manufacture/standardization etc.)
- Electricity demand and equipment sizing
- Social economic benefits
- Social factor

III. Economic Considerations

There is no doubt that electricity must be brought to rural areas. The question is how and when. The main purpose of making capital and operating cost estimates is to assist the decision makers in choosing the best electricity generation and distribution alternative and to plan the allocation of the necessary resources. The broad categories of alternatives include small diesel, supply by transmission from existing or proposed main grid, modification of grid layout, and creation of a local grid. MHG also lends itself to several alternatives from the technological and logistic stand point.

Capital costs are best examined by first taking as a base line the cost of modern equipment installed in a developed country. The list of the components of the capital costs can then be adapted to local situation, taking into account possible cost reduction factors or additional cost burdens as they may arise. It is true that the overall investment costs of a MHG unit is very site-specific. There are however, two elements that can be used as a starting point; first, the cost of an efficient set of electro-mechanical equipment bought in a developed country is fairly uniform and depends chiefly on the water flow rate and head available. Figure I gives a rough idea of those costs. Very noticeable on this figure is the very rapid decrease in investment costs as one goes from the lower and to the upper end of the scale in MHGs: while the equipment for a 50 kW unit may be around a $ 1000 per kW, this figure is nearly halved at the 200 kilowatt level. The other rule of thumb that can be used in an average situation is that the cost of the electro-mechanical equipment rarely exceeds 30% of the cost of the whole system. In the absence of other specific data, and for the purpose of general discussion, one may assume that the total cost of a project is at lease three times the cost of the electro-mechanical equipment. Accordingly, one might expect that providing a small community with 50 kW could cost an average $ 3000 per kW for a total investment of $ 150,000, while providing a slightly larger community with 200 kW

FIGURE 1. <u>Capital Costs for Electro-Mechanical Equipment</u>



Reference values in DM per kVA of machine set for synchronous type small hydro power plant

Source: Small Hydro Power Stations, Energy Department, March 1979, pp. 41-43.

Remarks:

1. $1 equals approximately 2 DM.
2. Transformer not included.
3. Hu is the Head: high head installations are significantly cheaper than low head installations at equal power rating.

may cost normally $ 1,500 kW for a total of $ 300,000. A few data points that complement the proceeding information and that were gathered during the preparation of the meeting include:

- the cost calculations for a 19.2 kW micro station in Peru using imported equipment show $ 3,800 per kW;
- investment costs expressed in 1977 dollars for stations of an average 15,000 kW in the United States represent $ 1,160 per kW;
- cost of a new turbine and generation set on an existing site in Norway, $ 1,000 kW for a 1000 kW station.

Investment costs associated with MHG units are therefore very high and far exceed the investment costs associated with Diesel generation or large hydro power plants.

Operating costs, as a consequence, are essentially capital related costs. Maintenance and repair costs are low, both because there is little to be done and because the required labor is usually less skilled than necessary for diesel generation. A MHG set can be expected to last about 30 years on average. A 750 kW unit being presently built in Namche Bazar in Nepal will be able to generate electricity at a reported cost of $ 0,08 per kWh.1/ Rough calculations show that a 50 kW unit might be able to generate electricity at an average cost of $ 0,12 to 0,15 per kWh, including capital related charges. Costs obviously should not be confused with prices since the pricing structure is a completely different matter.

Cost reductions can be achieved in a number of different ways. First, one may be able to make use of existing hydraulic structures such as dams, existing irrigation channals, old hydro-electric sites, etc. A recent study by the MITRE Corporation 2/ stipulates that the cost of fitting such structures with MHG units may be from 38 to 69% of the cost of a completely new installation in the case of 15 megawatt station. It may not be unreasonable to think similar savings can be

1/ Prof. S. Radler, Vienna - Private Communication, 1971
2/ Small Scale Hydro Electric Preliminary Programme Plan, MITRE Corp. 1978.

