geothermal exploration project
ethiopian lakes district rift

installation of
a back pressure unit
evaluation report
august 1984
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**Appendix 1 - Draft Telex for Request of Quotation**

**Figures**

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This report has been prepared in the frame of the contract (No. TA 26/EEC of 23/7/82 - Accounting 4 100.016.20.20) between the Ethiopian Institute of Geological Surveys (the implementing agency of the Ministry of Mine and Energy) and ELC-Electroconsult in order to evaluate the convenience of installing a back-pressure portable turbo-generator set in Aluto Geothermal field.

This report should have been prepared once the resources to feed the plant would have been definitely proved. But considering the fact that, according to the study done in 1982 by ACRES on the power market of the Interconnected Central System (ICS), a capacity and energy shortage would affect the system by 1986, it has been taken into consideration the possibility of mitigating this situation by the early installation in Aluto Field of portable back-pressure unit. This fact has required the anticipation of the study so that the order of the unit could have been placed as early as possible in order to have the plant on line to meet timely the requirement of the system.

In preparing this report in such circumstances we have faced the difficulty of dealing with a field where the resources are not yet proved and where speculations have to be made in assessing the events still uncertain. We hope, however, that thanks to the methodological approach implemented, we have reach a satisfactory result, although this exercise cannot be considered yet a feasibility study. Only when the results of next wells still pending (LA-6 and LA-7) will be available this report it will be possible to upgrade this report at the level of feasibility study.

During the implementation of this study, a part from the resource problem, we have faced also another subject which require a careful consideration too: the expected expansion of the Interconnected Central System and its relation with the growth of the energy demand.

A study of this system, is now under implementation by CESEN and ELC for the benefit of EELPA and the early results induce to believe that the conditions assumed by ACRES in 1982 in assessing the growth of the demand have considerably changed in the recent past, being the new forecast lower than two years ago.

Under these new hypothesis the capacity and energy shortage predicted by 1986 will be minimal and as far as the energy then will not even be a shortage till 1987 when the scheduled start of operation of Malka-Wakana hydropower plant with its 150 MW capacity will solve all
the problems of the Interconnected Central System for the following 4 or 5 years.

Therefore, only in case of a delay in the scheduled start-up of Malka-Wakana, the conditions of energy shortage will arise to justify from the economic point of view the installation of the back-pressure geothermal turbine.

Such situation now emerging reduces the urgency of a quick decision to install the back-pressure unit. This decision can be therefore postponed till the final results of power system study will be available. This postponement will consent to avail also of the two wells (LA-6 and LA-7) still to be tested and then to remove the uncertainty that has affected the preparation of this report.

This report therefore has to be considered as an interim report on the installation of the portable back-pressure unit, to be finalized only when all the pending uncertainties will have been removed.
2 CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

The exploration program implemented in the Lake District has led to the discovery of a geothermal field in the Aluto Area.

The extension and capacity of this field will be partially proved only when the results of the well LA-7, now under drilling, will be available. However, with the data presently on hand, the availability of resources sufficient to feed a back pressure turbine of 3-4 MW capacity can be demonstrated.

This turbine fed by three wells (LA-3 - LA-6 and LA-7 or LA-3, LA-6 and LA-4), can generate more than 25 GWh/year depending on the demand of the Interconnected Central System, to which the Aluto field can be connected by means of a 132 kV transmission line of 15 km length.

The economics of the installation of this back-pressure unit depend on the amount of energy, otherwise to be generated by diesel plant, that can be replaced by the Aluto's geothermoelectric energy. Such a situation would arise only if the start-up of Malka-Wakana hydropower plant is delayed.

Considerations other than economic however can justify the installation of the back-pressure unit.

2.2 Recommendations

Before taking any decision, await the results of the early tests on well LA-7. In the meantime, request quotations on the portable-unit and other supply to the manufacturers (see draft telex in Appendix 1).

Once the results of LA-7 will be available, decide the best suited exploitation scheme, evaluating exactly on the basis of the quotations submitted by the suppliers.

At that time more data on the Interconnected Power System expansion will be available and particularly on updated forecast on the future growth on the power and energy demand.

In any case, it will be indispensable to know as reliably as possible the expected date of start-up of Malka-Wakana because only its delay will justify from the economic point of view the installation of the back-pressure turbine.

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Considerations other than economic however shall be carefully evaluated such as for instance the other geothermal project going on in the Country which may induce to the installation of the back-pressure unit even if purely economic arguments would be not in favour of such a decision.
The geothermal fluids can be utilized to produce electric power by separation of the steam fraction to be introduced into a steam turbine. Basically, the following different schemes can be adopted (see Fig. 1):

A. Single flashing of the fluid at a given separation pressure (usually 5 to 10 bar) and utilization of the separated steam in a back-pressure turbine;

B. Single flashing of the fluid at a given separation pressure (usually 5 to 10 bar) and utilization of the separated steam in a condensing turbine;

C. Double flashing of the fluid at two different separation pressures (5-10 bar and the residual water furtherly evaporated at 1-2 bar) and utilization of the steam in a condensing turbine with double inlet for the two steam fractions at different pressure.

The amount of producible energy per unit mass of geothermal fluid at the well-head depends on the selected scheme as well as on the fluid enthalpy, which may be different in different wells and may vary during the field exploitation.

