LATIN AMERICAN
ENERGY ORGANIZATION

INTER-AMERICAN
DEVELOPMENT BANK

GUIDE FOR GEOTHERMAL FIELD AND PLANT OPERATION AND MAINTENANCE

Quito, Ecuador
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PRESENTATION

Based on the objectives of: a) promoting actions for the use and protection of natural resources in the Member Countries and in the region as a whole, and b) establishing policies for the rational development, transformation and commercialization of energy resources, OLADE, due to the oil crisis experienced during the decade of the seventies, began an activity program in 1978 aimed at promoting geothermal research and use, as an alternative resource to traditional energy sources.

For this, one of the first actions carried out by the Organization was to develop a methodology for geothermal exploration and exploitation adapted to the conditions and characteristics of the Latin American and Caribbean countries.

With the collaboration of different institutions and experts from both within as well as outside the region, in 1978 OLADE prepared the "Geothermal Exploration Methodology: Reconnaissance and Prefeasibility Stages." In 1979, the "Geothermal Exploration Methodology: Feasibility Stage" was prepared, and in 1980 the "Methodology for Geothermal Exploration and Exploitation in the Development and Production Stages". The latter, once revised, supplemented and updated, formed the "Methodology for Geothermal Exploitation" that the Organization published in 1986.

The availability of these methodologies allowed the countries in the region to direct their research and the use of their resources with a useful and easy tool. With support from OLADE and its methodologies, Haiti, Ecuador, Peru, the Dominican Republic, Grenada, Guatemala, Jamaica, Colombia and Panama, among other countries, carried out reconnaissances in their territories. Also with the intervention of the Organization, Nicaragua, Panama, Ecuador-Colombia, Haiti and Guatemala developed prefeasibility studies in several thermal areas in which favorable conditions had been observed for geothermal development.

The application of OLADE methodologies helped to increase the countries' knowledge regarding their resources, to the point that toward the decade of the eighties, 20 of the 26 Member Countries had already carried out reconnaissance studies, 17 countries had prefeasibility studies, 8 had feasibility studies and 4 were generating electricity through the development of some of their geothermal fields. However, the rapid geothermal technological development showed the need to update methodologies.

Since the geothermal community expressed in different international fora the need to review, update and even supplement OLADE documents, the Organization and the Inter-American Development Bank (IDB), through Technical Cooperation Agreement ATN/SF-3603-RE, decided to revise the existing guides and prepare six new ones for geothermal prospecting and exploitation. These guides, responding to the requirements of technical groups in the region, would be for the following aspects: Reconnaissance Studies, Prefeasibility Studies, Exploration of Feasibility, Assessment of the Energy Potential (based on the information gathered in the reconnaissance and prefeasibility states), Operation and Maintenance of Geothermal Fields and Plants and Preparation of Geothermal Plant Investment Projects.

The preparation of the new geothermal documents was carried out with the help of seven international consultants and eight experts from the region, with broad experience in geovolcanology, geochemistry, geophysics, drilling, reservoir engineering, geothermal field and plant operation and maintenance, and plant engineering and design.

The efforts of OLADE and the IDB to contribute to energy development in Latin America and the Caribbean are presented in this document, which contains the Guide for Geothermal Field and Plant Operation and Maintenance, with the purpose of placing in the hands of countries in the region a tool that can guide them in activities to be carried out in the exploitation of their geothermal fields for electric power generation.

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1. INTRODUCTION AND OBJECTIVE

Once the development stage has been covered, the exploitation stage begins, where the objective is to keep the plant generating at maximum capacity and as economically as possible, during its useful life.

This guide describes the activities that will be developed during the exploitation stage, both in the field as well as at the plant, and covers the management of the geothermal fluid from reservoir extraction to its conversion into electric power.

In the section covering the field, operation and maintenance aspects recommended for the wells are described, as well as the fluid management systems and complementary works, and continuous field monitoring. Support studies that need to be carried out to ensure project operation during its useful life are also mentioned, along with the criteria for replacement well drilling and the organizational structure required for this stage.

In the section covering the plant, operation and maintenance aspects of its different systems are dealt with, including applicable criteria. Main activities to be carried out in each of the systems are pointed out, as well as key points to bear in mind. Special emphasis is placed on specific aspects of geothermal exploitation and the organizational structure and infrastructure required for this stage are defined.

Field and plant operation and maintenance involve continuous activities that are carried out from their start-up operation until it is decided to close them.

Due to the dynamic characteristic of geothermal developments, constant analyses and assessment must take place of the results obtained from field exploitation, for which reason support is required from an engineering group.

2. FIELD OPERATION

During the operation phase of a geothermal field, the basic development scheme usually exists already with regard to the number of wells required to supply enough steam to the plant, as well as with regard to the disposal system. It is during this stage that important decisions are made regarding the course of actions to be followed in the field and plant, and were answers to the following questions must be found:

- Is it possible and convenient to increase the field's generation capacity?

- Is the spacing between the field's wells adequate or will it have to be changed?

- Is well density correct or is some part of the field being overexploited?

- When will it be necessary to repair or substitute the wells?

- How must the production of the different wells be prorated to respond to the demand curve, without running the risk of over exploiting one section of the field?

- Does the plant function adequately or will it be necessary to modify its design?

- What will reservoir behavior be under the actual exploitation scheme and under other different schemes?

- Is the fluid disposal system adequate? Would it be convenient to inject at the same production level or should other options be considered?

- Will it be necessary to build more wells to maintain the steam production level required for the plant, or will it be more appropriate to allow a natural reduction of the steam flow obtained from the field, involving also a decrease in the amount of electric power generated by the plant?

- What will be the most adequate moment to decide whether to terminate the project, due to the high maintenance and operation costs of the field-plant system?

These are but a few of the most important questions that will have to be answered. The main elements that will help in finding adequate answers to these questions are the series of data, measurements and studies obtained or carried out during field operation. If collected in a systematic and well-planned manner, they will reinforce and complement the information gathered on the field during the previous stages.

2.1 Well Monitoring

2.1.1 Production Wells

Production well assessment and management criteria for the operation phase are the same already indicated in section 2.4 of the Geothermal Development Guide prepared by OLADE and IDB (1994).

After well development, a log should be kept containing its history with regard to the following aspects:

- Wellhead pressure

- Degree of opening

- Steam and water flows
- Thermodynamic (pressure and enthalpy) and chemical evolution of the well under operating conditions
- Content of solid dregs
- Presence of scaling
- Temperature, pressure, spinner and calibration profiles
- Results of tests carried out
- Detailed reports on different interventions and procedures
- Behavior of mechanical elements installed

2.1.2 Injection Wells

When injection wells are being operated, the following information should be gathered:

- History of injection pressure and temperature
- Injection flow
- Variations in injection temperature
- Changes in the chemical composition of injected fluids
- Presence of scaling and/or corrosion, as well as problems either in the fluid conduction line, inside the well or in the formation
- Temperature, pressure, hydraulic spinner and calibration profiles
- Results of tests carried out
- Detailed reports on different interventions and procedures
- Behavior of mechanical elements installed

2.1.3 Observation Wells

In the event that unproductive wells exist in the field and their location and mechanical conditions adequate for measuring the behavior of the geothermal system, they can be adapted for well observation purposes. Naturally, it would be more convenient, though also more costly for the project, to have wells drilled expressly for this purpose. In these wells it is convenient to keep as continuous a log as possible of variations in the levels of the water level or pressure with respect to a set level. For this, an instrument can be installed inside the well to send the signal to the surface, where it can be easily measured and logged.

2.2 Operation of Fluid Separation and Conduction Systems

Basic operation tasks for the fluid operation and transportation systems can be summarized according to the following needs:

- Integration of the well to the plant system

- Water level control in the separator

- Quantization of the flow and determination of the quality of the separated steam

- Maintenance or repair of installations

- Sampling and analysis of fluid and solid dregs

- Well finishing in the plant system

2.3 Integration of the Well to the Plant System

The sequence of procedures for this operation is the following:

- Pipe blowing (whenever required)

- Heating of separator and pipes through regulated flow

- Pressurization increasing well flow until the separator's working conditions are achieved

- Interconnection of main branches or collectors that gather the fluid from other wells

During these procedures it is recommended that special attention be give to the following points:

- Water level within the separator

- Wellhead pressure

- Purging in steam pipes
- Separator pressure
- Collector pressure
- Possible leaks

To quantify separated water, procedures basically consists in sending it to the silencer, where it is measured through a spillway and its evaporation losses are calculated.

During separated steam quantization, it should be verified that there have been no losses from the separated water output pipe. Establishing the quality of the steam is done simultaneously in this procedure, through the sampling and chemical analysis of the steam and separated water.

Fluid sampling for chemical analysis and the quantization of solid dregs is done using the sampling valves installed in the water and steam discharge pipes.

2.4 Well Termination in the Plant System

The sequence of procedures carried out to take a well out of the system is the following:

- Close the entrance to the separator, trying to maintain constant wellhead pressure.
- Open the output valve to the silencer
- Close the cutoff valve of the pipes that collect fluids from the other wells. In this procedure, the same precautions must be followed as those indicated for the process of integrating the well to the system.

Operation procedures required for the maintenance or repair of installations, chemical sampling, entraining of solids and termination of the well in the system, will depend on the arrangement of the equipment, pipelines and valves.

Quantifying the mass flow of individual wells when the production of several of them is combined in a central separator is difficult to do and requires special facilities.

2.5 Period Tests and Measurements

As has already been mentioned, a monitoring program for the behavior of production, injection and observation wells should be carried out. In addition, a series of well bottom measurements should be carried out with certain regularity, in order to log changes caused by exploitation at reservoir level. These measurements are: during pressure tests and during fluid sampling for chemical analyses.

Pressure tests are carried out in order to detect any change in the reservoir conditions in the area of the well (changes in permeability, well damage factor, etc.) that could be attributed to exploitation and that indicate possible problems. The techniques for the different types of pressure tests that could be used are discussed in section 3.2.3 of the OLADE-IDB Guide for Geothermal Feasibility Studies (1994).

Chemical Measurements

From the very beginning of the initial exploitation stage of a geothermal well it is important to sample and analyze the fluids, to be able to characterize their chemical conditions in the reservoir. These initial conditions will constitute the point of reference with relation to which variations registered as a consequence of massive fluid extraction will be documented and interpreted.

Fluid sampling and analyses should follow the procedures and precautions indicated in section 3.2.3.8 of the Guide for Geothermal Feasibility Studies (1994). On each occasion, information should be gathered on the value of the specific enthalpy of the total discharge, as well as the sample pressure of each phase, to be able to calculate the composition of the total discharge of the well.

Complete sampling should include everything necessary to calculate the chemical conditions of the fluid in the reservoir, including potential hydrogen values (pH), the concentration of boron, silica and of the main ionic species (chlorides, sulphates, bicarbonates, carbonates, sodium, potassium, calcium, magnesium, etc.), and the concentration of the main volatile species (carbon dioxide, hydrogen sulphide, methane, hydrogen, ammonium, nitrogen and helium). It is also important to establish the isotopic composition (oxygen-18 and deuterium composition) of the fluid. The methodology to calculate the composition of the geothermal fluid in equilibrium with the reservoir, based on the analysis of fluids collected above ground, and the practical usefulness of these calculations, are described in section 3.4.2 of the Guide for Geothermal Feasibility Studies (1994).

Complete sampling and analyses, as described in the previous paragraph, should be carried out maximum once or twice a year, unless a process is under way for the initial characterization of the reservoir or if a detailed study is desired. More frequently, preferably once a month, partial sampling and analyses should be carried out, to complete the well's production history (flow rate, enthalpy, wellhead pressure) with the history of the appropriate chemical parameters to detect changes in the well's feeding zone. This might involve, for example, determining the concentrations of silica and of the main ions (sodium, potassium, calcium, chloride, sulphate, bicarbonate/carbonate, pH) in the spillway's brine, and determining the molar fraction of noncondensable gases in the steam. In these cases, sufficient information should also be collected to be able to calculate the concentration of these species in the total discharge. In section 3.4.2 of the Guide for Geothermal Feasibility Studies (1994), as well as in sections 4.1.2 and 4.2 of this guide, the usefulness of this history is described in further detail.

2.6 Supporting Geoscientific Studies

At the same time and as a consequence of the exploitation of the geothermal field, several supporting geoscientific activities will have to be carried out, especially with relation to the geology, geochemistry, geophysics and hydrogeology. In most cases, these activities will only be a repetition or continuation of the work initiated during the project's feasibility or development stages.

2.6.1 Geological Studies

During the field's operation phase, the geological studies will focus on supporting aspects related to the selection and location of drilling sites for replacement wells, decisions related the placing of casing and well termination. They will also serve to help the drilling and reservoir engineering groups to identify and resolve problems arising during well drilling and operation.

The geologist will participate in the preparation of well drilling programs, providing information on underground geological conditions and on the geological control that will have to be carried out during construction to identify the producer interval.

Taking into account the geological information, the reservoir's exploitation regime and the settling of the ground, an assessment will be carried out of the environmental impact this phenomenon could cause and the natural risks that the field could be exposed to will be determined. Likewise, if necessary, risks due to vulcanism or seismicity in the project will be assessed, based on the geological information and on the seismic monitoring of the area.

During field operation, the data base on the geological characteristics of both production as well as injection wells can be used. Decreased production in a well and field pressure and temperature drops will require and explanation, which could be given based on the study of the original geological characteristics of the well, correlated to its termination design and to the most recent information provided by the reservoir engineering group.

In the event of geothermal fluid emanations in the concrete cellar or in the platform area, it will be necessary to identify if they have been caused by the geological conditions of the upper part of the well and/or by damages in the well's pipelines and by bad cementation. Resolving this type of problem will require geological information from the data bank and the participation of the personnel responsible for the field's geology.

2.6.2 Geochemical Studies

The surface geochemistry during the field's operation phase will have to continue with the periodic monitoring of water wells, streams, rivers and springs (thermal and cold), to determine the evolution of the geothermal system and to carry out an environmental control. Temperature and flow rate measurements will be taken and water sampling and analyses will be carried out during selected periods of the year.

Depending on the characteristics of the geothermal fluid, of termination and of well operating conditions, on occasion there could be scaling problems in the pipelines or in the surface installations. Usually in high-temperature geothermal fields, the agents that cause scaling are carbonates (normally calcite) and silica. These problems begin to be detected during the operation of the first exploratory wells, for which reason precaution or mitigation measures should be adopted early on.

Silica scaling problems appear in high-temperature geothermal fields. The solubility of quarts in water monotonically increases with temperature in the 5°C to 340 °C interval, with a quasi-exponential dependence in the 150°C to 250°C interval (Fournier, 1989). In high-temperature reservoirs, the geothermal fluid in equilibrium with the rock has a high content of dissolved silica. When this liquid loses steam and its temperature drops (adiabatic cooling), as it moves up through the well, it becomes strongly oversaturated with silica and generates deposits of this mineral. Usually the sites most affected by this deposition are the segments of the installations close to the fluid's abrupt decompression points, such as changes in the diameter of the pipes, valves, orifice plates, etc. The most usual corrective measure to remove scaling consists in cleaning the well's pipes and the surface installations, through mechanical means.

The calcium carbonate deposition process is also associated with the adiabatic decompression of the geothermal fluid. When steam separation occurs, it drags away most of the carbon dioxide, elevating the brine's pH and, with this, also increasing the carbonate ion's concentration. If a sufficiently high concentration of calcium ion exists in the solution, calcite will be deposited. This problem has been resolved using inhibitors, which slow down the precipitation reaction.

