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SOME PROBLEMS ARISING FROM THE DEVELOPMENT OF POWER STATIONS AND ELECTRICITY SYSTEMS

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INTRODUCTION

The problems relating to the electric power industry that are discussed hereafter have been approached from the standpoint of the Latin American countries. There is an urgent need for electric energy, but the requisite financial resources are not always obtainable; it is therefore essential to use the limited funds available in the best possible way. The plants should be efficient and each one of them should yield results in proportion to its initial cost.

1. Selection of type and size of power station and alternative solutions

The principle elucidated below is broadly applicable in any part of the Western hemisphere, with individual variations for each country to adapt it to local fuel supplies and hydrological conditions.

(a) Type of power station

A technico-economic study, prepared by persons with a broad grasp of the situation derived from a vast fund of experience in their field, will indicate the type of power station that is likely to be the most suitable in each case. A project springs from an idea. The idea has to be developed, promoted and financed before construction can begin. The preliminary study will indicate the desirability, scale and general details of the project.

In the case of thermal plants (steam, diesel or gas turbine), the fixed operating costs (interest on investment plus depreciation) vary between 10 and 15 per cent of total investment. For the same type of plant, the total operating costs comprise the following:

(1) Fixed costs: 40 per cent

(2) Production costs: 60 per cent (fuel costs are approximately 45 per cent of the total production cost)

Definition:

Total operating costs = fixed costs + production costs

Production costs = cost of fuel, maintenance, labour and miscellaneous

In the case of hydraulic plants (including transmission lines), the total operating costs fluctuate widely, in accordance with the characteristics

/of each

of each plant. However, they usually comprise the following:

(1) Fixed costs: 80 per cent

(2) Production costs: 20 per cent

It is of prime importance to bear in mind the division of costs in thermal and in hydraulic power stations. It is popularly believed that hydraulic plants "hardly cost anything to run since water is free". Production costs are, in fact, low but fixed capital costs are frequently very high, and it often happens that the operating costs of a hydraulic plant exceed those of a thermal plant with similar capacity. One of the factors that is responsible for raising fixed costs per kWh to such a height in some hydraulic plants is the shortage of water during much of the year, which may reduce the plant's utilized capacity to less than 50 per cent. This has occurred in the case of some Mexican plants.

These examples are mentioned in order to stress the need for an extensive and knowledgeable analysis of each case before a decision is taken on the most suitable type of plant to install.

Broadly speaking, the different types of plants would have the following uses:

(1) Diesel plants - for demand up to a maximum of 2,000 kW.

(2) Steam plants - for unlimited demand from a minimum of 2,000 kW.

(3) Gas turbine plants - for demand from 1,000 to 25,000 kW, particularly where water is scarce.

(4) Hydraulic plants - for unlimited demand from a minimum of 1,000 kW, always provided that the hydrological and economic conditions are propitious in every way.

(5) Various combinations of any of the above-mentioned types of plant.

(b) <u>Size of power station</u>

The size of the plant to be set up will depend on the statistics of electric energy demand and on a study of the overall situation in the pertinent area. The general study which covers intangibles is extremely important; there are parts which have developed slowly in the past but show great promise for the future owing to new roads, high passes, new fuels or simply technological changes which, for any number of reasons, have favourable repercussions on the overall economy of the area under consideration. These are all factors that should be taken into account and are usually not apparent from the statistics.

/Once the

Once the "optimum" size of the power station has been determined, the possibility of acquiring one with an even larger capacity should be considered, if the cost is only a little more.

For example, in the planning guide, (see table 1), the following is noted:

(1) A plant of 3,000 kW costs 1.1 million dollars

(2) A plant of 5,000 kW costs 1.45 million dollars

Increase in capacity of (2) in relation to (1) = 66 per cent

Increase in cost of (2) in relation to (1) = 32 per cent

In other words, the increase in cost is very small in comparison with the additional capacity obtained in the larger unit. What seems to be surplus capacity often turns out to be very useful to meet unexpected rises in demand.

In the case of isolated systems, that have no connexion with other energy sources, it is important for the power station to have firm capacity. This means that, even should the most powerful generator be out of action (owing to a break-down or for routine inspection), the system would still be able to meet maximum demand. Under-industrialized countries with isolated systems are particularly prone to install several generating units of low capacity. For the greatest possible economy in relation to the initial investment and to the operating costs, it is necessary to install the minimum number of units with the maximum capacity within, of course, the framework of the system's requirements.