The B and C schemes are adopted in case the geothermal field capacity makes it possible to install a permanent Power Plant while the scheme A is adopted for Pilot Plants in order to utilize the energy from wells already drilled.

The installation of a portable back-pressure turbine of appropriate capacity in a geothermal field during the early stages of development offers many advantages:

. the continuous production of steam allows the collection of more complete and reliable data on the reservoir characteristics and that facilitates the optimization of the design of the full scale condensing power plant as well as of the general lay-out of the development scheme;

. the possibility of testing, on continuous basis, of the reinjection of the residual water;

. the corrosion tests on materials, the actual verification of scaling effects, the appraisal of the evolution of non condensible gases in the steam content to prevent future problems in the commercial operation of the full scale power plant;
. the generation of energy at a marginal cost, to be fed into the main interconnected grid allows a quick return on the investment.

Once the full-scale power plant starts its commercial operation, the portable unit can be easily moved to another field under development.

In the case of Aluto geothermal field these general considerations find a suitable application furtherly supported by the situation in the power system where an energy shortage is expected starting 1986.

Under these circumstances it would be advisable to install a portable back-pressure unit of the maximum size consistent with the availability of resources.

So far the production data of only two wells (LA-3 and LA-4) are available (LA-1 and LA-2 being out of the Aluto field and cold and LA5 to be drilled deeper) while LA6 is in the heating process although is expected to be a good producer. Therefore the proved joint capacity of LA-3 and LA-4 is about 2 MW (at back-pressure generation) and at least 1.5 MW capacity is expected from LA-6.

Speculations on the expected capacity of well LA-7, now under drilling, may lead to assign the distribution of "subjective probabilities" of the capacity ranges for this well (see paragraph 4.4), on which basis "risk analysis" evaluation could be formulated. With this approach the resources available at high degree of probability may be assessed up to 5 MW capacity. However, taking into consideration that the financing of the installation of the back-pressure turbine has to be secured throughout International Lending Institutions, whose conservative attitude may reject a "risky" approach, it is advisable to consider a plant of a capacity not higher than the resources already proved. Along this line we are therefore proposing and studying a generation scheme of 3-4 MW capacity whose final dimension will be decided on the availability of the turbo-generator set already existing in the supplier market, to minimize the delivery time.

As regards the alternative between a single turbogenerator set to be fed by two or more wells and several small sets to be installed at the well-head, we have discarded the latter for the following reasons:

. the cost per kW installed of a smaller unit is higher than the unit cost of a larger unit;
the single plant site will be located in a position close to the most probable location of the full-scale power plant. In this case the fluid gathering system to be constructed for the back-pressure unit will be utilized, without any major modification, later on for the final power plant.

In conclusion, this study will consider the installation of a back-pressure turbine of 3-4 MW capacity, fed by 2 or 3 wells and located in a suitable position to be definitely selected after the results of LA-7, but in any case corresponding to the location of the full-scale condensing power plant to be eventually installed on the Aluto field.
4.1 Previous Activities

The drilling activity presently going on in the Aluto Area, which has led to the discovery of a geothermal reservoir by the wells LA-3 and LA-4 (and most probably LA-6) is the outcome of a long exploration history.

Starting on 1970 the Ministry of Mines and Energy, with the assistance of UN/UNDP, has carried out the reconnaissance survey of most areas in the Ethiopian Rift from Danakil Depression to the Lakes District. Geological, geochemical and geophysical prospections were implemented in potential geothermal areas and as result some prospects were identified, in the Lakes District between Lake Abaya and Lake Langano.

Particularly four areas were selected for further investigations, namely from North to South: Aluto Caldera and North Langano, West Shala, Corbetti and North Abaya.

In 1978 the Ethiopian Government reached an agreement with the European Economic Community and the United Nations/UNDP to promote a Geothermal Exploration Project in the Lake District area, to be jointly financed. Scope of the Project was the location of a commercial geothermal field capable to support the generation of geothermoelectric energy up to the capacity of 30 MW, to be fed in the Ethiopian Central System.

On this occasion funds were allocated to drill nine deep exploratory wells of a nominal depth of 1 500 m, with the aims of locating a reservoir and determining the feasibility of geothermoelectric generation.

On early 1981 a Technical Review Committee, with the participation of experts contracted by the United Nations (Hochstein, Mahon, Nairn, Dench, McNitt) was called for a meeting to review and assess the available data on the exploration of the District Area and to make recommendations on further geoscientific activity, on drilling and measurement and particularly on ranking of areas for initial drilling and advising on well siting.

As result the choice of Aluto-North Langano area was recommended and the first two well sites located accordingly.

Well LA-1 was started on November 7, 1981 and completed on June 11, 1982 at 1 317 m depth; well LA-2 was started on July 6, 1982 and completed on November 15, 1982 at 1 602 m depth.
Both wells were cold and dry. After these results it was decided to drill the well LA-3 inside the inferred "caldera" in the Aluto complex. The well started on January 21, 1983 was terminated on June 13, 1983 at the depth of 2 144 m. The maximum measured temperature was 315°C at the bottom. Circulation losses indicated also a certain permeability.

Although production from this well is limited, fluid enthalpy is remarkably good so that LA-3 can be considered as a discovery well.

After that three more wells have been drilled so far in the central part of Aluto within 2 km radius from LA-3, out of which LA-4 is producing and LA-6 is expected to produce.

We may assume therefore to have found a geothermal reservoir, the extension of which has to be proved by further delineation wells.