Except on rare occasions (see section 3.2.3.9 of the Guide for Geothermal Feasibility Studies, 1994), a well built well under normal operation will not experience problems with corrosion. Problems could appear when due to the bad cementation of the casings, they are exposed to the formation on the outside. This could occur in the upper parts of the well, as a result of the action of acid fluids formed by steam absorption processes of the geothermal reservoir, due to water from upper aquifers. (Bixley and Wilson, 1985).

2.6.3 Geophysical Studies

During this stage, monitoring that might have started up during the development stage of any seismic activity in the field and surrounding areas should continue in order to more precisely determine any seismic or volcanic risks for the project.

Likewise, if a local levelling network exists, changes in the surface ground originated by the extraction of fluids from the reservoir could be monitored. This monitoring will allow to develop an investigation of the subsidence of the ground and its behavior, bearing in mind the subsoil's geology, the reservoir's exploitation ranges and the injection of residual fluids.

With regard to the geophysics of the wells, in the event that logging equipment is available, this study will be very useful, though costly, to determine the physical coupling and cementation conditions of the casing, as well as problems with collapsing or rupturing. In the event that such geophysical equipment is not available, sampling and chemical analyses of the fluids, combined with temperature logs, are often a resource in identifying this type of problem.

2.6.4 Hydrogeological Studies

During field exploitation, the hydrogeological investigation implemented in previous stages should continue, with special attention to the operation and maintenance of the hydrometeorological network and to the obtention and assessment of both surface as well as underground data. The purpose of this activity is to keep an updated hydrological balance of the basin and to attempt to quantify as realistic as possible the reservoir's hydraulic recharge.

During field exploitation, a systematic log of the hydrogeological parameters should be kept (static level, production, chemistry of the water, etc.) for each well, to observe the evolution of the field in response to the extraction of the reservoir's fluid and to the injection of the residual fluid.

This information should be analyzed with relation to the hydrogeological conditions of each well that were determined at the beginning of field exploitation. The data of the parameters registered will be stored in the data base, and reports and graphs should be prepared periodically or whenever necessary to explain the geological conditions of each well and of the field in general.

The hydrogeological information that has been systematically collected should be periodically incorporated to the hydrogeological model and particularly to the geothermal field's conceptual model.

The data from the hydrogeological parameters will back the systematic reservoir engineering studies that will continue on throughout field exploitation.

3. FIELD MAINTENANCE

3.1 Objective and Scope

The purpose of this activity is to keep the wells and all surface installations in the field, including equipment, conductor pipes and accessories and civil works, in the best working conditions.

3.2 Maintenance

Maintenance involves three main aspects:

a. Maintenance of wells

b. Well repairs

c. Maintenance of surface installations

3.2.1 Maintenance of Wells

Wells are classified into the following categories:

- Production
- Injection
- Observation

3.2.1.1 Production Wells

These are all the wells that are ready to go into operation to supply steam to the geothermal power plant and that require maintenance or repairs in order to ensure their productive capacity, as well as to prolong their useful life.

When considerable abatement is noted in the production of a well, as well as abrupt changes in the enthalpy and/or chemical composition of the fluids, in addition to entraining of solid matter, it is necessary to program the well's revision.

Before intervening in a well, a preliminary diagnosis of its physical state is needed. For this, the following needs to be known in detail:

- Construction design and background
- Operational background
- Production history
- Geochemical history
- Bottom logs

During well production, pipes can scale due to the precipitation of minerals contained in the geothermal fluids. Carbonates and silica tend to deposit in a larger or lesser degree in the pipes, obstructing and reducing the production capacity. The location and thickness of scaling can be detected with calibration logs.

Cleaning options for the production pipes will depend on the specific characteristics of each well and on the geothermal field itself (temperature, pressure, enthalpy, chemical components and operational risks). The alternatives are the following:

a. Cleaning of Scaling in Non-flowing (Static) Well

Once the decision is made to intervene in a well under operation due to its low production, one can proceed to shut it down. Once it has been shut down, all pipelines and surface installations joined to the valve tree should be disconnected, to avoid possible damages.

After this, the well's pressure is lowered, slowly shutting off the discharge in the heating line, so that the steam can condense within it and a hydrostatic column is formed equal to the reservoir's pressure. In this way, sudden temperature changes in the well's pipes will be avoided, which in contracting could cause ruptures.

The above operation can take place over a period of time that varies between a few hours to several days. In the event that the pressure does not fall it will be necessary to slowly introduce water or, if necessary, drilling mud. Once depressurization is achieved, it is recommended that bottom logs be run (pressure, temperature and calibration), to investigate the mechanical state of the well.

Scaling on the casing can be removed using rotary drilling equipment. The inconvenience of this procedure in cleaning scaling by using drilling fluids or water at temperatures of 20 to 30 Centigrade is that production pipelines cool down, with the danger of ruptures due to contraction. The use of a casing reamer helps to avoid this problem, but its use is limited to soft scaling that is not too extended. The temperature of the reservoir and the degree of resistance of the pipeline to the tension and compression are factors that play an important role in the probability of mechanical damages taking place.

b. De-scaling of Flowing Well Using Drilling Equipment

It is possible to de-scale production pipes while the well is flowing. In this case, the produced fluid serves as a means through which to transport the cuttings that fall off the flow line. It should be remembered that there is a higher risk in operations related to this alternative. The equipment used is the standard drilling equipment, with the difference that a cooling rotary preventer system needs to be installed in the wellhead, to allow operating the drilling tools under pressure. This procedure can be used mainly in low-pressure and low-enthalpy wells, as well as under conditions of reduced flows.

c. De-scaling of Flowing Well with Fluid Injection Equipment at High Pressure

It is possible to de-scale well pipelines by introducing a continuous probe with nozzles at its extreme to inject high pressure water, which could be mixed with solid matter (sand) or with a gel to help scaling to fall off due to the impact. Scaling cuttings that fall off the casing walls are extracted by the flow of the well.

Scaling cleaning systems with the well flowing have the advantage of reducing the risk of causing breaks in the pipes, since they do not undergo deformations due to temperature, as occurs when the well is no longer flowing and needs to be cooled to be able to intervene in it. Another equally important advantages is the reduction of the time in which the well does not supply steam for the plant.

d. Preventive Well Maintenance Using Scaling Inhibitors

In the case of wells with high scaling potential along the pipelines due to calcium carbonate deposits, they can be noticeably reduced by injecting a substance that inhibits the formation of carbonates, through a probe that is permanently installed in the well.

3.2.1.2 Injector Wells

Depending on the injection process used, there will be different maintenance problems. This will mainly depend on if waste water is inject with or without previous treatment.

The maintenance and cleaning of injector well pipes is done using the main methods used to maintain productive wells, as is described in the previous sector.

3.2.1.3 Observation Wells

Maintenance of observation wells is minimal, since they do not have a dynamic condition. In wells with H_2S emissions, the custom is to protect them using a casket of inert gas (Nitrogen). In this case, maintenance is limited to merely replacing the gas lost through leaks.

3.2.2 Repair of Wells

Beginning with drilling and/or during their useful life, wells can suffer mechanical damages that affect steam production or their injectivity, and additionally put the personnel and facilities at risk. For this reason, it is necessary to intervene to repair them and continue using them under safe conditions. In the opposite case, if they cannot be rehabilitated, they should be prepared to be shut down and left in the best safety conditions possible to avoid future problems. Damages suffered by wells are related mainly to the following aspects:

- Construction design
- Problems during drilling
- Problems during the installation of casings
- Type of cement and cementing operation
- Aggressiveness of geothermal fluid
- Operational problems during induction, heating, development, depressurization, etc.
- Chemical and thermodynamic characteristics of the fluids

Different types of damages or problems take place in wells, the main ones of which are described below:

a. Collapsing

This is flattening that occurs in the producer casing, caused by sudden heating and pressurization of water bubbles trapped in the annular space.

Collapsing partially or totally reduces the well's capacity, depending on the amount of damage, where one or more places can collapse in the same well.

When collapsing creates a partial obstruction and does not represent a dangerous situation, it is recommended that the well not be intervened until another event takes place requiring attention, as could be scaling or the production of solid matter (fragments of the formation, metal, etc.).

b. Corrosion of Production Pipelines

Corrosion can take place both inside as well as outside the casing, and can cause them to come loose. Corrosion attacks can be worse when the wells are in static condition (without flowing), or under purge conditions that allow the formation of steam condensation that forms acid solutions that damages the casing.

Casings can also be attacked by galvanic corrosion when pipes are combined with different metal characteristics, as well as by the effect of different stratum crossing through the well. These attacks are somewhat reduced when there is a high flow rate in the well.

Repairs on a well with corroded casings consist of installing and cementing an additional smaller pipe to protect the damaged section. It should be taken into account that these repairs could reduce the productivity or injectivity index.

c. Fractures in Production Casings

On occasions, fractures in casings are located in places where there is external protection from another casing pipe, which might not affect the production of the well and, therefore, does not require installing an additional smaller protective pipe.

When the fracture takes place in an unprotected area, which is next to the formation, rock fragments may break loose and get into the well and erode surface facilities (valves, conductor pipes and surface equipment). In addition, lower temperature fluids could go into the well, affecting production and accelerating scaling.

On the other hand, in the case of very severe damage, the geothermal fluid could move outside the pipes, with the risk of appearing in the surface of the ground surrounding the well. If this occurs, necessary procedures will have to be carried out to leave the well completely open, so that its internal pressure decreases and, consequently, so the flow through the fracture is stemmed.

To control the well, surface facilities are installed so that the flow can be channeled through the side lines of the valve tree. In the upper part of the well, high-temperature preventers with lubricators are installed, along with a cooling system. Along the bottom part of the valve tree, pipes are installed to inject fluids into the well.

Well depressurization is done by introducing a pipe, which could be whole or divided into sections. This pipe is lowered down inside the well until it reaches the production zone or the bottom. Water or drilling mud is then pumped through the pipe, while at the same time closing the side valves. Water or mud continues to be injected until wellhead pressure has reached atmospheric pressure. Later on, repair equipment can be introduced into the well to check it and to place a smaller casing to cover the damaged zone.

In most cases where the breaking of casings occurs in formations that are not very consolidated, the well begins to produce large amounts of solid matter. In these cases, production should be reduced until it reaches a level where the presence of solids is reduced to a minimum. If this operation cannot be controlled, it will be necessary to intervene the well.

Some methods to locate and to see cracks along the length of the well in more detail is through continuous calibration logs, rubber seal impression logs and the use of television cameras or sonic logs through which one can even observe damaged sections of the casing. The inconvenience of these methods is that the well must have been depressurized and be cold, which could damage the pipes even more.

On occasion, repairs on a well with damaged casings becomes very difficult, since the affected section has been displaced by the presence of cavities that form from the extraction of material from the formation. In these cases, the decision usually is to deviate the well and to drill it again, once more introducing the production pipes and leaving a new productive interval, either with slotted liner or simply an open hole.

d. Deficient Cementing Accessories

During cementing of the casing pipes, which is carried out in several stages, cementing couplings can remain open, allowing the entrance of fluids that cause the well to behave in a similar way to the case of a broken casing. The solution, therefore, can be similar to that used in cases of broken pipes, either injecting cement under pressure into the coupling holes (process known as squeezed cementing) or, if it is felt that the damage is very extended, by installing an additional, smaller-sized casing to cover the deficient accessory.

Plugging up the open cementing couplers with cement is not entirely successful in most cases, for which reason the problem could occur again.

e. Deterioration of the Cement in the Casings

The cement used for casings deteriorates over time. This variable depends on the quality of the cement slurry, the additives used in it and the procedure used during cementing. Degraded cement allows fluid from the reservoir to ascend through the pipes to the surface. This risk is reduced by installing surface protection casing pipes that provide more control.

On the other hand, a descending flow of lower-temperature fluids from shallower strata that circulate through the external wall of the casing and invade the producer interval could occur due to the annular space.

A possible solution to this problem consists of recementing damaged intervals, firing the casings and injecting cement under pressure. Another alternative, if the construction design allows it, would be a side deviation to redrill and install a new production pipe.

f. Corrosion of the Production Casings on Surface

Usually rain water and infiltration accumulates in the concrete cellars, wetting the external walls of the production casing, which in combination with oxygen causes corrosion.

To reduce this problem, it is recommended that the concrete cellar be periodically checked, avoiding the accumulation of water inside it. The thickness of the casing in this zone should also be measured periodically, using an ultrasonic log.

When the corrosion in the production casing reaches dangerous levels, to such a point that the personnel and facilities are at risk, the damaged section should be taken out and the wellhead reinstalled again, the following operations sequence indicated next: depressurization of the well and deepening of the concrete cellar until a section of casing in good conditions is found. The damaged casing is cut out and a new section is installed to replace it. If it is not possible to install a threaded section, the replacement casing should be carefully soldered, following the effort release techniques through previous and post-heating of the zone to be soldered. The wellhead is installed on this casing.

g. Obstructions in the Formation due to Scaling

On occasion, the thermodynamic and physical characteristics of the reservoir, along with those of the well's operation, cause the formation of a broad boiling zone in the formation, which in turn could produce scaling problems in the same, obstructing it and reducing its permeability.

Though this does not necessarily constitute a damage to the well, it is a serious problem and requires repairs to recover its original capacity.

The rehabilitation process in these cases consists, as a first alternative, in deepening the well is its construction characteristics and the depth of the reservoir allow it, to exploit another level of the reservoir. A second alternative, in the event that deepening the well is not physically feasible, consists in obstructing the originally producing zone using a plug at the bottom of the production casing, opening up a side window in the casing at the deepest level possible, directionally drilling a portion of the well a few meters away from the axis of the original well, and then continue drilling parallel until a zone of the reservoir is reached that is not affected by scaling.

Another alternative used when scaling is due to carbonates, involves injecting acids to dissolve them. This, however, has the disadvantage that it considerably decreases the useful life of the wells due to the action of the acid on the casing.

h. Well Abandonment

When due to reasons of low or no production, as well as to the high cost of maintenance work in a damaged well, if it is decided to abandon it, procedures should be carefully planned to avoid further problems in the future.

In damaged production wells that are no longer considered to be useful, the possibility of using them as injection wells should be considered, or to observe and monitor the reservoir's performance. For this, the wells should be repaired and adapted, installing if necessary smaller pipes with the purpose of sealing off surface zones that could have remained open and that interfere with the reservoir's response.

In wells that cannot be used for any of these purposes, it is recommended that cement plugs be placed in the lower part of the production casing, fill the well with drilling mud and leave a valve in with the purpose of avoiding unforeseen discharges.

In wells adapted for reservoir observation and that are considered to be safe, a master valve, pressure gauges and traps for gas release should installed. Monitoring should be carried out using equipment placed inside the well and connected on the surface to a continuous measurement and logging system, or through bi-weekly or monthly measurements of the water level. In some cases, temperature and pressure logs can be run two to four times a year.

3.2.3 Surface Facilities

Maintenance of the facilities of a geothermal field under exploitation involves all tasks aimed at conserving the good operational state of the mechanical elements and of civil works.

The system that allows conducting or managing the geothermal fluid is exposed to different phenomena, which in time cause the deterioration of the mechanical or civil elements, affecting the function for which they were designed. The main deterioration is caused by scaling, corrosion, erosion, wet and saline environment, high temperatures and pressures, chemical reactions, different land settling, draining and filtration of surface water.

Next, the main elements exposed to this type of degradation on the surface are indicated,with a brief description of their function, problems and maintenance.

a. Valve Tree

The valve tree is a device that fulfills the function of controlling the well's output flow, through a series of valves that regulate the discharge of the fluid being sent out either to the separator or to the silencers.

The concentration of the chemical compounds and the high pressures and temperatures of the geothermal fluids can affect seals and lubricating greases, causing leaks, corrosion, scaling and operational problems in the valves. This makes their operation difficult and could cause their elements to break and twist. If, in addition, solid matter is being carried with the flow, it could cause the erosion of the mechanical elements, with possible leaks.