For instance, in the case of an interconnected system (firm capacity despite the withdrawal of 66,000 kW), for which an installed capacity of 66,000 kW is proposed, the natural tendency a few years ago would have been to set up:

(a) Four units of 16,500 kW at a total cost of 14 million dollars; or

(b) Two units of 33,000 kW at a total cost of 11 million dollars.

Today the accepted practice would be to set up:

(c) A single unit of 66,000 kW at a total cost of 8.1 million dollars.

The unit of 66,000 kW would obviously represent a considerable saving, since the four units of 16,500 kW would cost 75 per cent more in relation to the initial investment, and their total operating costs (in the case of thermal power stations) would be at least 38 per cent higher. These figures are obtained as follows:

/Total operating

Total operating cost	Four units of 16,500 kW	One unit of 66,000 kW
Annual generation (80 per cent load factor) kWh	450,000,000	450,000,000
(1) Annual fixed costs (13 per cent of 14 million dollars)	1,825,000 dollars	
Annual fixed costs (13 per cent of 8.1 million dollars)		1,050,000 dollars
(2) Fuel at 0.0144 dollars/kg 3,200 calories/kWh	2,030,000 dollars	
Fuel at 0.0144 dollars/kg 2,700 calories/kWh		1,720,000 dollars
(3) Supervision, labour, materials at 0.0012 dollars/kWh	540,000 dollars	
Supervision, labour, materials at 0.0010 dollars/kWh		450,000 dollars
	4,395,000 dollars	3,220,000 dollars
Total operating cost/kWh	0.00974 dollars	0.00715 dollars
Cost difference per kWh	0.00269 (38 per cent of cost per kWh in the unit of 66,000 kWh)	

The substantial savings in the case of the larger unit are due to its greater efficiency, lower costs of labour, materials and fairly small fixed costs. In view of the improved manufacturing and operating techniques that are current today, one unit for the example given is perfectly feasible. Ten or fifteen years ago, it would have been doubtful whether one machine could have done the work of four on a permanent basis.

It is hoped that the examples that have been chosen will have served to illustrate the technique of equipment selection. Each situation undoubtedly calls for a special approach if an adequate solution is to be found.

A reference will be made in passing to the use of atomic energy for electric power generation. At the present time, it is doubtful whether a power station of less than 100,000 kW would be practicable. Moreover, the operating cost of such a unit would be 50 per cent more than the corresponding cost in a steam plant of equivalent capacity. This comparison refers to localities where fuel is abundant and fairly cheap.

In any case, whether the power station is of the diesel, steam, atomic or hydraulic type, it is important that its equipment should be of Preferred Standard make, as this is the standard manufacture and therefore cheaper.

/2. Economic

2. Economic criteria for the design and construction of power stations in areas hitherto unserviced

The main changes that took place in power stations during the last few years were due to the application of sound engineering principles rather than to the introduction of equipment or apparatus that were revolutionary in concept or use.

Automatic equipment for combustion and for controlling level, temperature and pressure is now in common use. Apart from ensuring that the machines operate in optimum conditions, automatic equipment usually provides visual data and information on operations, which could not be obtained before and which enable a better analysis to be made of the day-to-day problems that arise. The latest improvement in such equipment is the indicator panel. This has a flow diagram with all the control valves and instruments mounted in the right position with respect to the diagram. Miniature apparatus is used because of lack of space. It is evident that this type of panel offers numerous advantages, one of which is the possibility of training personnel rapidly.

In countries that are now highly industrialized, automatic equipment is particularly useful, since it reduces specialized personnel requirements to the minimum as regards both number and degree of specialization. For maintenance purposes, the manufacturers hold permanent training courses which can be taken by persons who are to be responsible for keeping the equipment in good working order. Latin American technicians and workers are usually very adept and quick at learning how to handle complicated apparatus.

The following aspects should be taken into account in designing a power station:

(a) All the parts of the plant should be allotted sufficient space to enable them to be inspected and repaired without difficulty. It seems superfluous to mention this point but, surprisingly enough, it is frequently overlooked.