4.2 Geology of Aluto Area

The Aluto Complex corresponds to an acidic volcanic system, originated during the Pleistocene and actively developed till the Holocene, inside the Ethiopian Rift.

In broad lines the Aluto area can be subdivided in three sectors:

. The Western Sector where fracture liners trending NNE are prevailing. These trends are related to the West Langano fault zone, along which are located the recent volcanic centers, emerging from the Aluto Complex;

. The Central Sector where most of the Aluto Complex itself is located, affected by mosaic-like structure of faulted blocks with recent volcanic centers emerging from the faults delimiting the blocks;

. The Eastern Sector where the mosaic-like structures of Aluto are intercrossing with Rift's structural alignment, striking NE.

The Aluto Geothermal Field lies within the Central Sector and particularly in its Southern and South-Western portion where the recent volcanic center of Aluto is outcropping.

The field is related to the thermal anomaly generated by the magmatic chamber that has produced the volcanic
centers and seems to be, from preliminary vulcanological considerations, of a rather large dimension;

The field is also related to an intensely fractured area at the crossing of the Wonji faults system with E-W faults.

The productive reservoir is in the basalt and ignimbrites of the Rift Series.

The stratigraphic correlations among the wells drilled so far indicate that within the field area, vertical displacements among blocks are negligible.

The location of well LA-7 is very interesting because is situated along one of the main faults of the Central Sector: its geological logs and temperature profile will be very useful to better understand the geometry and the vulcanological characteristics of the structure in its Western and South-Western extension.

4.3 Results of Producing Wells

The results of the first tests run in the producing wells LA-3 and LA-4 are described below. These results cannot yet be considered as final and will have to be confirmed and completed by further tests which will be run in the coming months.

Well LA-3 It is located at an altitude of 1 921 m a.s.l. Drilling ended on 30/5/83, at 2 140 m depth; a slotted liner was inserted between 1 035 m and the bottom.

Injectivity tests identified the level of highest permeability at the bottom, at 2 110 m, and measured an injectivity index of 9.7 kg/MPa s.

The maximum temperature reached in the well is 315° at the bottom.

The results of the production test are shown in Fig. 2: they are represented with curves indicating the enthalpy and the mass flow rate of the fluid extracted from the well as a function of well head pressure.

Enthalpy increases at the decreasing of pressure: at 15 bar abs it is 1 350 kJ/kg, which is the value for saturated at 300°C, and reaches 1 600 kJ/kg at 8 bar abs.
Such a behaviour indicates that flashing occurs in the reservoir as a response to the pressure drop due to the mass extraction.

This fact is confirmed also by the shape of the curve of mass flow-rate versus well-head pressure, which is flat at a value of 12 kg/s below 15 bar abs. In case of extraction of liquid phase only, the mass flow-rate should increase at the decreasing of the well-head pressure, thanks to the higher pressure differential between reservoir, this effect of higher pressure differential is compensated by the lower relative permeability of steam with respect to water; therefore mass-flow rate does not increase significantly; the only increase occurs in the enthalpy.

Under these conditions, the most probable evolution of the well is towards higher enthalpy and lower flow rate, depending on the heat exchanges between fluid and reservoir rocks, which are faster when evaporation occurs in the reservoir.

Further tests, in any case, are needed to finally confirm this expected trend.

Well LA-4 It is located at an elevation of 1 956 m a.s.l. The total drilled depth is 2 024 m reached on October 23, 1983; a slotted liner was inserted between 774 m depth and the bottom.

The highest permeability, as shown by the injectivity test, is encountered at 1 445 m depth. The injectivity index is higher then the one of well LA-3, being equal to 25 kg/MPa s.

The maximum temperature after heating, 215°C, was found at 1 445 m. The results of the production curve are shown together with those of LA-3 in Fig. 2: the behaviour of the two wells differ significantly one from the other.

The enthalpy of well LA-4 is stable, at a value of about 950 kJ/kg, which corresponds to that of saturated water at the permeable layer: the fluid in the reservoir remains in the liquid phase also after the well is opened.

The curve of the mass flow rate is very steep, the flow rate of the well decreases from 22 kg/s at 7 bar abs to zero at 1.6 bar abs.

If no significant changes in the fluid temperature occur after the beginning of production the fluid enthalpy
should remain stable and the pressure should decrease with a rate depending on the permeability and on the mass flow rate.

The low value of the MDP and the decrease of the pressure makes it advisable, if this well will be connected to the plant, to adopt a turbine inlet pressure of 1 bar lower than the one that could be adopted on the basis of the present well production.

The above considerations on the production characteristics of the wells LA-3 and LA-4, together with the uncertainty on the characteristics of well LA-6 and LA-7, make it advisable to adopt a flexible turbine, which can keep a high efficiency with varying conditions of the flow from the wells.

4.4 Availability of Resources

In the previous paragraph we have examined the results of the exploratory wells and particularly of those producing a geothermal fluid suitable to supply a geothermal turbine.

At this stage it is still too early to assess the reservoir potential, pending the production tests on LA-6 and the outcome of well LA-7 now under drilling.

However, some considerations can be made by means of a probabilistic approach assigning a probability distribution of possible ranges of capacity expected from LA-6 and LA-7, on the basis of the limited data available for LA-6 and on some assumption on the geology of LA-7.