When due to operation and safety reasons an element on the valve tree needs to be checked, it is preferable to replace the damaged part or the entire tree, without including the master valve, and then proceed with the maintenance in the workshop.

Whenever necessary, the master valve can be replaced. For this, the well will need to be depressurized. If one wishes to avoid this manoeuver to avoid the risk of damage to the casing due to cooling, this operation can be carried out using valve changing equipment, which consists of a hydraulic equipment that introduces a mechanical plug into the well, which is fitted with a seal with wedges that are fitted into the production pipe, impeding the flow of fluid to the outside and reducing any danger.

b. Conductor Pipes for Mixtures, Steam and Water

Surface pipelines lead the geothermal flow, in its different phases, between different points of the field-plant system. In the case of mixture or water conduction pipes, the most common problems that appear are internal scaling and displacement of the pipes, which can cause them to come loose from their ground supports. In steam conductor pipes, the problem that could appear is corrosion of the inner walls.

In mixture and separate water pipelines, it is recommended to install control flaps to be able to observe the degree of scaling and to be able to clean them, either mechanically or hydraulically. The external part should be protected with special paint for high temperatures.

In pipelines that conduct steam, it is recommended to install enough condensate purges, located strategically.

c. Thermal Insulation of Conductor Pipelines

Its function is to reduce heat losses in the geothermal fluid being conducted through the pipelines. In those cases were damage is observed in the thermal insulation, it is recommended that it be damaged sections be promptly replaced or repaired, to avoid the formation of condensate in the steam lines, or excessive heat losses in the mixture and separated water conduction lines.

d. Supports and Metal Structures

Their function is to place on the ground the loads due to the weight of the pipelines and fluids. The main problems that could appear in this case are corrosion, warping due to excessive effort of the elements and failures in the ground anchor.

For their maintenance, it is recommended that anticorrosive coating be used, that repairs and replacements be made, depending on the case, and that the sliding bearings be periodically inspected.

e. Drainage System

This system drains the condensate that forms in the pipelines. Problems observed here are plugging up due to scaling and/or as a result of scaling inside the equipment and pipes. It is recommended that the purges be periodically cleaned and the valves lubricated.

f. Silencer and Spillway

This component in the system reduces the noise caused by the discharge of fluids to the environment and allows measuring the flow rate of the water produced. The main problems observed in this case are scaling, erosion and corrosion. In the case of metal silencers, corrosion is what predominates. It is recommended that the silencer's chamber and the water channel be periodically cleaned.

g. Concrete Cellar

The concrete cellar supports the valve tree and helps avoid the entrance of surface infiltration water to the upper part of the well, thus reducing corrosion damages to the casing. The main problems observed are the deterioration of concrete, mud and fluid infiltration through cracks and fractures, and the accumulation of rain water. The concrete cellar needs to be frequently inspected and cleaned, sealing off cracks and fractures. On the other hand, it is recommended that a drainage system be contemplated in the design to eliminate water and solid matter that might form in it.

h. Well-Separator Interconnection

This part of the system consists of the connection of the separation system to the valve tree. It must be flexible enough to absorb efforts due to thermal dilation and different movements between the separator and the tree.

The most common problem seen in this section is erosion along the parts where the flow changes direction, which becomes more intense when fragments of rock are dragged along causing considerable and dangerous leaks. One solution to this problem involves installing a "T" shape connection instead of the 90 .

i. Equipment Protection System

The rupture disks and the safety or relief valve constitute the protection system to avoid over-pressure in the separator, which a ball valve is used to avoid the possibility of a considerable amount of water being dragged along with the steam.

When the equipment is exposed to a damp and saline environment, corrosion problems take place on the outside of the rupture disk causing leaks or cracks at even lower pressures. As a maintenance practice for the rupture disks, it is recommended that they be periodically inspected and replace, as well as that greater care be given to protect them against dampness. It is also recommended that two discs be installed parallel to each other, with different rupture pressures, placing a stop valve in the one with the lower range. It is also recommended that an eyesight inspection be carried out regularly, along with a hydrostatic test.

The ball valve may quit operating due to scaling in the space between the floating ball and its guide, as well as due to warping, breakage or wearing out of the latter. It is also common for the ball to stop moving due to breakage of the centering basket. In view of the importance that it continue functioning, periodic inspections should be carried out and its good thermal insulation should be kept up.

j. Separator

The function of the separator consists of separating the liquid and gaseous phases to later conduct them, applying the principles of centrifugal force and the difference in densities. The main problems seen in this equipment are erosion, due to solid matter, and scaling. It is recommended that it be periodically checked, de-scaled and cleaned, using the accesses installed for this purpose. Pressure outlets should also be periodically inspected and verified, as well as the water level indicator. Externally, the separator's thermal insulation should be kept in good state, and anticorrosive and enamel paint should be applied on the metal structure, bolts and screws and other exposed parts.

k. Stop Valves

Stop valves need to be installed in conductor pipelines in those places where changes are desired in the direction of the flows. The problems of these valves are similar to those mentioned in the case of the well's valve tree, for which reason a similar maintenance is recommended.

4. OPERATION AND MONITORING DATA INTERPRETATION

4.1 Study on Well Performance

During the productive life of the wells, it is recommended that a series of measurements be taken periodically, to know what the performance and evolution of the thermodynamic and chemical characteristics of the produced fluids are over time.

This periodic monitoring, through a correct interpretation, will help to detect and distinguish if the performance of a given well is due to mechanical or construction problems, or if it is undergoing a normal process typical of the producing zone.

4.1.1 Thermodynamic Monitoring

For monitoring from the thermodynamic standpoint, the following series of measurements should be made:

a. Surface Measurements

- Continuous logging of wellhead pressure and separation pressure
- Temperature measurement in some place close to the wellhead, to verify the thermodynamic state in the case of dry steam producer wells
- Periodic measurements, as frequent as possible, of the well's productivity in its water and/or steam phases, depending on the type of reservoir.
- Establishment of the production enthalpy through a mass and energy balance, in the case of mixture production wells, and directly from thermodynamic tables for dry steam production wells.

b. **Bottom Measurements**

- Pressure and temperature logs every time field operation allows limiting the well to minimum production or taking it out of production, without affecting the steam supply.

- It is also recommended that calibration logs be carried out on the occasions mentioned in the previous point, to assess the degree of scaling and/or detecting obstructions.

4.1.2 Chemical Monitoring

The follow-up of the chemical characteristics of the discharges of a well is important because it helps to detect changes in the conditions of the feeding zone. For example, when there is a contribution of water with a different salinity and temperature in the reservoir section that feeds a well, the changes in the chemical parameters (salinity, isotopic composition) will occur before changes in the thermal parameters (temperature, enthalpy). This is due to the fact that the alteration in the chemical parameters advances with the mixture front (chemical front), whereas the alteration of the thermal parameters (thermal front) is softened and delayed by the conductive transference of the rock's heat to the fluid.

Since the kinetics of the silica precipitation-dissolution process (quartz) is relatively fast at high temperatures, the silica geothermometer (Fournier and Potter, 1982) allows calculating the temperature of the reservoir close to the well. On the other hand, geothermometers with a cationic composition (among others, described by Nieva y Nieva, 1987; Fournier, 1979; Fournier and Truesdell, 1973), allow one to establish the temperature far away from the well. A comparison between the reservoir temperature values calculated with these two types of geothermometers allows detecting certain processes taking place in the well's feeding zone (Truesdell et al., 1985; Lippmann and Truesdell, 1990).

The histories of the chemical and physical parameters of a well should be considered together for the prediction or diagnosis of production problems. A structured procedure that has allowed to identify obstruction problems in surface pipelines, mechanical damages in the well's casing, invasion of cold water and silica scaling in the feeding zone, for the cases of wells in the Cerro Prieto geothermal field, has been described by Arellano et al. (1991) and CFE-IIE (1990). In the same study, a silica deposition speed parameter in the reservoir was defined, which allows one to diagnose production problems arising from possible damages to the formation, caused by silica scaling.

4.1.3 Performance Patterns

Through an integral analysis of the information that is obtained from the series of measurements and determinations described previously, where the well's construction and pre-operational (start-up) background is taken into account, the type of performance it will have can be inferred or diagnosed. Below, some performance patterns observed in several geothermal fields are described.

a. Scaling

When scaling occurs in a well, although there are no mechanical problems, the well's production and its wellhead pressure begin to decrease, parallel to an abatement rhythm that depends on the speed with which the scaling element is deposited (silica, carbonate, sulphide). During this period, the production enthalpy and the concentration of the chemical compounds could vary depending on the type of recharge. When scaling moves beyond the slotted liners—that is, within the formation—abatement of the production parameters becomes even more evident and pronounced.

b. Obstruction of Upper Part of Wellhead

When due to scaling or expelled matter the production hole and/or the curve that connects the valve tree with the separator become partially obstructed, the wellhead's pressure will increase while the pressure along the production line will decrease.

The enthalpy and the chemical conditions usually remain the same.

This event on occasion is eliminated naturally through unplugging and erosion of the fluids themselves. However, in most cases the flow needs to be veered to the silencers to be able to clean or replace the obstructed elements and, in this way, to reestablish production conditions.

c. Sudden Obstruction Underneath the Wellhead

On certain occasions, the well's casings could experience one or more collapses, without any breakage or entrance of water, with a sudden drop both in wellhead pressure as well as in the production volumes and with variations in the enthalpy and/or chemical composition.

After a collapse, it is common to see that the degree of abatement of the production characteristics increases, since the drop of additional pressure caused by the obstruction propitiates scaling.

A similar situation can be observed when the well throws out material from the formation, scaling falls off or mechanical elements left in the bottom rise up (for example, wire) and they lodge in some part of the production casing.

d. Entrance of Lower Temperature Water

When mechanical damages occur, such as fractures or dislodging of the production casing, as well as when there are deficiencies in the accessories, such as the hangers or cementing couplers, it is possible that fluids might enter into the well at those points.

Since these events usually occur at less depth than that of the producing interval, it is common to see that the incoming fluid has a lower temperature and different chemical composition. One can quickly see the problem when a sudden reduction of the production enthalpy takes place, with a change in the chemical composition (for example, in chlorides), depending on the magnitude of this change in the amount and characteristics of the fluid that is filtering. Since a mixture of fluids with different enthalpies takes place, a variation in the steam produced and/or an increase in water production might be observed, in addition to variations in the wellhead pressure.

On other occasions it is common to observe strong variations (rising and falling) in the thermodynamic (enthalpy and flow rate of steam) and chemical (chlorides) parameters, since the well is fed in a cyclical way by the different points of contribution. Bottom logs (pressure, temperature and spinner) can provide valuable information to define and understand these situations.

A variation of the problem that causes this pattern of performance is when instead of a point of secondary contribution to the inside of the well due to a broken pipe or deficient accessory, a flow occurs that goes don the annular space between the production casing pipe and the formation, which is due to a deficient cementing that allows lower enthalpy fluids from more superficial strata to descend, with a consequence mixing of fluids in the bottom of the well at a higher temperature.

The problem, described here could be aggravated by strong scaling, which accelerates with the mixture of fluids on the bottom with shallow fluids.

e. Recharge of Cold Water

One of the processes a well could experience and that relates to the reservoir and not to the well itself, is the mixture of fluids due to a natural recharging of the reservoir with lower temperature water with a different chemical composition.

In these cases, a gradual abatement of the production characteristics of the well can be observed over time. The enthalpy, chlorides and geothermometers are the classic parameters used to detect it. This process usually occurs in wells located close to the outside borders of the field, and will later on be observed in wells located inside it, as the recharge front continues to advance.

It should be noted that this phenomenon has been observed in some wells located in the central part of geothermal fields, which might be due to a vertical recharge of colder shallow fluids through cracks or fractures that affect the vertical permeability of the sealing layer.

f. Local Boiling

In a geothermal field, or in some zones within it, a process known as local boiling could take place. It is characterized by the appearance of a zone of two-phase fluids (water-steam) around the well, which usually tend to extend with time to the point in which it becomes a general boiling zone.

This process occurs in wells where the reservoir initially has a temperature very close to the point of saturation, with respect to the reservoir's pressure. Thus, as pressure abates due to the exploitation of the field, boiling occurs in the formation surrounding the well, moving away as pressure abatement increases.

It is also common for boiling zones to have little natural recharge, which results in greater abatement of the pressure. this process occurs in wells located in places where their connection to the rest of the reservoir is deficient. Rock heat is transferred to the fluids that are stored in the permeable spaces, in such a way that as pressure abates due to production, boiling occurs in the formation surrounding the well.

In these cases, the typical performance pattern consists of a noticeable increase in the production enthalpy, to the point where it might equal the steam enthalpy. The concentration of salts also increases and the geothermometers show a typical pattern indicated in detail in specialized technical literature.

g. Combined Effects

The patterns described above represent isolated cases. However, it frequently happens that a well might present one or more of the mentioned events, either simultaneous or consecutively. This makes it difficult to interpret the data observed.

4.2 Study on Reservoir Performance

With the exploitation of the field, the conditions prevailing in the reservoir change, and this is reflected in the performance of the wells.

Fluid extraction produces a reduction in the reservoir's pressure that tends to increase (or initiate) boiling in the formation and/or to allow colder underground water to move into the system.

The beginning or growth of the boiling zone depends on the magnitude of the decrease in the reservoir's pressure. This decrease depends on the volume of the extracted fluid, on the permeability and storage coefficient of the formation and on the amount of fluids naturally recharged or injected.

Boiling in the reservoir can cause the precipitation of minerals (silica, carbonates or oxides) in the formation's pores or cracks, reducing its porosity and permeability and affecting the productivity of the reservoir and wells. This productivity could also decrease due to the effects resulting from the existence of two phases, where the effective permeability of the formation decreases due to the joint presence of steam and liquid in the pores or cracks.

If the reservoir is open—that is, if it allows the entrance of colder underground water in a lateral or vertical form—in those zones close to the recharge areas, changes can be observed in the chemical characteristics of produced fluids over time. Other chemical changes are related to boiling within the formation or to the injection of colder liquids with different chemical characteristics.

Changes that occur in the reservoir as a result of field exploitation usually are determined in wells were logs and tests are being run or by inferring their performance. Only when these changes are very big is it possible to detect them using geophysical surface methods. One example is the study of the resistivity changes associated to the advance of colder water from the natural recharge or injection areas toward the production wells.

Average pressure and temperature variations in the reservoir can be directly logged if observation wells have been opened up along the production formation. Temperature and pressure logs in static wells could provide data on the reservoir, but often this type of register cannot be obtained due to the lack of adequate observation wells or due to reasons related to the field's operation.

If a water level appears in the observation wells, level changes should be logged. If there is pressure in the wellhead, the pressure variation in the reservoir could be measured using a capillary tube system introduced below the water level.

If periodic productivity or injectivity tests can be carried out, logs could be kept on the changes in the physical properties of the reservoir due to its exploitation. In general, these tests rarely are carried out during the field's operational phase, due to the need of keeping fluids supplying the plant and of eliminating waste fluids.

In addition, during field operation it is fundamental to establish the performance of the wells since they reflect changes that might be taking place in the reservoir or in the wells themselves. Not only should wellhead pressures, production and enthalpy be periodically measures (at least once a month), but also the chemical characteristics of produced fluids. In the case of injection wells, the volume, temperature and chemical characteristics of injected fluids should be logged.