realized in the case of micro hydro generation sets. Second, one may want to simplify the design and engineering of the proposed schemes. At the expense of the efficiency of the available energy conversion, and sometimes at the expense of the working life of the equipment, it is possible to use simpler and cheaper types of water turbines and speed governors. A classical example is that of the Banki-Mitchell turbine which has an efficiency limited to perhaps 60 or 70% but that does not require any castings or forgings. Third, local manufacture is usually a way of saving both in terms of foreign exchange and in absolute amount of currency units. This is due to the fact that most small turbines are individually made and have a high labor content. Forth, standardization of the design saves money not only at the initial stage by cutting down on research, development, engineering and tooling costs, but also later on as spare parts are cheaper and more readily available. It is even possible to design Banki-Mitchell turbines of different sizes that have many identical components.[1/] By making use of most of the previously mentioned cost reducing opportunities, the cost of a 19,2 kW unit in Peru[2/] has been brought down from $ 72,000 to $ 19,000. In particular, use was made of existing structure, local materials and local fabrication facilities. In addition to reducing the initial costs, those measures also bring the design, construction and operation of MHG closer to the population, with the usual benefits associated with "appropriate technology".

Equipment sizing is an important economic issue. As an indication of the power requirements for some typical rural development schemes the following very approximate examples have been quoted:[3/]

- 50 kW would power a small village and school;
- 100 kW would power a medium size village, school and medical centre;
- 200 kW would power a medium size tea or cotton factory by day and a village by night;

1/ Development of Equipment for Harnessing Hydro Power on a Small Scale, Mr. V. Meier, Kathmandu, Nepal, 1979.

2/ Case study of the pilot MHG at Obrajillo, Mr. E. Indacochea, R e S, Kathmandu, Nepal, 1979. p. 30 and 31.

3/ Small Scale Hydro-Electric Generation and Rural Development, Crown Agents, Kathmandu 1979. p 10.

- 300 kW would power a large saw mill by day and a village by night.

While the electricity demand traditionally doubles every 10 years in developed countries, the demand growth can be significantly larger in developing countries. Although few data are available on that subject in the case of MHG, one can learn from cases where the grid suddenly reached villages that did not have electricity before. Such occurence in Venezuela has reportedly 1/ resulted in a doubling of the demand in three years: this is due to a combination of factors which include development of local shops and small scale industries using the newly available electricity, increasing demand from individual households who are getting used to the new commodity and comparatively fasted growth of villages who have electricity and thus attract new inhabilants from neighboring villages or from semi-migrating populations. Proper equipment sizing is not only contingent upon proper global demand projections but also on projecting and insurancing the various components of the demand. By proper consumer information and pricing structure, one has to design incentives to:

- encourage the use of electricity when the demand is low (e.g. by promoting its use in small scale industryes; it takes only 2 kW to weld sheet up to 10 mm. thickness, and small drills, lathe,air pumps only require a few kW as well);
- discourage the use of electricity during peaks and discourage the use of oversized receptors (1 kW kettles instead of 3 kW kettles, 60 watt lamps instead of 100 watt lamps, etc.);
- encourage energy savings. For instance if a flat rate is charged to the user regardless of the amount of power used, they may find it cheaper to leave their equipment on permenently rather than to install switches.

1/ Private Communication, Mr. P. Richalet, 1979.

The social economic benefits that can be derived from MHG are the same as those that can be derived from rural electrification generally; education is prominent among those, since proper lighting of houses and schools increases the useable length of the day and permits reading at night. Health care, rural industrialization, and the general welfare of the populations benefit from the use of this renewable resource in a non-polluting process. Social factors that must be taken into cinsideration, however, also include a study of the local history and traditions and the possible changes in the occupational, housing and family structure and income, migration habits, and the sudden burden that is put on the capacity for adaptation of the community and the individuals.

ISSUE ON POLICY AND INSTITUTIONAL ASPECT

- MHG development plan is a part of national industrial development plan
- Rural electrification and rural development
- Survey of hydrological resources
- Feasibility study on MHG
- Legal aspect of MHG development (including ownership)
- Off-peak period (energy stored in batteries)
- Hydrological potentials available and yet cannot develop MHG - Why?
- Role of Government
- Role of international bodies

IV. Institutional Issues

A national energy and industrial development programme is usually considered to be a prerequisite for the harmonious industrialization of a developing country. No matter what the respective part of private initiative and government initiative, regulations and controls will play, the government will be called upon at several levels for assistance in the development of a MHG programme. On one hand the government has the mandate to insure that the best use is made of the land and water resources of the country. On the other hand, the government can only allocate a limited amount of financial and human resources to a MHG programme, which is in natural competition with other energy development programmes and more generally with the various components of the planned industrialization of the country. In order for the development of MHG stations to be well integrated in the overall development of the country, it must therefore be planned at the national level.