The table of Fig. 3 indicates the estimated probabilities of the possible ranges of capacity of the two wells and the combined probability of the cumulated capacity of both wells.

Such probabilities are based on the following assumptions:

. LA-6 will be surely a productive wells for the following reasons: temperature profiles indicate after 14 days a pattern and T values close to those of LA-3: circulation losses are important and indicate a permeability higher than LA-3. Therefore in the worst case its capacity will be equal to LA-3; most probably however its capacity should be larger.

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LA-7, almost 1 km west of LA-3 with high degree of probability, should be a producer for the following reasons: no physical barriers (neither structural nor stratigraphical) are detectable on surface between LA-3/LA-6 and LA-7. Even assuming that the alignment LA-3/LA-6 is the hottest portion of the field, the lateral temperature gradient should not be very different from the one existing between LA-3 and LA-4; therefore in the worst case, the temperature at total depth in LA-7 should be similar to that of LA-4.

The only possible adverse condition could be the lack of permeability; this is the reason why we have assigned 20% chances of zero production.

But taking into consideration the preliminary geological model of Aluto Complex (see ELC's Report GLE-D-6006 Geology of Aluto Volcanic Complex Preliminary Report) it appears that the location of well LA-7 falls in a very favourable area where there are good chances of intersecting the reservoir at a smaller depth; the existence close to the well site, of fractures and faults and of the "caldera" rim should enhance the probability of finding also a good permeability.

Looking at the table for the combined probabilities of the cumulated capacity of LA-6 and LA-7 (see Fig. 3) and at the corresponding curves of cumulated probabilities (see Fig. 5) we deduce the following considerations:

- there are 50% probability of having LA-6 and LA-7 as good producers.

In such case the Aluto field will be definitely confirmed as a commercial field which proved extension of 3-4 km2, large enough to consent the development of 50 MW in a condensing power plant.

In any case the steam available from the wells LA-3, LA-6 and LA-7 will be sufficient to feed a 10 MW condensing turbine, without any further drilling in the immediate future;

- considering the cumulated capacity referred to the Conversion with a back-pressure turbine, of the three wells LA-3/LA-4/LA-6 we have surely at least 3 MW with 90% chances of having 4 MW and 30% chances of having 5 MW;

- considering the cumulated capacity of the three wells LA-3/LA-6/LA-7 (still referred to conversion by back-pressure turbine) we have 98% chances of having at
least 3 MW, 83% chances of having 4 MW and 55% chances of having 5 MW.
5.1 Selection of the Size of the Turbine

After the consideration developed in the previous chapter on the resource availability, it appears that there is a certain range of options for the selection of the size of the portable back-pressure unit.

Within this range, however, the possible sizes present a different degree of probability as we have discussed, the question therefore is the limit of the risk that has to be taken.

If the system, starting in 1986, can accept as much energy as can be generated within the limit of the maximum capacity available for a back-pressure turbine, it would be wise, from this point of view select a unit size as big as possible even assuming a certain risk. On the basis of such consideration 5 MW capacity would be the better choice even if the degree of probability is not higher than 55%, considering that there are at least 83% chances of having at least 4 MW.

However, the technical problem exists that a unit of 5 MW capacity underfed at 4 MW has lower conversion efficiency than when fed at full capacity and the higher specific steam consumption would not even consent the capacity of 4 MW.

This reason discourages the choice of a 5 MW unit at this stage of knowledge of the field; therefore the recommended size is between 3 and 4 MW, the exact capacity to be installed depending on the quick availability from the manufacturer, of the package set.

In any case, if at the time of the final decision further information are available on the well characteristics (LA-6 and 7), it will be possible to modify the decision and order a 5 MW unit without any risk, improving the economics of the exploitation.

5.2 Alternative Schemes

At present, we have seen that at least 3 MW are sure from the wells LA-3, LA-4 and LA-6. Therefore, one possible scheme of exploitation is to connect these three wells to the power plant located in a site, suitable from the soil mechanics point of view, that minimizes the extension of the fluid gathering system (see drawing GLE 2).
In this case the residual water will be disposed in an evaporation pond to be located in the area most suitable from the morphological point of view.

This scheme, however, will be adopted only in case that LA-7 will not be a producer because the alternative scheme LA-3/LA-6/LA-7 (see drawing GLE 1) will be preferred due to some advantages such as a shorter length of the ducts, only one steam separator, and the disposal of residual water by means of reinjection in the well LA-4. The possibility of testing in the long period the reinjection at the periphery of the reservoir is a very valuable element, in view of the future optimized exploitation of the Aluto field.

Finally we wish to mention the possibility of utilizing only 2 wells (LA-3 and LA-6 or LA-6 and LA-7), should the capacity of LA-6 and LA-7 be sufficient to feed the 3-4 MW portable unit.

In any case the scope of this exercise is to prove the economical convenience of installing a back-pressure unit and if this convenience will be proved for the less favourable conditions any improvement in the exploitation scheme will furtherly enhance the advantage of the installation of the unit.

5.3 Turbine Inlet Pressure

Looking at the production curves of LA-3 and LA-4 (see Fig. 2) it appears that the two wells show different enthalpy values and different maximum discharge pressure (MDP) as well. As a matter of fact, while LA-3, whose enthalpy increases as pressure decreases, does not show significant reduction of the mass flow up to well-head pressure over 15 bars, the well LA-4 with an enthalpy of 950 kJ/kg independent of the pressure variation, shows a considerable reduction of the mass-flow already at lower well-head pressure values (around 7 bar abs.).