A reduction in the mass productivity of a well could be due to a decrease in the reservoir's pressure or permeability, to an increase of steam saturation in the same (effects of relative permeability), and/or to the presence of scaling or mechanical problems. An analysis of the evolution of the physical and chemical characteristics of the well and a calibration log could determine if it is due to problems in the well or not. If this were the case and the desire is to keep it producing, the decision will have to be made clean or repair the well. Carbonate scaling could be eliminated or significantly reduced if chemical inhibitors are used, the wellhead pressure is increased or if a submergible pump is installed (in medium temperature wells), to avoid boiling inside the well.

In some wells, scaling is due to the mixture of fluids with different chemical characteristics from different producing zones. In this case, it will be necessary to cement one or more of these zones to avoid different types of fluids from mixing inside the well and from reacting between each other.

In the case of and injection well, a reduction of its capacity quite possibly would be due to the precipitation of minerals in the well or in the formation next to it. A calibration log could determine where the scaling is located or if there was a mechanical problem. If the injectivity decreased due to scaling, the well should be cleaned and fluid treatment should be considered before injecting them, to avoid or reduce mineral precipitation.

An increase of enthalpy in production wells indicates an increase of boiling in the reservoir or a possible preferential flow of steam toward the well within the formation. If the enthalpy continues to increase, reaching values that correspond to superheated steam, there have been cases where the wells begin to experience problems, such as: scaling in the formation, wells or surface facilities; generation of corrosive steam; reduction of the contributing capacity of the productive zone near the well, due to its reduced permeability.

On the other hand, a reduction in the enthalpy of the produced fluids could be due to the entrance of lower-temperature water to the well. This could be related to a mechanical problem in the well or to the arrival of a front of colder fluids associated with the reservoir's natural recharge, to reinjection or to a change in the relative productivity of different zones contributing fluids to the well. In the latter case, due to pressure changes occurring in the reservoir, a lower temperature zone and an initially lower potential could at a given moment begin to dominate over a higher temperature zone that originally contributed most of the produced fluid.

Observing changes in the chemical conditions of the reservoir and that have been detected from the performance of individual wells allows characterizing some of the processes that take place as a result of the massive extraction of fluid and thermal energy. Detecting these changes after the first few years of extraction in some prospecting fields reveals a process of water invasion in the reservoir with a different chemical and isotopic composition than that of the original geothermal fluid (Truesdell et al., 1982).

It is extremely important to detect these changes in the performance of the reservoir to be able to revise field prospecting strategies and to try to prolong its useful life to the maximum.

An example of the form in which these changes can be detected is through an analysis of the variations in chloride, silica and stable isotope contents, as well as by obtaining temperatures based on silica and Na-K-Ca geothermometers (Truesdell et al., 1989 and 1992).

An increase in the content of chlorides and heavy stable isotopes (O^{18} and deuterium) indicate higher temperatures. A map showing the distribution of these parameters over time allows one to determine the advance of a cold water front in the reservoir.

Due to a difference between the equilibrium times of different geothermometers, an analysis of the temperature variations that they indicate allows being able to infer the processes that are taking place in the reservoir.

For example, the Na-K-Ca geothermometer changes very slowly and indicates the temperature of the zone from where the fluid originates. On the other hand, the silica geothermometer changes quickly and reflects the reservoir's temperature in the vicinity of the production wells. By comparing the temperatures (or corresponding enthalpies) measured at the well opening to those indicated by the silica and Na-K-Ca geothermometers, Truesdell and other researchers were able to establish the importance of boiling and of natural recharging in different parts of the Cerro Prieto field, as well as identify the boiling and condensation processes that control the chemical characteristics of the fluids produced by the different wells.

4.3 Updating the Field Model

During the operational phase of the field-plant system, data is gathered periodically on the production, injection and observation wells. In addition, information on the reservoir is obtained during cleaning operations, repairs and reassessment of existing wells and when replacement wells are drilled and assessed. It is also possible to obtain other data from geoscientific studies carried out during this phase of the project.

All this information should be used to update the reservoir's model. The methodology to be used is similar to that described in sections 3.4 and 3.5 of the Guide for Geothermal Feasibility Studies (1994). However, during this phase of the project there is a very important additional data base for the process of updating the model. It has to do with the production and injection data obtained from all the wells related to the field-plant system's operation.

Within field operation, the following information should be collected at least once a month:

For producer wells

- Wellhead pressure
- Separation pressure

- Steam and liquid production
- Enthalpy of the produced fluid
- Chemical characteristics of the produced fluid

For injection wells

- Wellhead pressure
- Injected volume
- Temperature of injected fluid
- Chemical characteristics of the injected fluid.

These operational data are extremely important to reassess the reservoir prospecting model. The values calculated by the model should agree with the data measured in the wells. However, generally there are discrepancies in the performance of one or more wells, which requires making changes in some of the parameters of the prospecting model being used.

Different changes may have to be made on the model to improve the correlation between the data measured in the production, injection and observation wells and those calculated by the model, depending on the magnitude of the discrepancies. It might be necessary to change the permeability distribution in part of the model, as well as the assumed productivity indexes of some of the wells, the characteristics of the sources and sinks and other parameters.

This revision process requires some experience in the use of numerical models and geoscientific data. For example, it is necessary to understand how a change in permeability affects the productivity calculated for a well. The characteristics that are already known with regard to the reservoir should also be taken into account when modifying a property in the grid used by the model. For example, it would not be reasonable to include a high permeability zone if this does not correspond to the information obtained from the drilled wells. However, this zone could be included in a modeled part of the system that has still not been explored or drilled, as long as it improves the correlation between observed and calculated values.

After obtaining a reasonable correlation (it is improbable that an exact one will be possible) between the results of the prospecting model and the production data and other information obtained from the field, the changes made to the model in a natural state must also be included.

The purpose is to verify that changes carried out do not significantly affect the results of the model in a natural state. If the effects of these changes are important, an iteration should be made between the natural state and exploitation models, until the adjustments made allow a reasonable correlation between what has been measured in the field before and after exploitation has begun and the output data of both models.

This process of updating the model should be carried out periodically (every one or two years), as new information on the wells and on the field in general are obtained. This will allow modifying, if necessary, the reservoir's exploitation strategy (Section 4.4) and revising the estimates on the field's potential (Section 4.5).

4.4 Updating the Field Exploitation and Operating Strategy

When the prospecting model has been updated based on the data collected during the field operation phase (see previous section), it will be necessary to update its management plans. The points that will be analyzed again are the following:

- Spacing to be used between wells to minimize interferences between them.

- Decline of the production wells.

- Changes in the average enthalpy of the fluids produced due to boiling or entrance of cold water.

- Number of replacement wells that will have to be drilled during the life of the project to maintain the plant's generation level.

- Possible effects of injection on the performance of the production wells.

- Location and design of the injection wells to be able to reduce possible effects of thermal interference in the production wells and optimize the sweeping of heat stored in the reservoir's rocks.

If modifications have been made to the prospecting model since the last time in which it was assessed, it will be necessary to carry out sensitivity studies and use a conservative approach in predicting the future performance, as well as avoid the use of too optimistic estimates that could affect the future operation of the field-plant system (Section 3.5.2 of the Guide for Feasibility Studies, 1994).

4.5 Updating Initial Estimates of the Field's Proven Potential

During this phase of the project's operation, there is a better knowledge of the reservoir's characteristics and of the geothermal system in general.

Using the prospecting model that has been updated (Section 4.3) it will be possible to revise previous estimates made on the field's potential.

During the assessment of different prospecting strategies (see section 4.4) it is assumed that the amount of energy to be extracted from the reservoir during the life of the project—that is during a 20-year period—corresponds to the total installed capacity at the plant. On the other hand, when the field's potential is estimated, an attempt is made to determine the highest amount of geothermal energy that it can produce at a comparable or lower cost than other types of energy.

The prospecting model allows calculating the physical (and chemical) effects that a certain amount of megawatt-years (or megajoules) could have over the reservoir and the wells of a project, in view of a given production/injection scheme. Contemplating these conditions, the model predicts, among other things, the future characteristics of the production wells and the total number of wells (including replacement wells) that will have to be drilled during the lifetime of the project.

With the help of the updated prospecting model and a cost analysis associated with the project, the different levels of electric generation can be studied once more (or the thermal energy extraction levels), as well as different management plans for the field. A study of the results of the model and of the economic analysis will indicate the maximum geothermal energy that can be extracted from the reservoir during the lifetime of the project, at a competitive cost with relation to other energy sources.

This new estimate of the potential of the field might indicate that:

a. There is excessive installed capacity at the plant.

b. The initial estimate on the field's capacity was correct.

c. The field has more potential than that initially estimated and during a period of a certain amount of years will supply sufficient geothermal fluids to generate a given amount of MW of electricity, or keep a direct use project operating for a given capacity of MJ/hour.

If the field's capacity was overestimated, it will have to be decided whether to make changes in the field-plant system to reduce the economic impact that this overestimate might cause. For example, it might be decided to operate the system at its maximum possible capacity during a shorter period, or reduce the steam supply to the plant to extend the commercial life of the project to a maximum. These decisions will have to be adopted after a careful technical and economic analysis, which will depend on the conditions prevailing at that moment.

If the study indicates that the field's potential is higher than that estimated initially, the installation of one or more additional plants might be considered. In making the decision of increasing the project's capacity, it should always be taken into account that the forecasts given by the prospecting model are based on many estimated data. This innate uncertainty in the results of the model means that the total updated capacity of the project will be lower than that indicated by the same.

5. RESERVE AND REPLACEMENT WELLS

5.1 Objective and Scope

Every geothermal project needs to have reserve wells if a relatively constant generation level is going to be maintained for the plant. These wells—some of them production and others injection wells—go into service when some of those on line need to be intervened, or when the capacity of the existing ones is lower than what is required to operate optimally or at the maximum level of the well-plant system. Considering 3 MWe as the average capacity per well, ideally there should be one reserve well for ever four production wells and one for every three injection ones.

With time, the wells tend to have construction-type, corrosion or scaling problems. In many cases, they can be put back into line once they have been repaired or cleaned. In other cases, however, this is technically impossible or anti-economic and they have to be abandoned, making their replacement necessary. In certain cases, they can be converted into observation wells.

A field modelling study is only able to estimate the minimum number of replacement wells that will have to be built during the lifetime of a project. This number corresponds to those that have to be added to existing wells to keep up the steam supplied needed by the plant and to continue with the injection of waste fluids.

The number of replacement wells (production and injection) that will have to be built in a field due to damages of pipelines as a result of construction, corrosion or scaling problems can only be estimated approximately. The average life span of a production or injection well depends on the procedures and materials used for its construction, development and maintenance, as well as from the area's geology and the characteristics of the geothermal fluids, which are factors that vary from one field to another.

5.2 Well Substitution Criteria

A production well is no longer economic when its productivity, temperature and steam/water ratio decrease too much, or when there are changes in the chemical characteristics of the produced fluid that make it corrosive or too scaling. In the case of injection wells, the operation costs could increase excessively if they precipitate inside the well or from the formation of some dissolved salts in the injected brine.

In many cases it is possible to clean or repair the pipes of a well or to drill it again, allowing it to be put back on line. In other cases, on the other hand, they cannot be repaired due to the costs involved or to technical difficulties. The decision of whether to abandon or not a well is generally based on the cost involved, assuming that repairing it will be technically feasible. It will be necessary to decide what is more economic: whether to repair or clean the well and put it back into operation with a lower capacity than the original, or to replace it with a replacement well located in the same area.

The productivity or injectivity of a replacement well can be estimated based on experience or on simulation models. These models can predict the approximate productivity of the well, based on its design and location.

On the other hand, the economic analysis of the different options available depends on the costs involved and on the price that could be obtained for every mass unit of produced steam (MWe-hour generated or megajoule produced). These values depend on the region or country being considered.

6. ORGANIZATION, TIME AND COSTS RELATED TO THE FIELD OPERATION AND MAINTENANCE STAGE

6.1 Objective and Scope

The objective of the field's operation and maintenance stage is to supply the plant with steam to keep up nominal capacity, until it is considered economically convenient. This stage, therefore, only ends when it is decided to shut down the plant.

The intervention program should not be rigid, since it also depends on the reservoir's general evolution, but it should be clear and timely, as required in any engineering project. Therefore, it is necessary to continue collecting and interpreting data from field operation, as well as the economic parameters of the electric system, to decide and support the well intervention program.

6.2 Programming and Control

Programming and control of any project, no matter what its type, size or location is, should be based on correct decisions as to what has to be done and, once the decision has been made to proceed with the activities, it should be based on programs prepared for that purpose, that show in graphic form the different events to be carried out and their scope, as well as the sequence and duration agreed upon by the people responsible for the different groups that participate in the development of the project.

The objective of the field operation and maintenance programs is to provide a basic tool to plan and coordinate activities, to serve as a means of communication and to allow follow-up and the preparation of progress reports, facilitating control over the project and decision making to establish corrective measures in the event of a deviation.

In general terms, to program the field's operation and maintenance, the two following types of activities should be developed:

a. Engineering program.

b. Decision on plant shut down.

6.2.1 Engineering Program

The purpose of the field engineering program is to design the works and program key activities within the entire scope of tasks, establishing main and critical activities, as well as the interrelationship with other engineering disciplines and between different groups involved in the project, with their limitations and interdependence.

The engineering program has to develop a timetable, studies and calculations, the preparation of specifications, the evaluation of bids, the revision of manufacturer information, preparation of blueprints, dispatch of information to the project, etc.

During the implementation of the project, the projects real and forecasted events will be indicated at the same time, to be able to establish delays or advances in the program and to carry out whatever corrective actions may be required, for which reason it should be periodically updated.

A timetable should be prepared with key dates for planned interventions, including the necessary human resources and materials. The assessment of these resources will be the basis to prepare the budget for the activities.

The design of the works and the timetable can be revised as results are obtained on the evolution of the production of operating wells, the production of new ones, production areas discovered through the exploration of the reservoir, injection performance, etc.

The first draft of the intervention program begins by taking into account the results of the development stage, to assess the future performance of the wells. In each case, to determine the time, labor and equipment for the intervention, the information on the project and on similar projects should be taken into account.

It is suggested that a general program be prepared for five years of operation. With this as a basis, negotiations can begin to obtain the funds needed to cover the budget, with a detailed annual program at the beginning of each administrative year.

The timetable will be based on the time needed for well maintenance, which varies a lot depending on the type of intervention and sometimes goes beyond the time needed to drill a new well. For new wells, the time depends on the organization of the drilling activities (with own equipment or under contract), the type of reservoir (depth, type of formation), the type of drilling equipment and the well's profile. It is estimated that, with the equipment on the site, the time required for the final design, mounting and the well tests with the equipment, maintenance might be carried out from 2 to 3 months.

6.2.2 Criteria for Service Shutdown

During a plant's operation changes can take place in the field-plant system (quality and quantity of generated steam, damages in the wells or of important equipment) or in the external conditions (energy market, start-up operation of other plants) that modify the economic framework of reference considered during the project's feasibility and development stages.

This economic framework of reference evidently indicated that the geothermal plant was viable, so that it was decided to proceed with the field development and plant construction stages.

However, when due to technical or economic reasons it is no longer feasible to intervene existing wells or increase the number of wells to keep electric power production at adequate levels, a decision could be made to shut down the field-plant system.

This economic assessment constitutes the basis to justify the intervention of the wells (maintenance and drilling). The cost of the interventions themselves should be compared to the benefits achieved from the sale of the power produced, bearing in mind the information provided by the different work groups.

In the event that a decision is made to close down, this will usually not occur immediately, but will require quite a lot of time (around the order of years), during which period the plant will continue to operate, at a gradually decreasing capacity, with routine maintenance being carried out for the plant and the field.

During this time, safety measures will have to be adopted to be able to close the wells later one and disassemble surface facilities, following procedures to reduce the residual environmental impact to a minimum and that allow returning the site of the project, in as much as possible, to its initial condition.