The planning of small scale hydro-electric power generation must be an integral part of the rural development scheme. Since the turbine will be able to provide a given quantity of current twenty-four hours a day, it is essential to develop productive uses for electricity early on so as to absorb as much as possible of the potential output of a rural hydro-electric scheme, particularly in its off-peak periods. This involves planned improvements in local agriculture, agro-industry, small workshops and repair shops, water supplies and irrigation, as well as improvements in community services such as health care and education. In addition to social benefits, such planning entails significant economic benefits because the installed equipment is better utilized and because more important generation and utilization of electricity makes for significant economies of scale.

The survey of the hydrological resources of the nation is usually supplied or facilitated by the government and overease. Although there is still a very serious lack of hydrological data in many developing countries, the inventory of the water resources is of crucial utility if one is to insure that the development of MHG programmes will complement rather than interfere with other uses of the national water resources such as irrigation, potable water distribution, erection of large hydro-electric projects, fishing, tourism, recreation, and other possible benefits.

The legal framework in which the promoters, builders and operators of MHG units must operate is fairly complex. The utilization of the land and of the water resources is governed by the law. At the same time the generation and distribution of electric power to the public is usually very strongly regulated. Such activities are sometimes directly carried out by an agency of the government or a nationalized company, or in the more liberal cases by one or several private companies, monopolistic in nature, whose rates are regulated by the government and who have the obligation to serve the public in very specific terms. Legal problems may therefore arise when a small operator or village community sets out to generate electricity for public use. The establishment of power selling prices and policies in the case of isolated MHGs can be a difficult institutional issue. Quite often, exceptions to the rule must be made so that full advantage can be taken of the potential for MHG. The regulations designed to protect the environment can have a significant technical and economic impact on MHG projects. Requirements for fish ladders, to take only one example, can make the capital costs of the project prohibitive. Finally, the liability of the designer, builder, owner and operator of MHG generation and distribution system in case of system failure, property damage and personal injury is not to be underestimated. Incidentally, insurance costs in the case of local appropriate technology utilization may be high and represent a significant economic burden.

The creation of a receptive technical setting is again the responsibility of the government. Technical information structures that preferably make use and build on existing structures can be developed. China is an example of such successful structural design; its elements include standardization of equipment and historical progression from very small units of a few kilowatts to slightly larger ones and still larger units: it also includes the organization of the transfer of technology from those who have acquired the experience first hand to those who wish to install MHGs. Finally, it includes the division of responsibilities for the design and fabrication of the various components; for instance while the turbine is usually made in China by the community sponsoring the projects, the alternators are made in more centralized plants. Finally the encouragement of academic endeavours and the creation of research, development and demonstration programmes is the responsibility of the government.

Financial and fiscal incentives must be designed once the extent to which the government wishes to encourage MHG has been decided. China again and other countries propose cheap loans with extended repayment periods, while Peru subsidizes the price at which the electricity is sold to the users. Other fiscal incentives may range, for instance, from investment tax credits to accelerated depreciation periods.

AREAS OF CO-OPERATION

- Publication of MHG Manual (Contents)
- MHG information exchange system

V. Follow-up Activities

The substance of the information, conclusions and recommendations assembled by the participants to the Seminar/ Workshop will be edited and made available to the participants and all other interested parties upon request.

While it can be expected that most of the relevant issues will be brought up during the meeting, it can not be expected that all discussions will be conclusive on all points. In particular, some elements of economic data and cost benefit calculation methodology of MHG as compared to other possible alternatives (e.g. larger hydro-electric plants, thermo generation etc.) will still be missing after the meeting. One of the tasks of the workshop is therefore to clearly define the needs for further UNIDO sponsored consultancies in such areas of general interest.

Finally, many countries have been or will be approached with specific proposals for the installation of MHG units. Those solicitations may come from inside the countries or from outside promoters. UNIDO will be available to independently assess the soundness of the proposals, and will provide assistance at the levels of pre-feasibility, feasibility, technology transfer and work monitoring.