Therefore under these conditions, while for the well LA-3 the selection of the turbine inlet pressure does not affect significantly the mass-flow, in case we want to utilize the production of LA-4 we cannot adopt inlet pressures higher than 6 bars abs.

The specific consumption curves (see Fig. 6) indicate the amount of fluid to be extracted to produce a unit of energy in function of the turbine inlet pressure and of the fluid enthalpy.
Looking at the production curves of LA-3 and comparing them with specific consumption curves of LA-3, we deduce that the minimum specific consumption (approx 34 kg/kWh) corresponds to an inlet pressure of 7 bars abs.

The same considerations apply to well LA-6 and LA-7 which are expected to have similar production characteristics.

In the case of LA-4 (with a constant enthalpy of 950 kJ/kg), the minimum specific consumption corresponds to an inlet pressure close to 6 bars abs.

On the basis of these considerations, for the two alternative schemes under study, we can select the turbine inlet pressure depending on the wells to be connected.

In the case of Alternative 1, taking into consideration that the specific consumption is close to the minimum in the pressure interval 6-10 bars abs., and the production characteristics of wells LA-6 and LA-7 being still uncertain, it is advisable to select an inlet pressure of 6 bars abs.

In the case of Alternative 2, the selection of an inlet pressure of 6 bars abs. is imperative for the reasons previously discussed.

As far as the selection of the design pressure of the turbine is concerned, it is important to note that turbines of this size already exist in the market with a considerable operational flexibility under different inlet pressure (between 5 to 10 bars abs).

This operational flexibility make possible to utilize the same back-pressure turbine even if the characteristics of the new wells, still unknown, are considerably different from the existing one, or if in the future, during the exploitation of the field, the characteristics of the producing wells will substantially change. Finally, when the turbine will have completed its role in Aluto field, it will be possible to utilize it in other geothermal fields even with characteristics different from the ones prevailing in Aluto.

5.4 Fluid Gathering System

The traditional scheme of geothermal fluid separation, collection and transmission is: steam separator at the well head, steam line to the power plant, residual water line either to the power plant (in case of low pressure
flashing in separators close to the power house) or to the disposal system.

In the recent past, however, the transportation of the biphasic fluid from the well head to a centralized separation station, generally close to the power plant, has been introduced and satisfactorily tested.

A comparison between the two methods leads to the following considerations:

. The investment cost of two-phase transmission is lower due to the fact that only a single pipeline is required to carry the biphasic fluids (instead of a double pipeline for steam and water separately) and only one centralized separator instead of single separators at each well head.

. The pressure drop between the well head and the power plant is much more important in the case of two-phase transmission because of a higher friction in the ducts of the biphasic fluid (turbulent motion instead of laminar in the case of steam alone). In the case of Aluto, for instance, this pressure drop can be as high as 2 bars (against 1 bar for the steam alone). This fact requires to operate the wells at a higher well head pressure.

. The efficiency of the separation at the power plant is higher (about 5%) than that of the separation at the well head. As a matter of fact, the operating pressure required in the first case is lower than the operating pressure required in the second one: therefore for the separator at the power plant the steam/fluid ratio is higher, while the fluid extracted from the well is generally lower;

. The handling and disposal of the residual water is simpler in the case of two-phase transmission because all the residual water is concentrated in only one point, and with only one line it can be conveyed to the disposal system. This is even more convenient when pumping is required.

In this stage of development of Aluto field, it is advisable to adopt a two-phase transmission system with steam separation at the power plant area. This solution allows a lower investment cost, and at the same time it does not imply any reduction of the power produced as an effect of the higher pressure drop: this thanks to the characteristic of the production curve of well LA-3, which has also been extrapolated to wells LA-6 and LA-7.
Moreover, in this way it will be possible to test this scheme for the possible adoption in the full scale development of the project.

Only for well LA-4, when used as a production well (Alternative 2), it is necessary to install a cyclonic separator at the head of well LA-4 in order to keep the pressure drop between well and plant as low as possible: the two-phase flow in the piping would have caused much higher a pressure drop in the line, and a higher well head pressure. Due to the shape of the production curve of this well, such an increase of the well head pressure would have decreased significantly the flow rate of the fluid extracted.

Here follows the description of the equipment to be installed in the two different alternatives, described in paragraph 5.2.

**Alternative 1 (see drawing GLE 3)**

Each well is connected to the nearby existent silencer through a discharge line.

The two-phase line connecting each well to a single cyclonic separator situated in the Pilot Plant area, shall have a diameter of 12" for the LA-3 and LA-7 wells and 16" for the LA-6 well.

The cyclonic separator is calculated for 70 kg/s of fluid with 1 600 kJ/kg of enthalpy and equipped with water level regulation, overpressure protection systems and discharge to emergency atmospheric separator.

On the steam line (24") will be installed the ball check valve, the safety valves and the moisture eliminator.

On the residual water line, the reinjection pump complete of valves and regulation equipment will be installed in a suitable position. The reinjection water pipe shall have a diameter of 12".

**Alternative 2 (see drawing GLE 4)**

Each well is connected to the nearby existent silencer through a discharge line.
The two-phase line, connecting the LA-3 and LA-6 wells to the cyclonic separator situated in the Pilot Plant area, shall have respectively a diameter of 12" and 16".