6.3 Costs

The costs associated with a geothermal field are divided as follows:

- Investment costs: including all expenses before and during the field's commercial operation.

- Generation costs: including all expenses after beginning the commercial operation.

This division allows making a clear distinction between well operation and maintenance (repairing or replacing wells and their connection to the fluid transportation system) and the drilling of production wells required to start up the plant's operation (development stage).

With regard to generation costs, items are grouped as follows:

- Operation and maintenance of surface systems, which includes all repair costs of steam lines, roads, waste water treatment, etc. and, in general, any spending not attributed directly to the plant or the wells.

- Well repairs, corresponding to repair costs in the case of pipe corrosion, scaling, mechanical failures, etc.

- Well replacement, which involves the costs of drilling new wells either to replace those that have definitely failed and are not able to be repaired, or to complete steam production or the injection capacity due to the reservoir's own abatement. Included here are drilling expenses for any drilling that has to be done for exploratory studies, to determine the extension of the field and to ensure plant operation at a full load capacity.

- Well operation and maintenance, which includes labor, replacement parts, special equipment, etc.

- Indirect administrative costs, which generally covers different administrative items, the average of which amounts to around 11% of the direct costs.

Typical estimated costs for replacement wells are indicated in table 6.1. This table was made with 1992 costs, for projects in distant zones from drilling material supply centers. Very little can be said regarding the costs of well repairs, since they are very variable and can even cost more than a new well. These costs require a careful assessment in order to not incur in unnecessary expenses.

6.4 Organization of the Project

For the operation and maintenance stage of a 35 MW geothermal field with 20 wells, an organizational structure such as that indicated in the organizational chart of figure 6.1 is recommended. The main levels of responsibility are described next.

APPROXIMATE DRILLING COSTS FOR REPLACEMENT WELLS (1992 values)					
DEPTH (m)	1000	1500	2000	2500	3000
COST PER METER (US$)	500-650	500-650	600-800	700-950	750-1000

Table 6.1

General Field Superintendence

It is defined as the area responsible for all activities related to field operation and maintenance, which includes the wells and both mechanic as well as civil surface facilities, with the exclusion of those related to the geothermal power plant.

The General Field Superintendence is subdivided for a better performance in two ares: Well Superintendence and Surface Facilities Superintendence.

6.4.1 Well Superintendence

Is in charge of all activities related to construction, repairs, maintenance or control of the underground part of the wells, subdividing into the Drilling Group and the Repairs Group.

Drilling Group

This group has the responsibility for preparing the programs, design and specifically of building both production as well as injection or observation wells, as well as preparing the basis for the drilling contracts, in the event that this is not done through direct administration. It is therefore responsible for implementing or supervising well construction, according to what is established in the Guide for Feasibility Studies, section 3.2.1.5.

Repairs Group

This group is responsible for interventions in the maintenance, repair and shutdown of all production, injection or observation wells, as well as for procedures in wells that are out of control.

Field Operation and Maintenance Organization Structure

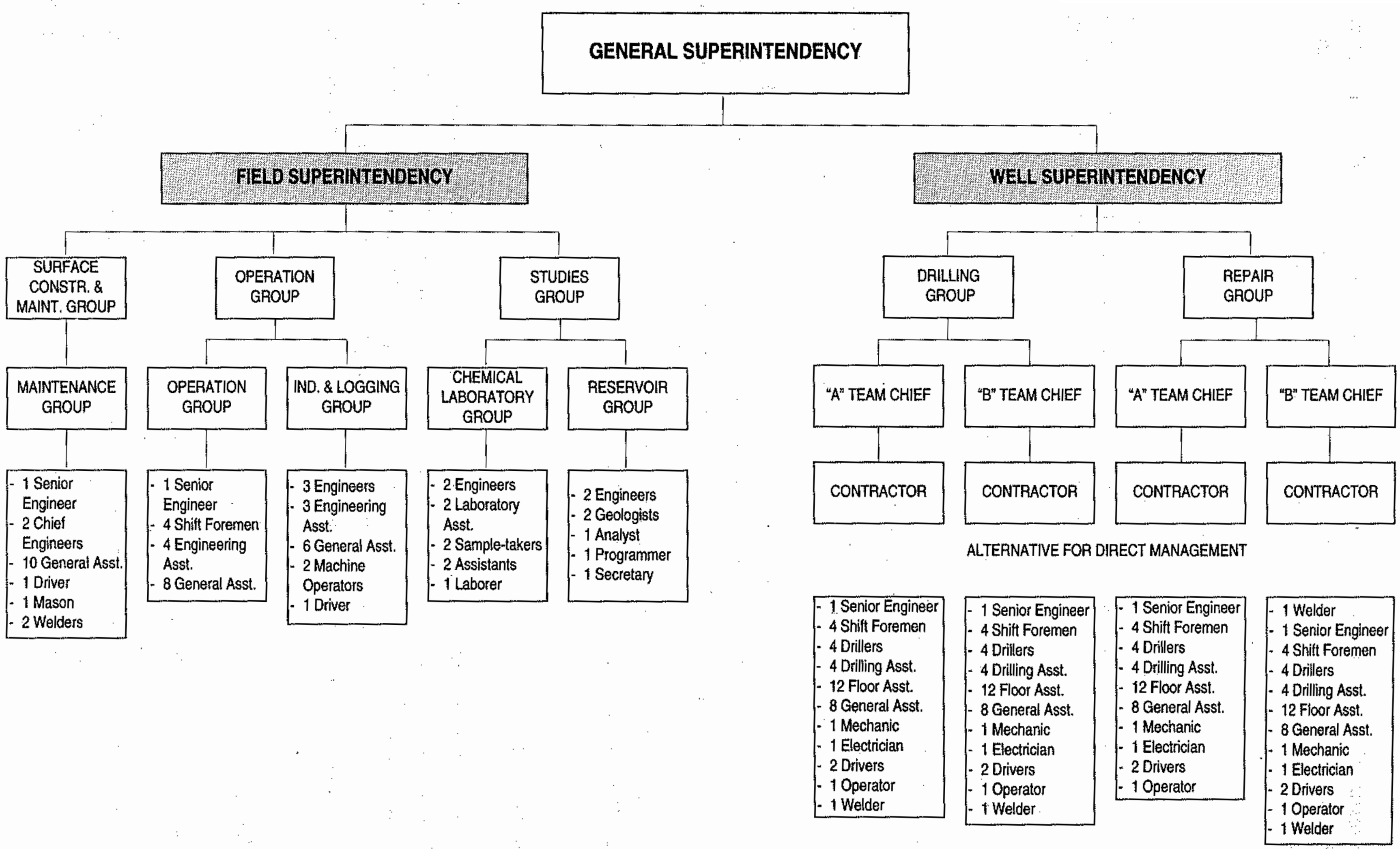

Figure 6.1

It is also responsible for the preparation, design and specifications for well repairs, as well as for the basis of contracts in the event that this operation is not carried out through direct administration, in which case it is responsible for the supervision.

6.4.2 Surface Facilities Superintendence

It is responsible for all activities related to the operation and maintenance of the wells' surface facilities, as well as for the analyses or studies on well and field performance, for which it is subdivided into: Construction and Surface Maintenance Group, Operation Group and Study Group.

Construction and Surface Maintenance Group

Once the plant and all the field facilities have been built, it is necessary to carry out some additional construction for the replacement and repaired wells. For this, a construction group is needed with its corresponding support staff, to prepare the designs and basis for contracts, as well as to supervise the work during construction and start-up.

As soon as well facilities are finished it is necessary to provide maintenance for civil and mechanical works in the field, to avoid having them out of operation. The most needs occur during well start-up and during the continuous supply of steam to the geothermal power plant.

This group must prepare the basis for contracts and carry out the corresponding supervision during implementation when additional maintenance is not provided through direct administration.

Operation Group

It is in charge of all operations carried out in the wells once they have been constructed or repaired, and covers the observation, induction, heating, development, assessment and start-up stages, as well as depressurization of wells, including the operation of all facilities for production, injection and observation wells. It is also responsible for supervising the field 24 hours a day and of thermodynamic monitoring, through surface and well bottom measurements.

Study Group

It is responsible for following up on the wells' physical-chemical characteristics, preparing forecasts regarding their future performance. It is also responsible for exploitation policies and well intervention programs, supported by geoscientific and statistical studies. In addition, it must provide support through a chemical laboratory for field activities and chemical monitoring, and through a petrographic laboratory for drilling activities. It must also support the operations of the well repair and operation groups.

6.5 Materials and Equipment

The needs for space and equipment to develop activities related to field operation and maintenance are indicated in figure 6.2, considering a 35 MW geothermal power plant with 20 wells. For every additional 35 MW, 10% should be increased.

FIELD OPERATION AND MAINTENANCE REQUIREMENTS

	GENERAL SUPERINTENDENCY	FIELD SUPERINTENDENCY	CONSTR. & MAINT. GROUP	OPERATION GROUP	STUDIES GROUP
OFFICE FLOOR AREA (m2)	60	50	30	30	30
COMMUNICATIONS Telephone Radio	 2 1	 1 1	 1 1	 1 1	 1 1
TRANSPORTATION Pickup truck	 1	 1	 1	 1	 1

	DRILLING GROUP	CONSTRUCTION GROUP	MAINTENANCE GROUP	OPERATION GROUP	INDUCTION AND LOGGING GROUP	CHEMICAL LABORATORY GROUP	RESERVOIR GROUP
OFFICE FLOOR AREA (m2) SHOP FLOOR AREA (m2) LABORATORY FLOOR AREA (m2)	60	60	30 250	60 100	60 100	60 50 150	60 50
COMMUNICATIONS Telephone Radio	 1 1	 1 1	 1 1	 1 5	 1 3	 1 2	 1 1
TRANSPORTATION Pickup truck 3-ton truck 8-ton truck Crane truck	 2	 2	 2 2 1 1	 3 1 1	 2 2 1	 2	 2
COMPUTER EQUIPMENT Personal computer Printer Plotter	 1 1	 1 1			 1 1 1	 1 1 1	 1 1 1
MISCELLANEOUS EQUIPMENT			1 30-ton crane 1 air compressor 2 welders 1 sandblast equipment 1 motoformer 1 dredger		1 sinking equipment 1 air compressor 1 logging equipment 1 15-30 ton crane 1 preventer washer and wedges injection casing mud pump	1 gas chromatographer 1 spectrophotometer 1 furnace and stove 2 scales 2 conductimeters miscellaneous equipment	

Figure 6.2

6.6 Offices, Laboratories, Workshops and Transportation

Taking into consideration a 35 MW geothermal power plant, the requirements for transportation, communications, computer equipment, etc., and space for offices, laboratories and workshops needed to carry out the activities described in each of the sections of the field operation and maintenance organizational chart are indicated in figure 6.2. For each additional 35 Mw installed in the field, there should be a 10% increase.

6.7 Personnel

For a 35 MW geothermal plant, the minimum number of staff needed to carry out the different activities, according to the organization of the geothermal power project, is described in section 6.4 of this guide. Practical training will be needed in different geothermal fields under exploitation, with the purpose of reducing the number of accidents and/or damage both to the personnel as well as to the wells and their facilities. It is estimated that the number of staff should increase by 10% for every addition 35 MW.

A minimum of three months of training is necessary for the personnel at leadership and supervision levels. Personnel training at other levels is also necessary and can be provided in the same geothermal field to be developed, for an initial period of one month as a minimum.

Personnel training at all levels should continue throughout the operational life of the geothermal field, with support form external consultants.

6.8 Consultants

For better results in the activities carried out by field personnel and to better complement their training, it is recommended and desirable to have support from external consultants for the most complicated activities, such as: drilling, repairs, construction, maintenance and operation of wells, as well as for different geoscientific studies.

The consultants, along with the field personnel, should prepare the implementation procedures for the different main activities carried out in the project.

7. PLANT OPERATION

7.1 Objectives and Scope

The function of a geothermal power plant is to produce electric power in a continuous, efficient, reliable safe and economic way, based on energy from geothermal steam.

The following are essential requirements for this purpose:

- Functional facilities, with appropriate and good quality equipment.

- Adequate maintenance of the facilities

- Correct operation of the plant

To achieve the good operation of the plant, the following is needed:

- Well-trained staff

- Operation policies based on technical considerations

- Operation procedures based on the best engineering criteria and on the recommendations of equipment manufacturers.

- Effective supervision and coordination of operations.

A continuous revision of the plant's operating conditions allows knowing what the performance of the equipment is over time and contribute information to assess the results of the operation.

Normally, the plant forms part of an electric system with generation from different energy sources. Plant production will be ruled by the power control center of the system, according to the demand and the system's economy.

In an interconnected system, it is advisable for geothermal power plants to operate as base load plants since, on the one hand, they do not consume fuel and, on the other hand, as well production is not regulated, if it does not generate, steam cannot be stored and has to be emitted to the air.

7.2 Operation of Plant Systems

The systems that intervene in carrying out the different processes of the plant's energy generation cycle are described below:

7.2.1 Steam System

This system includes from the point of delivery of steam to the wells to the entrance point to the turbine and to the ejector or turbocompressors. Therefore, the operation of this system has to be coordinated with the well area.

Before putting this system into service the first time or after major maintenance of the unit, steam blowing should be done to clean out the pipes and to avoid strange matter from entering into the turbine.

Once this system has been put into service, the following key points should be kept in mind:

- Verify that there are no limitations or licenses on carrying out work on the system.

- Verify that all equipment has been correctly installed and that no registers have been left open.

- Verify that all valves are in their correct position.

- Verify that all condenser purges are open.

- Verify that all instruments are in operating condition.

- Verify that the pressure regulation system and the safety valves are in operating conditions.

Once all verifications have been made, the pipes are gradually heated up and pressurized up to the turbine stop valves, making sure at all times that the purges and steam traps are draining the condensate and that there are no anomalies in the system. When normal operating conditions are reached, turbine start-up maneuvers can start.

During normal operation, it should be made sure that all operation parameters are within the established limits. Any deviation requires corrective measures.

To place this system out of service, the stop valves are closed, discharging steam through the pressure regulation system and making sure that the pressure does not go over established limits. Care should be taken in draining all the condensate to avoid corrosion problems in the equipment and pipelines.

7.2.2 Water Condensation System

Before starting up the turbine, the condensation water system should be put into service. Before proceeding to carry out the maneuvers to start up this system, the following should be verified:

- Verify that there is not work license on the equipment that will be put into service and that no one is working on it.

- Verify that all pieces of equipment have been properly installed.

- Verify that the cooling tower is ready for operation and that the normal level of water exists.

- Verify that the condenser is ready with the manholes closed.

- Verify that all instruments are in operating condition.

- Verify that all electric panels are energized.

- Verify that controls and protections are operating.

Once all these verifications before start-up are made, the corresponding maneuvers are carried out according to the start-up procedures for this system, bearing in mind all manufacturer recommendations and key points to watch over to detect any abnormality.

During normal operation it should be made sure that operation parameters stay within established limits. Aspects requiring more attention are:

- Supervision of pump operation, checking their load current, lubrication, cooling, vibrations and the operation of suction valves and pump discharge.

- Supervision of the cooling tower, keeping an adequate distribution of the water and making sure that the ventilators are operating correctly.

- Application of the chemical treatment.

7.2.3 Gas Extraction System

To maintain the vacuum in the condenser, two types of gas extraction systems are used:

- With steam ejectors

- With mechanical equipment: compressors or vacuum pumps

Systems based on ejectors have a very simple, safe and reliable operation. They require little maintenance, but consume a lot of steam. On the other hand, systems based on mechanical equipment consume less energy but require more care in their operation and maintenance.

It is important that this system operate correctly, since any deficiency in it will affect the vacuum of the condenser and this in turn will cause a reduction of the turbine's capacity.