(b) The pipes and electric conductors should be as short as possible. This cuts down investment, maintenance and production costs.

/(c) Similar

(c) Similar equipment should be grouped together. This prevents duplication of work and makes for more efficient operation.

(d) The design should be governed by the most modern engineering principles and the equipment contemplated should be the most efficient and appropriate for the case in question.

Another factor with a bearing on the efficiency of the power station is the site of construction. The plant should have traffic facilities for materials, fuel, personnel and transmission lines. The site should be big enough to allow further expansion to take place. It is a very common mistake to set up the power station in a small area, which may be sufficient for its immediate needs but whose inadequacy is apparent from the first moment of expansion.

All too frequently, a site is mistakenly chosen with a difficult topography, either because of the lack of proper drainage during flood periods (as in the case of a Mexican plant which is in danger of being entirely engulfed when a neighbouring river overflows) or because the subsoil is soft and costly piles are required to bear the weight of the equipment.

The building itself should be so designed as to enable all the equipment, e.g. the principal crane, to be used easily and efficiently. In addition, as mentioned before, the building should be a mere enclosure in which each machine and piece of apparatus is readily accessible for inspection or repair. In no case, should architectural considerations take precedence over the functional. The number of pillars should be kept down to the minimum, since these always create problems whenever an expansion has to be made. The structure should preferably be of steel. Reinforced concrete is also a possibility, but it is very difficult to introduce any changes into structures made of this material. The cost of the building is approximately 25 per cent of the total cost of the plant; hence, it is false economy to reduce expenditure on the building unless this would ensure that the equipment, which represents 75 per cent of the cost, would thereby be used more efficiently.

3. Advantages and disadvantages of interconnected systems

An electricity system is an assembly of machines, apparatus, instruments, and transmission and distribution networks, etc. for the generation,

/transmission, distribution

transmission, distribution and utilization of electric power. It has been compared with the circulatory system of the human body, in which the arteries resemble the transmission lines, the capillaries the distribution network, and both combine to give every single consumer electric energy or "the blood of civilization".

When two isolated systems are joined electrically by means of an interconnecting line for their mutual benefit, the simplest type of interconnecting system is thus formed.

Although it may not seem very appropriate to deal with this subject from the standpoint of its advantages and disadvantages, it is undeniable that nay statement in favour of interconnexion would be incomplete without the arguments against it. This is rather paradoxical, since, if the reasons for interconnexion have been duly considered from all angles and the aims pursued have been carefully thought-out, the existence of any drawbacks should be inadmissible.

Power stations or systems are generally interconnected for the following reasons:

(1) Greater flexibility and/or stability of operation and, therefore, continuity of service;

(2) Better utilization of installed capacity and, as a result, less duplication of installations or investment.

It is clear that if, in order to avoid the cost of installing an additional generating unit in a power station, a larger sum is spent on interconnecting the plant with another which has idle capacity, there is no economic justification for the interconnexion. There may, of course, be "extra-economic" reasons for the interconnexion, but, in this paper, pride of place has necessarily to be given to economy in investment or in the operation of the power station.

In order to analyse the advantages and disadvantages of interconnexion, the Guanajuato-Michoacán-Chapala interconnected system will be used as an illustration; this combines thermo-electric and hydraulic power stations, which supply electric power to the States of Guanajuato, Querétaro, Michoacán and Jalisco in the centre of Mexico and to part of the States of San Luis Potosí and Nayarit. The system is shown in figure I. Table 2

/indicates the

indicates the main characteristics of the power stations that compose the system.

According to table 2, total installed capacity is 252,608 kW, of which 177,938 correspond to hydraulic units (H) and 74,625 to thermal units (V), i.e. approximately 30 per cent capacity is in the thermoelectric plants. Practical experience counsels a minimum of 35 per cent thermal capacity for combined systems, in order to guarantee the continuation of the service during long periods of drought and because most water resources are used primarily for irrigation, electric power generation taking second place.

The advantages of the Guanajuato-Michoacán-Chapala interconnected system include the following:

Flexibility. This consists in the greatest possible use of natural resources; hydroelectric units operate with the maximum regime available and remaining demand is met from thermal capacity.