The cyclonic separator is designed for 40 kg/s of fluid with 1600 kJ/kg of enthalpy and will be equipped with the same protection, regulation and emergency discharge equipments of the Alternative 1.

In the LA-4 well head area it will be installed another cyclonic separator calculated for 40 kg/s of fluid with 950 kJ/kg of enthalpy with the same auxiliary equipment as previously indicated.

The steam line of well LA-4 will have a 10" diameter and will be connected to a steam collector at the plant. The steam coming from the cyclonic separator of wells LA-3 and LA-4 flows the same collector.

All equipment between the steam collector and the turbine are the same as for Alternative 1.

The line carrying the discharge water of well LA-4 to the atmospheric separator will have a 10" diameter.

5.5 Effluent Disposal

The disposal system of the residual water to be adopted depend on the alternative which will be finally chosen, as discussed in the previous paragraphs.

In the case of Alternative 1 (LA-3, LA-6, LA-7), the residual water coming from the single cyclonic separator located near the plant will be pumped through a pipeline to the well LA-4 where it will be reinjected. The pump is required due to the difference in elevation existing between the plant site and the well LA-4 (LA-4 being approximately 60 m higher).

In the case of Alternative 2 (LA-3, LA-6, LA-4), the residual water coming from the two cyclonic separators at the separation pressure of 6 bars abs. (the one at the well head of LA-4 and the other near the plant) will be collected and conveyed to an atmospheric separator where, after flashing of the steam fraction at atmospheric pressure, the liquid phase will be discharged by gravity through a pipe or a canal in an evaporation pond.
This pond, assuming an evaporation rate of 2 000 mm/year and a rainfall rate of 1 000 mm/year, therefore with a net yearly evaporation rate of 1 000 mm, shall have a surface of approximately 1 km², and will be located in the morphologically suitable site existing in the central depression of Aluto.

Alternative 1 is surely preferable to Alternative 2 from the environmental point of view and for the opportunity it gives for long term testing of reinjection; but its selection is controlled by the outcome of well LA-7.

5.6 Transmission Line

The power plant will be connected to the Interconnected Central System in the existing Adami Tulu substation by means of transmission line of 14+15 km long.

The transmission system, designed to be utilized also for the final condensing power plant and capable to transmit efficiently up to 80 MW, will consist of:

. 1 step-up transformer 4.5 MVA, 13.8/132 kV with a complete 132 kV bay installed in Aluto;

. 132 kV, transmission line, single circuit, steal tower from Aluto substation to Adami Tulu substation;

. 1 complete 132 kV bay installed in the existing Adami Tulu substation.
6.1 Introduction

On the basis of the exploitation scheme discussed in the previous chapter, the corresponding estimated investment costs are indicated here below.

The difference between Alternative 1 (LA-3, LA-6, LA-7) and Alternative 2 (LA-3, LA-4, LA-6) is negligible as far as the total investment is concerned, Alternative 2 being a little more expensive in its fluid gathering system component. The difference, however, falls within 5% of the total investment cost and therefore within the limit of estimation accuracy.

6.2 Investment Cost Estimate

The costs indicated result from our recent direct experience in supply and erection of equipment and in installation of similar nature as well as from unofficial communications from manufacturers. To confirm these estimates it is recommended to request quotations in from different suppliers, utilizing the draft telex (referring to the Alternative 1) annexed, in Appendix 1 of this report.

Description of the Supply

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost US$ x 10^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pilot Plant</td>
<td></td>
</tr>
<tr>
<td>Turbogenerator set 3.5 MW-4.5 MVA</td>
<td></td>
</tr>
<tr>
<td>13.8 kV 50 Hz complete with: excitation and voltage regulation systems,</td>
<td></td>
</tr>
<tr>
<td>lubrication and air cooling systems, protection and synchronizing equip-</td>
<td></td>
</tr>
<tr>
<td>ments, valves, strainers, discharge, steel base and accessories</td>
<td></td>
</tr>
<tr>
<td>Equipment</td>
<td>1000</td>
</tr>
<tr>
<td>Transportation and Erection</td>
<td>300</td>
</tr>
<tr>
<td>Civil Works (power building)</td>
<td>100</td>
</tr>
<tr>
<td>2. Fluid Gathering System</td>
<td></td>
</tr>
<tr>
<td>Steam separating equipment includ-</td>
<td></td>
</tr>
<tr>
<td>ing collector, moisture eliminator, valves, rupture discs and access-</td>
<td></td>
</tr>
<tr>
<td>sories</td>
<td></td>
</tr>
<tr>
<td>5 000 meters of pipes for fluid gathering including: special pieces,</td>
<td></td>
</tr>
</tbody>
</table>

GLE-D-6060 6-1
bends, supports, accessories and thermal insulation

Equipment (ex work) 900
Transportation and Erection 1000

3. Transmission Lines and Substations

Transmission line, 132 kV, steel towers, from Aluto to Adami Tulu substations

Aluto substation, 132 kV equipped with step-up transformer 4.5 MVA, 13.8/132 kV, circuit breakers, dis-connecting switches, PT and CT, lightning arresters, protections, steel structures, cables, light-ing and accessories

Adami-Tulu substation, 132 kV (ex-tension) complete with circuit breakers, disconnecting switches, P.T. and C.T., protections, steel structures and accessories

Equipment (ex work) 900
Transportation, C.W. and Erection 500

TOTAL 4500
7.1 Energy Generation

Assuming a plant net capacity of 3.5 MW, the energy generated yearly by the back-pressure unit at different capacity factors, will be as follows:

<table>
<thead>
<tr>
<th>Capacity Factor</th>
<th>Yearly Generation GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>15</td>
</tr>
<tr>
<td>0.6</td>
<td>18</td>
</tr>
<tr>
<td>0.7</td>
<td>21</td>
</tr>
</tbody>
</table>

7.2 Basic Assumptions

The economic evaluation is made by the Discounted Cash Flow Method (DCF) to calculate the Internal Rate of Return (IRR) at constant money.