Before putting a gas extraction system based on steam ejectors into service, the following should be verified:

- That no work license exists on the equipment

- That the ejector condensers are closed

- That the valves are in the correct position

- That the pollution control system is ready for operation

- That instruments are in operating position

- That the water condensation system is operating

- That the steam line is pressurized

After all verifications are made, the ejectors are put into service, following the start-up procedures for this system. One starts by putting the second set of ejectors into service and then the first.

Once the vacuum in the condenser at full load has been lifted, this system requires little attention, since all it needs are adjustments in the flow of water to the ejector condensers to control their temperature.

Gas extraction systems based on mechanical equipment can be powered with electric motors or steam turbines. Before putting one of these systems into operation, all verifications should be made with regard to the arrangement of the equipment, making sure that both this system as well as other related systems (condenser, steam, electric, etc.) are ready to operate.

Start-up procedures for this system should be carried out in the sequence indicated in the manufacturer's instruction manual, with special attention to whatever care must be taken during this process and watching out for key points.

During normal operation, this equipment requires constant supervision. At the moment, systems with an automatic control are being manufactured, which allows them to operate more efficiently and provides more protection against errors.

To avoid serious air pollution problems from taking place due to the discharge of hydrogen sulphide, the pollution control equipment should be permanently supervised.

The gas extraction system should be put out of service once the turbine has stopped. For this, the corresponding shutdown procedure should be followed.

7.2.4 Turbogenerator and Auxiliary Equipment

Since this forms the plant's main equipment, it deserves more attention with regard to its operation and maintenance and should therefore be equipped with the best control and protection systems. In general terms, the turbogenerators used in geothermal power plants are not substantially different from those used in conventional plants, for which reason the same operation criteria can be applied.

Before starting up a turbogenerator, the following should be verified:

- Verify that no work license exists on the equipment and that it has been installed correctly.
- Verify the turbogenerator's lubrication system.
- Verify the turbine's control system.
- Verify the generator's seal oil system.
- Verify the generator's self-excitation system.
- Verify the substation's equipment.
- Verify that the instruments are operating.
- Verify the unit's auxiliary service equipment.
- Verify that the protection equipment is operating.

To begin the turbogenerator's start-up sequence the following is required:

- Lubrication system operating
- That the turbogenerator has been rotating long enough to ensure that the arrow is straight
- The generator's seal oil system operating
- The H_2 and CO_2 system in service and that sweeping of the air in the generator has been done with CO_2 and of the later with H_2.
- Steam system operating
- Turbine seals system operating
- Circulation water system operating
- Gas extraction system operating
- Reestablish turbogenerator protection
- Control system put into operation

Turbine start-up should be carried out following the operational sequence of the manufacturer's start-up procedures, constantly watching over the following parameters:

- Pressure and temperature of lubrication oil
- Temperature of the metal and lubrication oil and the entrance and discharge of the bearings
- Speed
- Differential expansion and expansion of the casing
- Eccentricity and vibration of the arrow
- Vacuum and temperature of turbine discharge

Once the regime's speed has been attained and the conditions have been stabilized, the real operation of the turbogenerator's protections should be tested. After this, one continues with the generator's self-excitation operations, according to the manufacturer's instructions, taking special care in watching over the operating conditions of the generator and of the main and auxiliary service transformers.

During normal operation, it is desirable that the unit always work with the most efficiency possible. As a general norm, it is recommended that the units operate at their maximum capacity.

To take a turbogenerator out of service, under normal conditions one should proceed first to reduce the load to a minimum value, change the auxiliary equipment, switch on the machine and then fire the turbine. During this operation, the procedure for turbogenerator shutdown recommended by the manufacturer should be followed, watching over the operating conditions.

7.2.5 Electric System for the Plant

This system is formed by the following:

- Generator
- Substation
- Auxiliary services equipment

The operation of the generator was described in section 7.2.4.

The substation holds the voltage transformation equipment, equipment for the plant's connection to and disconnection from the electric network, buses, current and power transformers, lightning rods and other elements associated with the installed equipment.

To connect the unit to the bus or the bus to the transmission line, synchronization procedures are needed before shutting off any switch at the substation. The operational care in this area are no different from that taken at a conventional plant, but depend on the equipment installed.

The auxiliary services equipment includes all the unit's electric equipment, such as:

- Transformers
- High- and low-voltage power panels
- Motor control centers
- Control panels
- Electric motors
- Direct current system
- Measurement and electric protection equipment
- Lighting
- Emergency generator

To start up the unit, the auxiliary services are fed through a start-up plant, or by taking power from the substation through a start-up transformer that reduces the voltage of the electric network to the value of operation of the auxiliary equipment.

Normal feeding of the auxiliary services is supplied by the unit's auxiliary transformer, which is connected directly to the generator.

Starting up electric feeding begins first with the higher voltage and then proceeds progressively to lower voltages. The start-up sequence of the electric equipment should correspond to the unit's start-up needs.

Switches should have local and/or remote, and manual or automatic operation. Voltages and operation currents should be watched, as well as the temperature and oil level of transformers and the operation of protections.

The emergency generator should be periodically tested to make sure it is in condition of operating automatically in the event of an interruption of the power from the emergency bus.

The direct current system that feeds the firing, instrument, control, emergency lighting, seal oil pump, computer systems, etc. should be kept operating always with a battery charger in service and another backup one ready for automatic start-up. This system requires constant and careful supervision, monitoring the voltage and output current of the battery charger, the conditions of the battery bank and the operation of the alarms.

Communication

The following communication systems are used:

- Internal communication using loudspeakers and amplifiers
- Private telephone (internal)
- Public telephone
- Intercommunication (carrier, radio)

7.2.6 Supervision, Control and Protection System

Supervision and Control

Control serves to coordinate the operation of the plant's different pieces of equipment, with the purpose of supplying the energy required by the system under the characteristics desired.

The control of a geothermal power plant is much more simple than that of a conventional thermal power plant, since it does not have sophisticated control system for the steam generator and the auxiliary services. The steam supply from the wells is kept under a condition of stable pressure, through a simple pressure control system.

The plant can be manually operated or require a certain amount of automatization. There is a general tendency to concentrate all measurement, protection, regulation and command devices needed for the plant's operation in the control room.

Under manual operation, command actions are carried out manually, but the activating mechanisms can be electric, pneumatic or hydraulic.

The automatization levels most used in plants are:

- Generation unit with centralized control and automatic controls operating independently
- Plant with automatic detection that uses a computer to register the values of operation

parameters, detects deviations and carries out routine calculations for immediate inspection of operations personnel.

- Automatic plant, where the computer and associated controls automatically carry out verification, start-up, monitoring, equipment adjustment and shutdown operations.

The main benefits obtained in using automatic controls are:

- Improves supervision of the operation
- Increases the plant's operational efficiency
- Reduces the probability of equipment shutdown
- Improves reliability and accuracy of data
- Requires less operations personnel

An automatic system requires a larger investment and more specialized maintenance.

The plant's operational needs will be largely determined by the type of control used.

Protection

The purpose of protection is to determine deviations in normal operation values and intervene in an independent way to protect the facilities from possible damages as a result of these deviations.

Facilities can be protected in the following way:

- Through signals (alarms), if it goes over parameters that do not represent an immediate danger of damage.
- Through load reduction, if the deviation of a parameter can be corrected by reducing the load.
- By disconnecting the system, if there is immediate danger of any damage occurring.

A good protection system has the following characteristics:

- Good coordination of the different protections
- Use of schemes with higher redundance

- Selective signals for the functioning of different protections

Protections for the turbine:

- Firing due to high speed
- Firing due to solenoid
- Firing due to low vacuum
- Firing due to low oil pressure to bearing
- Firing due to failure of drive bearings
- Firing due to high amount of water in the steam
- Manual firing
- Discharge device due to low vacuum

The electric equipment is exposed to suffering serious damages if an abnormal operating condition takes place over a period sufficiently long to cause damage in its insulation.

Apart from the causes that originate it, failure could occur due to any of the following conditions:

- Short-circuit
- Overload
- Current return
- Sub-tension
- Over-tension

When a piece of equipment experiences failure, a disturbance occurs in the system that also affects the other pieces of equipment and could lead to cause other failures if not isolated in a timely way.

To protect the main pieces of equipment adequately, such as the generator, main transformer, auxiliaries' transformer, start-up transformer, transmission bus and line, isolated and independent protection systems are installed for each piece of equipment.

A relay is an automatic-operation protection device whose function is to detect a failure in the circuit and cause the system to quickly disconnect in order to isolate the failure zone and avoid further damage. The operation of a relay also activates the alarm system to indicate to the operator that the protection has worked.

Whenever a firing relay is activated, the causes for it to have started up should be investigated and the system should not be started up again until it is certain that the failure no longer exists and that the equipment has suffered no damage. Block relays that can be manually replaced are used to avoid the protected circuit from starting up again alone.

Damage to a main piece of equipment turns out to be very costly, not only due to the repair costs themselves but even more so due to the loss of energy that is no longer generated while the equipment is out of service.

It is important that the operations personnel become familiar with the protection equipment installed in the plant an that they understand the function of each device, so that when a protection operates they will be able to interpret what caused that operation and what to do to put the system back into safe conditions in the least time possible.

Protection of the main electrical equipment:

- Differential relay of the generator
- Differential relay of the main transformer
- Differential relay of the auxiliary transformer
- Differential relay of the bus
- Ground relay of the generator
- Inverse power relay
- Field loss relay of the generator
- Over-current relay of the generator
- Ground detection relay of the generator field
- Distance relay of the transmission line
- Sudden pressure relay of the transformer

7.2.7 Fire Safety System

The purpose of the fire safety system is to protect human lives and property from fire. A fire at a plant can cause damage to vital pieces of equipment and seriously affect the plant's generation system and economy.

Areas of highest fire hazard are:

- Cooling towers
- Hydrogen system
- Battery room
- Turbogenerator lubrication system
- Electric panels and inner substations
- Command room
- Cable network
- Transformers

The main causes of fire are:

- Self-ignition of sulphur deposits
- Electric short-circuits
- Carrying out welding tasks without the proper protection
- Lighting fires or smoking
- External causes, such as lighting, etc.

Means of extinguishing fire:

- Pressure water stream
- Pulverized water
- Water, chemical powder and CO_2 extinguishers

An adequate form of extinguishment should be used for each type of fire. The best way to fight a fire is by avoiding it. For this, effective preventive measures should be adopted. The use of detection systems allows fighting a fire from its initial stage, with a better probability of controlling it.

The pumping system should be backed by a pump with a 100% capacity internal combustion motor and able to operate in the event of failure in the electric supply.

Operations personnel needs to be well trained in the use of fire-fighting equipment, to be able to respond in an emergency. A program of routine inspections and tests should be established to make sure the system is in operating conditions at all times.

7.2.8 Miscellaneous Systems

Air compressors

Compressed air is used for pneumatic instruments and for general services. Normally, reciprocating compressors are used with 100% double-capacity equipment, to count with one equipment in operation and another as backup.

For instruments, air free from humidity and H_2S is needed, for which reason it is put through absorbent H_2S filters and air dryers.

When pneumatic switches are used at the substation, another compression system is required to supply air for their operation.

Operational care for this equipment is conventional. Air pressure and temperature, condensate traps, lubrication, filter and cooling systems, etc. need to be checked.

Service water

The water for bathrooms, dining halls and services in general should be of good quality and free from microorganisms. Depending on the quality of the water available, some kind of treatment may be necessary for its use.

7.2.9 Environmental Control

The main sources of contamination at a geothermal power plant are:

- Waste water
- Solids
- Gases
- Noise

Waste water

Waste water comes from the surplus of the circulation water system and from the plant's drains.

Circulation systems with a cooling tower are those with the highest pollution problems, due to the concentration of solids as a result of evaporation. The main pollutants in the surplus water from the towers are: mineral acids, sulfates, sulphur, sulfides and iron oxide. These contaminants can be found in the form of dissolved solids and in suspension and come both from the contaminants in the steam as well as from the chemical treatment, from the environment and from the chemical reactions that take place in the circulations water system.

The most common contaminants in the plant's drainage system are: organic matter from sanitary drains and industrial waste collected by this system, such as oil, detergents, chemical products, etc.

To control pollution due to waste water, it will have to be injected or undergo a sedimentation or clarification treatment, with the elimination of the other contaminants until it can be released into the zone's drainage network.

To ensure that water is of acceptable quality it will have to be constantly monitored.

Solids

Salts from well discharges and saline dust from the environment that are carried by the air can cause failures in the substation's and transmission line's electric insulation, as well as corrosion problems in the facilities.

As a result of this contamination there could be interruptions due to insulation failures and the maintenance needs will increase. To avoid or reduce this contamination, a solution should be found that addresses the factors that cause it.

Gases

Part of the noncondensable gases carried by the geothermal steam is removed from the condenser by the gas extraction system and the other part dissolves in the circulation water and is partially liberated in the cooling tower. Part of the gases continue dissolved in the water, forming compounds as a consequence of the chemical reactions that have taken place.

Though it is not feasible to control the quality of gases discharged by the cooling tower, due to the use of mixture condensers, the pollution levels due to this reason usually stay within tolerable levels, since they are diluted by the air circulating in the tower.

Due to its high toxic and corrosive characteristics, hydrogen sulphide is the main pollutant in gases extracted from the condenser. To avoid air pollution problems, it is important to keep the pollution control system operating adequately.

To protect the personnel from the toxic effects of hydrogen sulphide, it is recommended that the concentration levels of this gas in the air not go over 10 ppm. As a safety measure, workers should use protection and emergency equipment, in addition to installing a monitoring system with alarms to alert about any concentration that could put their lives into danger.

Noise

Noise is considered to be a pollutant that affects the health of people, causing irreversible hearing damage, affecting behavior and contributing to accidents as it interferes with voice communication and alarm signals.

The main sources of noise in a geothermal power plant are: steam and compressed air discharges into the air; steam ejectors and rotary equipment.

Much of the noise can be controlled at the original source. Others have to be controlled by installing isolating noise barriers between the source and the receptor. When the noise level is high, workers should use protection equipment to be able to carry out their work under these conditions.

8. PLANT MAINTENANCE

8.1 Objectives and Scope

The purpose of maintaining a geothermal power plant is to keep the machinery, equipment, buildings and in general all facilities and services in good operating condition, between the limits set with the entity supplying the geothermal fluid and the point of delivery of the electric power to the transmission network, to guarantee the plant's safe and efficient operation.

The concept of maintenance includes all work related to keeping facilities and equipment at a satisfactory level to be able to fulfill their function in economic conditions.

Beginning with the plant's planning phase, maintenance requirements for each facility should be kept in mind. A good design should satisfy the following requirements, among others: a) that the facility be functional, and b) that it require as little maintenance as possible.

Once the plant has been built, maintenance requirements will be determined by the following factors:

- The size and type of facility

- The equipment selected
- The characteristics of the fluids being handled
- Environmental conditions
- The characteristics of the electric network it is connected to
- The company's operation and maintenance policies
- The company's social and technological environment
- The age of the facilities
- The availability of replacement parts

Maintenance policies are all the guidelines set by the company to achieve that purpose. As an example, we have the following:

- To maintain the plant's equipment under optimal operating conditions.
- To reduce the possibilities of equipment failure and unnecessary maintenance.
- To establish criteria regarding maintenance techniques, methods and procedures.
- To optimize the use of available resources, particularly of materials.

Maintenance policies should be based on the best technical criteria applicable in this matter.

In general terms, maintenance is classified in:

- Preventive maintenance
- Corrective maintenance
- Improvements of facilities

The maintenance of a geothermal power plant should fundamentally based on the modality of preventive maintenance.