With few exceptions, hydraulic generation warrants lengthy consideration because of the uncertainty of the river regimes. When little rain has fallen, the amount of water available for generating purposes is reduced while demand for electric energy increases because deep wells have to be drawn on to obtain water for irrigation. In such areas, it is essential to have adequate thermal reserves, for emergencies of this kind and, so to speak, to "ward them off" in adverse years by means of greater water conservation or control in the case of both natural resources and reserves.

During the rainy season, electricity demand is lower because a large part of the area served is agricultural. Moreover, hydraulic stations are able to produce more power since a large number are the run-of-river type, and this enables maintenance programmes to be carried out in the different thermoelectric plants without the rationing of supplies.

Greater firm capacity. Since the system has an installed capacity of 252,608 kW, of which the largest unit (Cóbano) has 25,000 kW, there is a firm capacity of 227,608 kW, i.e. 90 per cent of installed capacity. This is the standard percentage for interconnected systems.

Less installed capacity. If the areas served by the interconnected system have different cycles or "schedules" of current utilization, interconnexion will yield more since less investment has to be made in fixed equipment.

/Since the

Since the area supplied by the Guanajuato-Michoacán-Chapala system includes agricultural load centres (parts of Bajío, Jalisco and Michoacán), industrial centres (León, San Luis Potosí, Irapuato and Guadalajara) and residential zones, maximum demands do not coincide; this enables installed capacity to be reduced, as the different consumptions can be covered by an exchange of energy.

Greater stability of service. It is natural that the larger the number of interconnected plants, the more effective will be the "probability" factor in ensuring that maximum demand in one area does not coincide with maximum demand in another. The aim of interconnexion is to guarantee an adequate supply on the premise that demand on a specific power station or area will not necessarily coincide with that on another.

If the areas interconnected had exactly the same rhythm of activity and their uses lasted the same length of time, it would be more than doubtful whether interconnexion were either justifiable or beneficial. For instance, there might be two interconnected agricultural areas, in which crops and irrigation cycles were identical and whose other claims on current were also exactly the same. In this case, the advantages of interconnexion would be very remote, and an economic justification would be untenable; even when the systems or areas in question are very extensive and have numerous generating units, the "probability" factor may tip the balance in favour of interconnexion.

Lower operating costs. An isolated plant should be in a position to meet consumer demand in the area it serves. As the plant's capacity is distributed among various units, it should be able to satisfy maximum demand, even with its biggest unit out of action. When the interconnexion of isolated systems does not involve a disproportionate amount of investment, a reserve unit may serve several plants and thus avoid duplication.

Until recently the Guanajuato, Michoacán and Chapala divisions operated as individual economic units. Hence, it often happened that less electric power was demanded from the El Cóbano hydroelectric station (which has no regulating reservoir) than it was capable of generating, and that, as a result, the water unused by its turbines had to be run off. All this overflow of water represented lost energy.

/The system

The system of operation was recently revised. El Cóbano generates to the limit of the capacity permitted it by the flow of the river (without running off a drop of water), and variations are dealt with by the thermal plant at Celaya and the hydroelectric plants of the Chapala system. In this way, Celaya can economize on fuel and Chapala can store up water in its big regulating reservoir, formed by the lake of that name.

It is hoped that this example shows how absolutely essential it is for natural resources to be put to the best possible use by means of interconnexion. Moreover, the operation of plants with a high load factor logically costs less per kWh.

Greater facilities for utilization. As may be seen from table 3, interconnected systems cover a large part of central Mexico, and have an extensive transmission network which, with the minimum investment in transmission lines, enables rural areas to be supplied with electricity.

What may be termed the disadvantages of an interconnected system include, inter alia:

Creation of central offices. These offices should have the requisite accounting staff; personnel to take charge of the programming of construction, and the operation of the system and load dispatch; maintenance personnel for the mechanical and electric equipment; and a central department responsible for distribution, transmission lines, meters, purchases and legal aspects, etc.

Communications system. The intercommunication system is another disadvantage because it is relatively costly to operate and maintain. The Guanajuato-Chapala-Michoacán system has a telephone network and radio equipment linking up the principal load centres and generating plants, as well as radiotelephonic apparatus for communicating with the main offices in Mexico City.

Protection system. In order to give adequate protection to the power transformers, generators and lines, it is necessary to have a protection system including switchgears, relays, fuses, disconnecting switches, etc. This equipment is relatively expensive to buy and maintain.