The basic assumptions of the Cash-Flow are the following:

a. Investment (disbursement): the investment cost, as indicated in Chapter 5, disbursed at the beginning of the year;

b. Benefit (cash inflow): the saving in the purchasing of fuel-oil necessary to generate the same amount of energy as generated by the back-pressure unit in a diesel plant located in the Central Region, assuming a cost of fuel of 250 US$/ton and a specific consumption of 0.24 kg/kWh (0.06 US$/kWh);

c. Residual Value of the Investment (cash inflow): we have assumed that the operation of the back-pressure unit will last for 3 years, after which a condensing turbine power plant will start its commercial operation.

After these three years we have assumed that:

- the residual value of the turbo-generator will be 500,000 US$ corresponding to 50% of the cost of the equipment, excluding transportation, erection and civil work cost;

- the residual value of the fluid gathering system will be 1,600,000 US$ corresponding to the 22/25 of the initial cost assuming the commercial life of the system (to be utilized without any significant change also for the condensing power plant) is 25 years;
the residual value of the power transmission system will be 1 200 000 US$ corresponding to the 22/25 of the initial cost, for the same considerations as per the previous point;

d. Operating cost: 100 000 US$/year.

7.3 Cash Flow

With the assumptions previously discussed the cash flow results as follows:

<table>
<thead>
<tr>
<th>Years</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outflow US$x10^3</td>
<td>-4 700</td>
<td>-100</td>
<td>-100</td>
<td>-100</td>
<td>-</td>
</tr>
<tr>
<td>Inflow* US$x10^3</td>
<td>-</td>
<td>+1100</td>
<td>+1100</td>
<td>+1100</td>
<td>+3300</td>
</tr>
<tr>
<td>Net Cash Flow US$x10^3</td>
<td>-4 700</td>
<td>+1000</td>
<td>+1000</td>
<td>+1000</td>
<td>+3300</td>
</tr>
</tbody>
</table>

* with capacity factor of 0.6

7.4 Internal Rate of Return (IRR)

Under the hypothesis of the cash flow indicated in the previous paragraph it results an IRR of 10% in constant money.

This value is reasonable enough to justify the investment, but it is very sensible to the variation of the capacity factor and to the cost of investment.

The sensitivity analysis of the IRR to those parameters is shown in Fig. 7.

From this analysis, it results that the IRR is very sensitive to the variation of the capacity factor and that below a value of this parameter of 50%, the installation
of the back pressure unit is not justified from the economic point of view.

Therefore, it is very important to know as accurately as possible the updated schedule of the development of the power system and the corresponding expansion of the capacity and energy demand.

In any case, considerations other than purely economic lead to the conclusion of the convenience of installing the lock pressure units.

Such considerations can be summarized as follows:

. interest in having a pilot plant in Aluto, to test, on the long run, a field the characteristics of which are not very clear;

. importance of operating (even if in a pilot plant) a geothermal field for power generation to train personnel at different levels of responsibility for the future development of the geothermal resources of the country;

. availability of a flexible, portable generation unit that can be moved from one field to another to initiate the trial operation in new fields under development before their commercial operation;

. demonstration that geothermal energy can be generated wherever resources are available, at a cost comparable with the hydro resources, and with a flexibility surely higher.

Milan, August 1984
ROM/CMA/JAR/GDE
SCHEME: BACK PRESSURE TURBINE

A

Well

Two-phase line

Water line

Cyclonic separator

Steam line

To the atmosphere

Generator

Silencer

Water discharge

SCHEME: CONDENSING TURBINE

B SINGLE INLET

Well

Two-phase line

Water line

Cyclonic separator

Steam line

Cooling water

Generator

Condenser

Silencer

Water discharge

SCHEME: CONDENSING TURBINE

C DOUBLE INLET

Well

Two-phase line

Water line

MP steam line

Cyclonic separator

Turbine

Generator

Cooling water

Condenser

LP cyclonic separator

Silencer

Water discharge

ALTERNATIVE SCHEMES FOR GEOTHERMAL POWER PLANT

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Fig.1
PRODUCTION CURVES OF WELLS LA-3 & LA-4
# Probabilistic Evaluation of the Resource Availability

## Analysis of Possible Events

<table>
<thead>
<tr>
<th>Likelihood of Occurrence (LA3 &amp; LA4)</th>
<th>LA6</th>
<th>LA7</th>
<th>LA6 + LA7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of the outcome (%)</td>
<td>Outcome MW</td>
<td>Probability of the outcome (%)</td>
<td>Outcome MW</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>60</td>
<td>2</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

* Resource capacity is referred to conversion by back-pressure turbine
PROBABILITY DISTRIBUTION CURVES OF THE CAPACITY OF CERTAIN SETS OF WELLS