To carry them out, maintenance activities should be classified according to their specialty in the civil, mechanical, electrical, chemical, instrumentation and control areas.

8.2 Preventive Maintenance

Preventive maintenance is defined as the work carried out on a piece of equipment or facility to avoid failure or interruption or to keep them within previously established economic limits for the period of their useful life. This type of maintenance is mostly carried out when the equipment is being operated.

When a maintenance program is established, it should be done on the basis of a cost-benefit analysis, balancing the total cost of uninterrupted preventive maintenance against the total cost of preventive maintenance with a certain amount of interruptions. It is important that the cost of preventive maintenance not exceed the probable loss due to interruptions.

Preventive maintenance should be based on the observation of the performance of the equipment over its lifetime and from its start-up on. It is known that the equipment is more susceptible to failing during the initial operating period and towards the end of its useful life.

Preventive maintenance is subdivided into:

- Routine maintenance

- Chemical treatment

- Major maintenance

8.2.1 Routine Maintenance

Routine maintenance involves all those activities of preventive maintenance that are repeated over regular intervals and that follow a work routine. Its purpose is to avoid having equipment fail during its useful lifetime.

Once the maintenance requirements for each piece of equipment are known, work routines and periodicity are established and an annual routine maintenance program is set up.

Field and operation conditions are determinant in establishing periodical routines.

To establish the maintenance requirements, the following concepts should be considered:

- **Critical and Noncritical Criteria.** They establish the conditions of each piece of equipment with the complete process and the consequences of failure in the system's operation. The equipment that causes serious consequences in the system's operation, such as in its safety, production, costs, etc. is considered "Critical." The equipment where its failure does not have serious consequences on the system is considered as "Noncritical".

- **Criterion of Admissible Levels.** It establishes values that usually result from tests that indicate when the equipment is coming close to a limit condition of danger and that makes it necessary to repair or replace it.

- **Criteria of Manufacturer's Data.** File of Results. It provides information on the limits of life expectancy and suggests time intervals in which to carry out tests and to provide maintenance according to the service offered by the equipment.

- **Inspection.** It consists in subjecting the equipment to a series of detailed observations and obtaining its characteristic data in order to have general information on its state and operation.

- **Revision.** This refers to a detailed physical examination that should be done to the equipment or part of it, as well as to the elements that condition its operation, in order to detect and correct damages, abnormalities and/or deficiencies.

- **Verification.** This involves subjecting the equipment to detailed examinations and tests that allow one to detect abnormalities and ensure that it is apt to continue operating.

Work that is generally accepted as part of routine maintenance includes conservation and minor repairs to the machinery, buildings, structures, etc.

Below, the most common routine maintenance activities in a geothermal power plant are listed:

Mechanical Maintenance

a. Main Steam System

The content of contaminant solids, humidity or water and noncondensable gases transported in the geothermal steam, can cause scaling, corrosion and erosion problems in this system to a larger or lesser degree. This will require a specific maintenance program for each plant.

Maintenance actions, in addition to self-conservation, should be aimed also at avoiding the following:

- Entrance of water and solid matter to the turbine

- Equipment clogging up

- Steam leaks

- Accumulation of water in the pipelines

Maintenance activities for this system are:

- Revision and testing of safety valves
- Revision of the pressure regulation system
- Revision of the humidity separator
- Revision of steam filters and traps
- Revision of seals and lubrication of stop valves
- Revision of pipelines, supports and insulation

b. Turbogenerator and Auxiliaries

This module is formed by the following:

- Turbogenerator
- Lubrication oil and control system
- The generator's seal oil system
- The generator's H_2 and CO_2 system
- The turbine's steam seal system

With some variations, the equipment of this module corresponds to that of a conventional plant and its maintenance should be carried out following the manufacturer's recommendations.

The following are specific problems of this system:

- Tendency of the control valves to stick and for there to be an emergency shutdown of the turbine, caused by the scaling and corrosive action of the contaminated steam. These elements need to be frequently checked and necessary corrections made.
- Scaling occurs especially in the first row of nozzles, which reduces the pathway area of the steam and, consequently, the capacity of the turbine. This makes it sometimes necessary to stop the system prematurely to carry out non-programmed maintenance to recover the lost capacity. On occasions it is possible to use some washing technique with the turbine rolling, to remove this scaling and avoid a costly shutdown.

- When water from the cooling tower's circulation system is used to cool the lubrication and control oil of the turbogenerator and the hydrogen of the generator, scaling and corrosion problems could take place that require further attention.

- Due to the corrosive characteristics of steam in the presence of oxygen, it is important that the turbine's seal system be in good operating condition to avoid attacks on these parts.

c. Condensers

Mixture condensers used in geothermal power plants, either of a barometric or low-level type, normally require little special attention when the materials of their internal elements have been selected well and they receive adequate major maintenance.

d. Noncondensable Gas Extraction System

In units with gas extraction based on steam ejectors, there are the following elements:

- Steam ejectors
- Ejector condensers
- Steam pipes, valves and filters
- Condensation water pipes and valves
- Noncondensable gas pipes and valves
- Pollution control equipment

Due to the highly corrosive nature of gases and of the condensate, special care should be given to providing maintenance for the parts that come into contact with these fluids.

When gas extraction takes place through compressors (vacuum pumps), the maintenance of this equipment is more delicate and should be carried out following the manufacturer's recommendations. Special emphasis should be placed on lubrication, maintenance of seals and on the dynamic problems of both the compressor as well as of the motor machinery.

Since hydrogen sulphide is a highly toxic gas, maintenance actions should avoid any possibility of this gas leaking or of a failure in the pollution control equipment.

e. Circulation Water System

When water comes from an external source there are normally few maintenance problems. In a system using the same condensed steam as a source of water supply for the circulation system, more or less serious problems could take place with the deposits of solids and the corrosion of some of the elements in the system.

Typical maintenance of this system is as follows:

- Circulation water pumps: lubrication, revision of seals and of the pump's cooling lines, cleaning of the motor's coolers, prevention of dynamic problems.

- Suction and release valves: revision of operators, revision and adjustment of gaskets.

- Water pipelines and duct: revision of pipes, accessories and supports.

f. Cooling Tower

In this facility there are problems of solid deposition, corrosion and degradation of wood. This is described in more detail in the chapter on chemical treatment.

Maintenance actions for this area are:

- Revision and lubrication of ventilators

- Revision of gaskets and lubrication of water distribution valves

- Cleaning of water distribution pools

- Revision of the tower's blinds, filling and covers

g. Cooling Water System

If water from the circulation system is going to be used for direct cooling, problems could take place in the oil and hydrogen coolers, as was mentioned above.

If the cooling water is in a closed system and water is used from the circulation system with a tower, scaling and corrosion problems could take place in the heat exchanger.

h. Fire Prevention System

If good quality crude water is used, the problems in this system will be as normal as those in any other similar system, with additional problems being the action of the corrosive environment, such as the area of the cooling tower. If water from the circulation system is used, there could be problems with the equipment that would be similar to those seen in the system.

As normal tasks we have:

- Revision and lubrication of motor pumps
- Lubrication and tuning of internal combustion motor
- Revision of network of pipes, valves, hydrants, hoses, aspersion systems, etc.
- Revision and reloading of fire extinguishers.

i. Service Water System

Maintenance of this system is circumscribed to regular inspections of pumps and of the network of pipes and fittings.

j. Compressed Air System for Services and/or Instruments

In general terms, maintenance of this system is conventional, depending only on the type of equipment used.

In order to avoid problems, especially regarding pneumatic instruments, activated carbon air filters or similar products that absorb hydrogen sulphide are used.

k. Air Conditioning and Ventilation

Air conditioning equipment, additionally to keeping temperature under control, is used to achieve pollution-free environments by means of absorbent filters. This is very important especially to protect vital electric equipment against the action of hydrogen sulphide.

Additional to the recommended maintenance for the kind of equipment used, a maintenance program should be developed for the filters as well as for the air-cooled condensers which are susceptible to the action of hydrogen sulphide.

The ventilation equipment used to eliminate heat also serves to remove undesirable gases from the environment in order to protect the equipment and personnel's health.

l. Miscellaneous Equipment

- Emergency electric plant: lubrication and tuning servicing

- Cranes and hoists: inspection and lubrication.
- Maintenance equipment: according to the needs.
- Other equipment: according to the manufacturer's recommendations.

m. Painting

In a corrosive environment such as that of a geothermal power plant, painting plays a very important role in general maintenance. Appropriate and systematic application of paint prevents deterioration of equipment and metal structures by the existing environmental conditions.

Electric Maintenance

Maintenance requirements of electric equipment are determined by the type of equipment installed and by the conditions it is under. The development of the maintenance program should take into consideration the manufacturer's recommendations as well as those from experience in operating the equipment. The program should consist of all inspection, checking and verification activities required by each piece of equipment.

Inspection serves the purpose of collecting as much information as possible on each piece of equipment, from the manufacturer as well as from field experience, in order to establish its typical data and the initial operating conditions, since this information is a point of reference for analysis and decision-making to be undertaken in the future.

Inspections of electric equipment have the purpose of proving the performance of the elements that compose each one of the pieces of equipment. Regular inspections and appropriate maintenance result in greater safety, reliability and cost-effectiveness in their operation.

Regular inspection tasks are the following:

- Inspection of connections, fuses, cables, contacts, etc.
- Inspection of insulations.
- Mechanical inspection.
- Lubrication of mechanisms.
- Inspection of mechanical and electric adjustments.
- Cleaning of parts.

- Replacement and repair of parts.

Electric tests are the basis for verifying with more certainty the conditions of the design, manufacturing and operation of equipments and materials, allowing to determine the kind of maintenance that each piece of equipment requires. The tests should be performed periodically and, therefore, should be part of the preventative maintenance programs.

The tests most usually performed are:

a. Rotating Equipment

- Insulation resistance.
- Power factor.
- Ohmic resistance.

b. Transformation Equipment

- Insulation resistance.
- Power factor.
- Excitation current.
- Transformation to polarity ratio.
- Ohmic resistance.

c. Sectionalizing Equipment

- Insulation resistance.
- Power factor.
- Ohmic resistance.
- Synchronism and operating time of circuit breakers.

d. Voltage Regulators

- Transformation to polarity ratio.

e. **Power Cables, Buses, Lightning Arresters and Bushings**

- Insulation resistance.
- Power factor.

f. **Insulation Systems**

- Ohmic resistance.

g. **Insulation Oils**

- Power factor.
- High AC potential or dielectric rigidity.
- Oil resistivity.
- Neutralization number (acidity).
- Interphase tension.

h. **Electric Contact Points**

- Determination of hot points and determination of temperature at the connections.

i. **Battery Bank**

- Electrolyte density test.
- Voltage test.
- Capacity test.

j. **Battery Charger**

- Verification of floating and equalizing voltages.
- Polarity tests.

k. **Measuring, Control and Protection Switchboards**

- Insulation resistance of the insulating base.

- Application of voltage to all circuits that receive voltage signals.

- Calibration and verification of the operation of detectors.

- Verification of alarm operation.

- Verification of signal lamps operation.

- Verification and calibration of electric instruments.

Instruments and Control

The instruments serve as a guide to operate and preserve the equipment; they are the basis for secure, continuous and efficiènt operation.

The instruments installed at the plant depend on the level of automation considered by the design: the higher the automation, the higher the number of instruments and degree of specialization. Instruments for measuring mechanical amounts can be of mechanical, pneumatic, electric or electronic operation.

By their function, instruments may be for measurement, protection or control.

a. Measurement

Measurement equipment measures the varying conditions of the process such as temperature, pressure, level, flow, speed, vibrations, eccentricity, differential expansion, etc.

Measurement may be local or remote. The instruments can be indicators, recorders or totalizers. For remote measurement, transmitters or transducers are used.

Due to the great diversity of instruments that are found on the market, specific maintenance of these equipments should be performed following the manufacturers' recommendations and taking into account the conditions they will be exposed to. Periodic inspections and calibration verification should guarantee at all moments that the equipment is at its best operating conditions and has an acceptable degree of precision.

b. Protection

Protection devices have the purpose of protecting the pieces of equipment against any possible damage under abnormal conditions. These devices can indicate a condition of risk by means of an alarm signal, or produce the disconnection of the equipment when a dangerous conditions is present.

Due to the serious repercussions that a failure in the equipment can produce, the protection devices require special attention during maintenance in order to provide them with the highest possible degree of reliability. Operation, adjustments and coordination among protection systems as a whole should be verified periodically, according to protection logic.

c. Control

Control serves the purpose of coordinating the functioning of the different pieces of equipment at the plant with the needs of the electric system. Control may be manual or automatic. Today there is a growing trend to use computerized automatic systems; however, pneumatic, hydraulic and electro-hydraulic systems are still being used.

Control driven devices may operate pneumatically, hydraulically, electrically or electromagnetically.

A periodic calibration verification of sensors, control signals and operating devices should be undertaken, making the necessary adjustments according to the manufacturer's recommendations.

Civil Maintenance

Accelerated deterioration of civil works due to the lack of appropriate maintenance, besides being expensive may also originate damages to the facilities and produce unsafe conditions for the personnel.

With the purpose of preserving the good state of these works it is necessary to establish a preventative maintenance program. The critical areas that will require greater attention according to the particular conditions of each plant should be identified.

The most usual tasks in this area are the following:

- Cleaning of offices, engine room, control room, workshops, yards, roads, etc.
- Preservation of buildings: floors, roofs and walls.
- Maintenance of metal and concrete structures, ramps, platforms, stairs, handrails, etc.
- Fixing and application of paint and coatings.
- Cleaning and maintenance of drainage systems.
- Maintenance of roads, green areas, fences and supplementary works.

8.2.2 Chemical Treatment

The purpose of chemical treatment is to eliminate or minimize the undesirable characteristics of a fluid by adding chemical products that provide desirable properties.

In geothermal power plants without condensation and in those with condensation that use external water for cooling, such as a river or lake, chemical treatment is practically unneeded.

In condensing geothermal power plants that use condensed steam as the source of cooling water, and that use direct contact condensers and cooling towers, chemical control of this water is very important because of the aggressiveness of the steam contaminants, such as carbon dioxide, hydrogen sulphide, ammonia, salts, etc. in conjunction with the impurities that contaminate the circulating water and air, such as microorganisms, dust and oxygen, besides the impurities added by the chemical treatment.

The impurities produced during water circulation are mineral acids, sulphates, sulphur, sulphides and iron oxides. As a consequence of this contamination the following conditions are created in the water: high conductivity, dissolved solids and solids in suspension, and low pH.

Besides these contaminants and impurities great amounts of microorganisms and bacteria develop in the water, becoming a severe biological problem.

Following are the main problems that a cooling water system may have as well as their causes and control principles.

a. Corrosion

Corrosion in cooling systems becomes a serious problem since it causes high repair and replacement costs. The main variables that cause water to have corrosive properties are the concentrations of dissolved CO_2, H_2S and O_2 in the water, pH and dissolved solids.

It is estimated that one third of the hydrogen sulphides present in the steam is dissolved in the circulating water, which causes it to be aggressive to iron, steel and related alloys, even in absence of oxygen.

Low pH increases the corrosion speed of steel. It is desirable to keep pH in a range of 6 to 8 by adding chemical products.

High concentrations of solids in the water increase its conductivity which favors corrosion. Chlorides are especially dangerous for aluminum and rust-resisting steels.

The increase of water temperature and speed also increase corrosion.

Galvanic corrosion can also take place by contact between metals or different alloys.

Gaseous hydrogen sulphide in a humid environment, even in absence of oxygen, attacks concrete and metals.

To prevent corrosion the most important measure is to have made a good selection of materials that will resist the attacks of the environments that they will be exposed to. In this sense it is necessary that selection be based on the results of corrosion tests of a wide variety of materials that have been exposed to real conditions of operation.