Maintenance of interconnexion lines. Here, the problem is the cost of keeping the lines in good condition. This involves the establishment of camps along the whole length of the lines, whose personnel are responsible

/for the

for the regular revision of the interconnexion and transmission networks, for replacing insulators and for repairing towers and poles.

Interconnexion lines. The economic aspect, or cost of the lines, is a drawback. Transmission lines cost a great deal per kilometre and call for heavy investment. The region supplied by the Guanajuato-Chapala-Michoacán system has undoubtedly benefited far more from interconnexion than if it had had to depend upon one isolated plant in each zone. The modern trend is definitely towards the interconnexion of systems.

4. Economic aspects of the combination of thermal plants (including atomic energy) with hydroelectric plants of all types

The combination of thermal and hydraulic power stations in interconnected systems gives excellent results, particularly in countries where water resources are scarce owing to the lack of heavy-flowing rivers with big falls.

Hydroelectric stations are usually far from important energy-consumption centres, and heavy investment therefore has to be made in transmission lines which, in order to guarantee continuity of supply, should have a double circuit. Thermoelectric plants are generally set up near consumption centres, which is a great advantage, even though their installation is sometimes greatly hampered by lack of water for the condensation plant or of adequate means of communications for the transport of fuel. The latter is a very remote contingency, and, as regards the former, gas turbines are extremely useful for sites where water is very scarce. Gas-driven units are preferable to diesel plants because of their lower maintenance costs since virtually the only element in motion is the rotor. As regards economic yield, they are slightly more expensive than steam turbines. The limitation of the gas turbine is its capacity, since the very largest are approximately 25 MW. In common with diesel engines, gas turbines have the virtue of needing very little time to enter into operation, which makes them ideal for freeing the peaks that correspond to hours of maximum demand.

So far, the atomic plant has been fundamentally a steam-driven unit, and its commercial use will follow the refinements or simplifications achieved through the acquisition and operation of the atomic energy unit and the disposal of its by-products (isotopes). Nevertheless, in extensive

/systems where

systems where there are prospects of substantial expansion, consideration is already being given to the need for introducing generation on the basis of nuclear reactors, in order to keep up-to-date with industrial development and the training of specialized personnel. Wherever fuel is expensive to buy, atomic power stations will have a very important part to play. At this time, atomic plants are already being developed with great success in England, and it is hoped that within the next five or ten years their cost will be comparable to that of any thermal plant.

It is believed that the ideal combination would be that of hydro-electric power stations - designed so as to enable their equipment to be used with a high load factor - in conjunction with large steam-driven thermal plants, which would generate most of the electricity, and, lastly, with gas turbine units to free the peaks. Combinations of this kind would reduce operating costs by excluding steam turbo-generators or hydraulic units with low load factors from the line. Some possible equipment combinations may be studied in table 3.

5. Conclusions

The different concepts which have been laid down in this paper are of a general nature, since they were approached from the point of view of their utility for all the Latin American countries rather than their application in a specific area.

Latin America has problems peculiar to itself which cannot be solved by the criteria prevailing in highly industrialized countries. The development of the electric power industry will have to conform to the economic situation of the region and its social requirements, which are of a very special kind and bear no resemblance to those in Europe and North America. Latin America should use its own material resources as much as it can and endeavour to perfect its grasp of scientific techniques in relation to the electric power industry. This will give it the necessary autonomy to plan, design and construction in accordance with the requirements of the individual countries in the region.

/Table 1

Table 1

PLANNING GUIDE - STEAM POWER PLANTS a/

November 1960

Rate capacity, kW	3 000	5 000	7 500	10 000	12 650	16 500	22 000	33 000	44 000	66 000
Turbo generator										
Continuous maximum capacity, kW	3 250	6 250	9 375	12 500	12 650	16 500	22 000	33 000	44 000	66 000
Steam pressure, lbs/sq.inch	400	400	600	600	600	850	850	850	850/1 250	850/1 250
Steam temperature °F	750	750	825	825	825	900	900	900	900/950	900/950
Generator cooling	Air	Air	Air	Air	Air	H_2	H_2	H_2	H_2	H_2
Steam generator										
Boiler capacity, lbs/hr	42 000	70 000	100 000	125 000	150 000	175 000	225 000	350 000	500 000	650 000
Approximate total cost of entire plant, millions of dollars	1.1	1.45	2.0	2.6	2.7	3.5	4.2	5.5	6.8	8.1
Cost per kW of continuous maximum capacity, dollars	294	232	213	208	213	212	191	167	154	123

a/ The equipment included in this list is manufactured in the United States.