Probability

Capacity MW

LA3*LA4+LA6+LA7
LA3*LA4+LA6
LA3*LA6+LA7
CUMULATED PROBABILITY CURVES OF THE CAPACITY OF CERTAIN SETS OF WELLS

Probability

Capacity MW

LA3 • LA4 • LA6 • LA7
LA3 LA4 LA6 LA7
LA3 LA6 LA7
SPECIFIC CONSUMPTION OF FLUID FOR THE BACK-PRESSURE PLANT

Fluid $h = 800 \text{ kJ/kg}$

- $\eta_{ad} = 0.70$
- $\eta_m = 0.985$
- $\eta_e = 0.965$
- $p_c = 0.8 \text{ bar}$

TURBINE INLET PRESSURE (bar abs)

SPECIFIC CONSUMPTION (kg/kWh)

GLE-D-6060

Fig. 6
ANALYSIS OF THE SENSITIVITY OF IRR TO THE CAPACITY FACTOR AND TO THE INVESTMENT COST

- **Base case**
- **+10% invest. cost**
- **-10% invest. cost**
Draft Telex for Request of Quotation
TO: Mitsubishi  
Tokio  
Japan
Toshiba  
Tokio  
Japan
Fuji  
Tokio  
Japan
Kawasaki  
Tokio  
Japan
Tosi  
Legnano  
Italy
Gie  
Milano  
Italy
Ansaldo  
Genova  
Italy
General Electric  
Schenectady  
USA
Elliot  
New York  
USA
Gec  
London  
G.B.
Westinghouse  
Philadelphia  
USA

SUBJECT: Request for Quotation
Geothermal 3.5 MW portable turboset for Aluto
field - Ethiopia

AAA GENERAL

EIGS has decided to implement in shortest time the
exploitation of Aluto geothermal field by means of a
back pressure portable 3.5 MW turboset.

The shortest delivery time will be highly
appreciated.

BBB LOCAL CONDITIONS

Site elevation 2 000 m asl
Atmospheric pressure 0.8 bar
Max ambient temp.
Mean temp.
Min temp.
Geothermal fluid enthalpy 1 600 kJ/kg
Total dissolved solids 3 000 PPM
pH 7 - 9
Gas content in separated steam 2% by weight

CCC BASIC DESIGN DATA

Nominal capacity 3.5-4.5 MVA-50 Hz
Min capacity 3 MW
Max capacity 4 MW
Steam pressure at turbine inlet 6 bar abs.
Turbine back pressure 0.8 bar abs.
Range of steam inlet pressure from 5 to 10 bar
abs.

Wells connected to the steam separator 3
Total capacity of flow 42 kg/s
Enthalpy 1 600 kJ/kg
Max well head pressure 19 bar
Corrosion allowance 2.5 mm

Black start and stop to be provided.
Suitable protection against ambient corrosion by hydrogen sulphide shall be provided.

The equipment shall be new, of standard construction, designed for geothermal application.

**DDD STEAM SEPARATION AND GATHERING SYSTEMS**

Steam separator shall be located at power plant area; water shall be pumped to the reinjection well and steam shall be conveyed to the moisture separator

Limit of supply is master valves on well heads and existing silencers.

Main equipments are:

- 1 cyclon steam separator 250 ton/h - 1 600 kJ/kg, complete with piping, valves, hot water tank, ball check valve, rupture disc and relief valve.

- 1 hot water (159°C) reinjection pump (delivery head of 15 bar, max flow rate 230 t/h) complete of valves and hot water level regulating system.

- 2 000 m of 16 inches, ASTM grade B, schedule 20, two phase liquid pipes. EIGS will supply the topography for the project.

- 2 000 m of 12 inches, ASTM grade B, schedule 20, two phase liquid pipes. EIGS will supply the topography for the project.

- Thermal insulation min 1.5 inch.

**EEE TURBOSET AND ACCESSORIES**

The turboset shall be designed for indoor installation. Adequate metallic housing for turboset with control room, one office and store facilities shall be included.

Main equipments are:

- High efficiency mist eliminator automatic water discharge and high level protection.

- Turbine generator rated 3.5 MW - 4.5 MVA, 50 Hz, 13.8 kV portable type on steel base plate.
Steam driven aux. oil pump.
Steam silencer at turbine outlet.
Air cooling for turbine oil and generator.
Brushless type excitation preferred.

**ELECTRICAL EQUIPMENT**

Main equipment is:

- Equipment at generator voltage including cables, circuit breaker, C.T. and PT surge protection and generator protection.

- Step-up transformer 4.5 MVA, 50 Hz, wiring delta/star from 13.8 to 132 kV, no load tap changer = 2 x 2.5%.

- 132 kV equipment including disconnecting switches, oil breaker 1 250 A - 2 500 MVA, PT and CT, lighting arresters for one complete bay.

- Generator synchronizing and protection panel.

- Low voltage auxiliary services panel.

**Please inform by return telex to EIGS**

a. Interest to quote  
b. Minimum time for quotation  
c. Shortest delivery time  
d. Should unit be available even with different characteristics but with shorter delivery time.

**Firm quotation is expected through letter accompanied by technical description and catalogs for:**

1. Steam separation and gathering system  
2. Turbo-generating set  
3. Electrical equipment

Separate quotations for CIF and erection plus civil works for each item are requested.
JJJ Technical clarifications if any shall be asked to EIGS.

Regards.