Table 2

Power station	Unit number	Type	Date of entry into operation	Capacity kW	Generating voltage kV
Zumpimito	1	H	1944	800	6.6
	2	H	1944	800	6.6
	3	H	1944	2 400	6.6
	4	H	1944	2 400	6.6
Bartolina	1	H	1940	400	0.48
	2	H	1940	350	0.48
Granados	1	H	1942	940	3.15
Cobano	1	H	1955	26 010	13.8
	2	H	1955	26 010	13.8
San Pedro Poruas	1	H	1957	1 600	3.15
	2	H	1905	305	0.5
	3	H	1930	960	3.15
Tirio	1	H	1905	216	5.0
	2	H	1905	216	5.0
	3	H	1928	240	5.0
	4	H	1930	640	5.0
Cointzio	1	H	1943	480	6.6
San Pedro	1	H		173	3.5
	2	H	1912	192	5.0
	3	H	1912	200	5.0
San Juan	1	H	1904	120	1.0
	2	H	1904	120	1.0
Colimilla	1	H	1950	12 800	13.8
	2	H	1950	12 800	13.8
	3	H	1950	12 800	13.8
	4	H	1950	12 800	13.8
Puente Grande	1	H	1910	2 800	6.0
	2	H	1910	2 800	6.0
	3	H	1910	2 800	6.0
	4	H	1927	6 000	6.0
	5	H	1946	9 000	6.0

Table 2 (continued)

Power station	Unit number	Type	Date of entry into operation	Capacity kW	Generating voltage kV
Las Juntas	1	H	1938	6 000	4.0
	2	H	1942	5 000	4.0
	3	H	1956	4 000	4.0
El Salto	1	H	1959	2 975	2.3
Guadalajara	1	V	1957	6 250	13.8
	2	V	1957	6 250	13.8
	3	V	1957	6 250	13.8
Itzicuaro	1	H	1926	392	2.3
	2	H	1926	200	2.2
Botello	1	H	1911	4 050	2.3
	2	H	1911	4 050	2.3
Platanal	1	H	1903	1 000	2.3
	2	H	1903	1 000	2.3
	3	H	1906	3 600	2.3
Sabino	1	H	1909	1 200	2.3
	2	H	1909	1 200	2.3
Las Rosas	1	H	1906	400	0.525
	2	H	1906	400	0.525
	3	H	1911	400	0.525
	4	H	1949	1 600	0.525
San Francisco	1	H	1952	344	0.525
Celaya	1	V	1948	9 375	13.8
	2	V	1958	16 500	13.8
	3	V	1958	16 500	13.8
San Luis Potosí	1	V	1936	2 500	4.16
	2	V	1938	3 500	4.16
	3	V	1948	7 500	13.8

Table 3

POSSIBLE COMBINATIONS OF VARIOUS TYPES OF PLANTS

	Steam turbine	Hydraulic turbine	Gas turbine	Diesel engine	Atomic **plants
Combination I	Variations	Base	Base and maximun	Peaks	
Combination II	Base	Variations*	Peaks		
Combination III	Base	Base		Variation and peaks	
Combination IV	Variations	Base and peaks			Base
Combination V	Variation	Base	Peaks		Base
Combination VI		Variations	Base and maximum	Peaks	

Note: In each combination, an attempt has been made to use the intrisic characteristics of the equipment to the best possible advantage.

* Practical when large reservoirs exist for storing water.

** Costly because this particular type of plant has a low load factor.

Variations: The peaks and troughs of demand are taken.

Base: Operating with a constant load.

Base and maximum: Operating with a constant load at maximum capacity.

Peaks: Maximum demand occurring daily for a few hours.

Map I

Mapa I

INTERCONNECTED SYSTEMS OF GUANAJUATO, CHAPALA AND MICHOACAN-ZUMPIMITO

SISTEMAS INTERCONECTADOS GUANAJUATO, CHAPALA Y MICHOACAN-ZUMPIMITO