The use of some types of rust-resistant steels, special alloys, coatings and plastic materials give good results in aggressive corrosive environments. Use of carbon steels in direct contact with the fluid should be avoided.

b. Biological Problems

Circulating and cooling water systems present most favorable conditions for the development of microorganisms since they contain nutrients needed for their feeding such as hydrogen sulphide, ammonia, sulphur, iron and carbon. A favorable atmosphere is also present since some of them depend on oxygen and others on carbon dioxide. Even more, water temperatures are ideal for their growth.

Although most microorganisms in the cooling system water do not attack the system directly, they can form big colonies and cause problems with the pipes and cause deficient heat transference at the heat exchangers. Under these deposits metal corrosive bacteria can develop which remain protected against bactericide action.

Among the microorganisms that develop easily in the cooling water system there are the following:

- Bacteria that deposit sulphur, that cause deposits that corrode metals.
- Bacteria that deposit iron, that cause pitting in aluminum.
- Ferrobacteria, that deposit ferric hydroxide that form corrosion cells.
- Corrosive bacteria, such as sulphovibrio that reduces sulphates to gaseous hydrogen sulphide which produces deep pitting in metal parts.
- Sulphur bacillus, that produces sulphuric acid from sulfur or sulphides.
- Nitrous bacteria, that produce nitrous oxides from ammonia, which combined with water becomes nitric acid.

- Bacteria that form gelatinous colonies that are deposited and cause obstructions and protect other bacteria mentioned above.

To control these microorganisms bactericides are used, but their immunization capacity makes it necessary to change the kind of bactericide used continuously.

c. Deposits

Deposits of solids in the cooling system generally cause obstructions and reductions in the diameter of pipes and reduce the efficiency of heat exchangers. Sulphur and sulphides in particular cause corrosion and serve as food for bacteria; insoluble calcium and magnesium salts may produce scales; and dust and organic materials produce scales and become food for microorganisms.

To avoid water dissolved solids from being deposited dispersive substances are used that keep the solids in suspension so they can be drained with the excess waste waters.

d. Problems with the Cooling Tower

Wood of the cooling tower is subject to three kinds of attack: chemical, physical and biological. In most cases these three kinds of attack occur simultaneously.

- Chemical attack. Chemical deterioration of wood is produced in the form of delignification. The most common chemical substances during this attack are oxidant agents such as chlorine, or alkaline substances such as sodium carbonate and hydroxide.

- Biological attack. Wood can be damaged by the attack of microorganisms such as fungi and bacteria that feed on it and cause its destruction.

- Physical attack. One of the physical factors that affects wood mostly is high temperature, which produces structural changes and makes it more susceptible to biological attacks.

Chemical Analysis

Corrosion processes, scaling processes, biological processes, etc. are dynamic and, therefore, control measures should be frequently adjusted on the basis of chemical control analysis.

The results of chemical and bacteriological analysis of the circulating water determine in what conditions the water is in and which chemical treatment is appropriate to be applied.

8.2.3 Major Maintenance

Major maintenance of a generator unit has the purpose of restoring the original functioning conditions of all equipments and facilities that integrate it, so the unit will fully recover its capacity, efficiency, safety level and degree of reliability.

To undertake major maintenance the unit is put out of service, the internal parts of all equipments are inspected in detail to determine their state, and, if so deemed, the necessary repairs or replacements are carried out. Complementary to this, all verifications required by each piece of equipment are undertaken, such as adjustments, allowances, calibrations, tests, etc.

The period between these maintenances depends on the particular conditions of each plant, but can fluctuate between one and two years. There are certain tasks that should be done at greater time intervals.

Major maintenance should be programmed to be carried out during the season of less demand on the electric system that is interconnected to the plant.

The necessary conditions to be able to provide good maintenance include the availability of enough stored spare parts and materials, qualified personnel and appropriate tools and equipment to undertake the tasks.

The development of the maintenance program following the critical route technique or PERT (Program Evaluation Review Technique) allows reducing implementation time to the minimum, taking advantage of labor and, consequently, obtaining the best maintenance cost. Bar graphics are valuable auxiliary tools to record the progress of the maintenance process.

The most common tasks undertaken in a major maintenance program are the following:

a. Main Steam System

In this system corrosion and scaling problems may appear which affect the equipment's life span as well as its performance. Maintenance consists of removing the scales that have formed and correcting the ware by repairing or replacing the affected parts.

Special care is required with safety valves, pressure regulating valves, humidity traps, steam filters and purgers.

b. Turbogenerator and Auxiliary Systems

The main problems that may appear in the turbine by effect of geothermal steam are:

- Scaling in the blades and nozzles as well as in the emergency stop valves and control valves resulting from solids carried by the steam. This scaling reduces the turbine's capacity and efficiency.

- Erosion especially in the last blade stages, originated by the water contained in the steam.
- Corrosion of parts where steam contacts air, such as turbine seals and valve trees.

In general terms the maintenance of the turbine consists of:

- Complete disassembly and assembly.
- Cleaning of the rotor and of the nozzle diaphragms.
- Nondestructive tests to determine emerging failures of the rotor and nozzles.
- Inspection of bearings, main oil pump, governor, etc.
- Verification of rotor alignment.
- Verification of allowances between moving and fixed parts.
- Inspection of control and stop valves and of steam filters.
- Verification of instruments and of the turbine control and protection systems.
- Inspection of the lubricating system.
- Inspection and cleaning of the oil coolers.
- Inspection of the turbine's seal system.

The following procedures apply for the generator:

- Inspection of the rotor, stator and excitation systems.
- Inspection of bearings and seals.
- Electric tests.
- Verification of instruments and of turbo-generator control and protection systems.
- Inspection of generator oil seal system.
- Inspection of generator H_2 and CO_2 system.

- Inspection and cleaning of hydrogen coolers.

c. Condenser

In the equipment problems of corrosion and deposit of solids may be present. For maintenance, the panel doors should be opened and all internal elements should be inspected, such as pans, sprinklers, pipes, coatings, etc., and the necessary corrections should be made.

d. Noncondensable Gas Extraction System

Due to the aggressiveness of the fluids managed by this system, maintenance requirements depend firstly on the type of materials used by the equipment installed.

In units that have steam ejectors, maintenance tasks are summarized as follows:

- Inspection of internal elements of ejector condensers.

- Inspection of ejectors, filters, valves and steam pipes.

- Inspection of water valves and pipes.

- Inspection of gas valves and pipes.

- General inspection of pollution control equipment.

- Calibration of instruments.

In gas extraction units using compressors:

- Disassembly, inspection and general cleaning of pipes and compressor.

- Inspection of lubricating system, seals, valves, pipes, etc.

- Verification of allowances, alignment, ware, balancing.

- Verification of the control, protections and measurement.

- General inspection of the pollution control equipment.

e. Circulating Water System

General maintenance aspects of this system are:

- Disassembly of the pumps to check ware of bearings, shafts, etc.
- Inspection of bearings and motor lubricating and cooling systems.
- Inspection of motor-pump alignment.
- Electric tests of motors.
- Inspection of valves and operators.
- Inspection and cleaning of pipes.
- Verification of controls, protections and instruments.

f. Cooling Tower

Maintenance requirements depend on the kind and features of the tower installed. A mechanical-draft tower demands much attention for its maintenance. At greater operation time the maintenance requirements are also greater, up to the point that important replacements should be made to keep up capacity, efficiency and safety.

Special care should be taken regarding chemical treatment of the circulating water since the tower's life span depends on it.

The tasks that should be undertaken on a tower are:

- Removal of muds accumulated in the basin.
- Inspection of water distribution valves.
- Inspection of ventilators and their motors.
- Inspection of the structure, fillings, humidity eliminators, shutters, water distribution basins, covers, etc.
- Electric tests of motors and verification of their controls and protections.

Since sulphur deposits accumulated at the tower have a very low ignition point, it is necessary to keep it permanently wet when it is out of service to prevent fire.

g. Cooling Water System

All equipments of this system should be checked: pumps, heat exchangers, filters, valves, etc.

h. Fire Prevention System

As a safety measure, in-depth maintenance of this equipment is not advisable when any of its units is out of service. Its maintenance should be programmed when all the units of the plant are in service, always being cautious that at least one pumping equipment is available.

i. Electric System of the Unit

The equipment of this system should receive the following maintenance:

- Main transformer: electric tests performed at the windings and complete tests at the insulating oil; if necessary, it should be treated to regenerate it.

- Machine circuit breakers: maintenance according to the type of breaker, electric tests, mechanic inspection and verification of its control and protections.

- Switch blades: electric and mechanic tests according to their type.

- Current and voltage transformers: electric tests and verification of measurement.

- Distribution switchboards and control centers of low voltage motors: electric and mechanic tests, verification of controls, protections and measurement.

- Central control switchboard: instrument calibration, verification of remote controls and of protections.

- Insulation inspection and cleaning.

8.3 Corrective Maintenance

Corrective maintenance is understood as that one that should be provided to a piece of equipment to restore its functioning conditions when it is failing.

In a geothermal power plant, as with any public service generating plant, interruptions of service besides resulting in high costs for the company, have highly negative social and economic impacts on the area served.

For the company the cost of a failure results from adding the implicit cost of maintenance to the cost of the energy that is not sold or to the additional cost of generating that energy by other means. Normally when a critical piece of equipment fails, the latter cost is several times greater than the maintenance cost. For this reason in a geothermal power plant a maintenance policy based on corrective maintenance is not applicable.

Even though it is desirable not to have to carry out any corrective maintenance at all, practically no plant is free of this need in greater or lesser extent. One of the responsibilities of the maintenance team is to proceed quickly and cost-effectively with the repairs required by any faulty equipment.

When a failure occurs troubleshooting should be performed to firstly determine its causes, and secondly to take the necessary corrective measures to prevent it from occurring again.

The evaluation of corrective maintenance should serve as a reference to measure the degree of effectiveness of the preventative maintenance program and, at the same time, serve as an assessment tool when adjusting the program or deciding on changes in the installation.

When corrective maintenance cost, including forced maintenance, is less than 10% of the cost of preventative maintenance, it is considered that the preventative maintenance program is reasonably acceptable.

8.4 Improvements on Installations

A good maintenance job is not possible if the installation has improper equipments or if these have been installed without taking into consideration future maintenance needs. If any of these conditions are present the problem should be analyzed pursuing a cost-effective technical solution. Occasionally it is preferable to make some changes at the installation than trying to establish a maintenance program in adverse conditions.

The purpose of making changes at the installation should have several of the following aspects in mind:

- To reduce cost.
- To improve safety conditions.
- To increase the equipment's capacity, efficiency or reliability.
- To simplify the operation.
- To improve conditions to provide maintenance.
- To reduce maintenance.
- To reduce failures.
- To improve the operating conditions of the equipment.

- To increase the equipment's life span.

Improvements can consist of modifying the installation or replacing a piece of equipment for another one with certain advantages.

Usually the cost of these improvements is considered an investment and not a production expense. Its amount obviously depends on the extent of such improvements, but it can be said that a good quality project should not require more than 5% of the total investment cost to undertake the changes.

9. ORGANIZATION, TIMING AND COSTS OF THE PLANT'S OPERATION AND MAINTENANCE STAGE

9.1 Objectives and Scope

The operation and maintenance stage of the plant has the purpose of keeping the generator units functioning efficiently and cost-effectively during their lifetime in order to have a safe and reliable energy supply that will provide the desired benefits.

In general terms a geothermal power project contemplates repayment periods between 20 and 30 years depending, among other factors, on the existing knowledge on the reservoir and the risk factor used for recovering the investment.

The plant's lifetime can differ from the payment period. Consequently, the operation and maintenance stage should cover the plant's lifetime from the beginning of its service.

Due to the dynamic properties of geothermal fields, the goals of this stage should be pliable to the changes that may occur, analyzing and assessing the results obtained at all moments.

9.2 Programming and Control

In order to achieve best results, careful planning should be carried out concerning the plant's operation and maintenance.

General and specific goals should be set and short, intermediate and long term working programs developed following each company's policies and taking into account other experiences in similar projects

Programs are valuable planning tools and are useful to:

- Assign the sequence and duration of an activity.

- Determine the resources that will be needed to implement it.

- Optimize the use of available resources.
- Develop expenditure budgets.
- Coordinate the activities of the different departments of the plant.
- Follow-up on the accomplishment of the tasks and detect any alteration on time.
- Evaluate the management of the plant.

Control is a management function that implies evaluating and correcting activities to ensure that they are carried out according to the established programs. The basic control process includes three steps:

- Establishing models.
- Measuring performance by comparison with those models.
- Correcting alterations.

The initial programs are developed based on the operating and maintenance instructions provided by the equipment manufacturers, the information on the project and the existing experience on similar facilities. The particular experiences gained at each plant should serve as feedback to improve the succeeding working programs.

The working programs are developed using critical route techniques, PERT and bar graphs.

The following programs should be developed at least:

- Operation program.
- Major maintenance program for all units.
- Preventive maintenance program.
- Facility improvement program.
- Program for expenditures.

A five-year general operating program is advisable, to be used to raise funds to cover the budget, as well as a detailed annual program at the beginning of each fiscal year.

9.2.1 Operation Program

The operation program is ruled by the estimated availability of equipments (based on the maintenance programs), by the projection of demands on the system's energy control center, and by the experience of previous years.

9.2.2 Major Maintenance Program

It is advisable that a general major maintenance program of the units for a period of 5 to 6 years (that will be updated each year) be developed, as well as a detailed program for each one of those maintenances.

9.2.3 Preventive Maintenance Program

An annual preventive maintenance program should be developed by integrating the monthly programs of each maintenance department of the plant.

9.2.4 Facility Improvement Program

When the improvement of the existing facilities has been decided a specific program should be prepared for each particular case.

9.2.5 Expenditure Program

The expenditure program is developed by scheduling the monthly allocations—determined by a cost analysis—for labor, materials, equipments, etc. to carry out the plant's operation and maintenance programs.

9.3 Costs

The costs of a geothermal power generating plant are divided into:

- Investment costs.
- Generation costs.

The investment costs or fixed charges include the annual payments of all allocations assigned before the plant is put into commercial service, as well as the subsequent investments that are made to extend the plant's capacity or to improve its facilities.

The amount of this cost depends on the amount of the investment, the interest rate and the period to pay the investment.

The power generating costs of a geothermal power plant consist of all the allocations assigned after beginning commercial operation and have the following general structure:

a. Geothermal fluid supply cost or field operation and maintenance cost, depending on the case, which includes the repair and replacement of wells and the operation and maintenance of fluid conduction systems, roads, etc. with their indirect costs.

b. Operation and maintenance cost of the plant, which includes operation materials, maintenance materials, spare parts and equipments, salaries and social benefits.

c. Indirect cost of the plant, comprised by the plant's technical and administrative expenses and the payment of taxes, duties, insurance, etc.

d. Indirect cost of the electric company's general administration which results from the prorated charges of the regional and/or national administration that correspond to the plant.

9.4 Organization

The personnel required to operate a geothermal power plant may be grouped as follows:

- Technical direction.
- Operation.
- Maintenance and repairs.
- Administrative and auxiliary services.

Organizational structure should be based on determining and dividing the members' functions and assigning hierarchical levels, that is, defining the authority and accountability that corresponds to each level.

For the operation and maintenance stage of a medium-sized geothermal power plant an organizational structure as shown in figure 9.1 is advised. Its levels are described as follows.

9.4.1 General Superintendency of the Plant

It has the function of directing and coordinating the technical and administrative tasks, and is responsible for the outcomes and good performance of the plant as a whole. It is the plant's highest authority, and is responsible for reporting and/or holding working relations with external organizations.

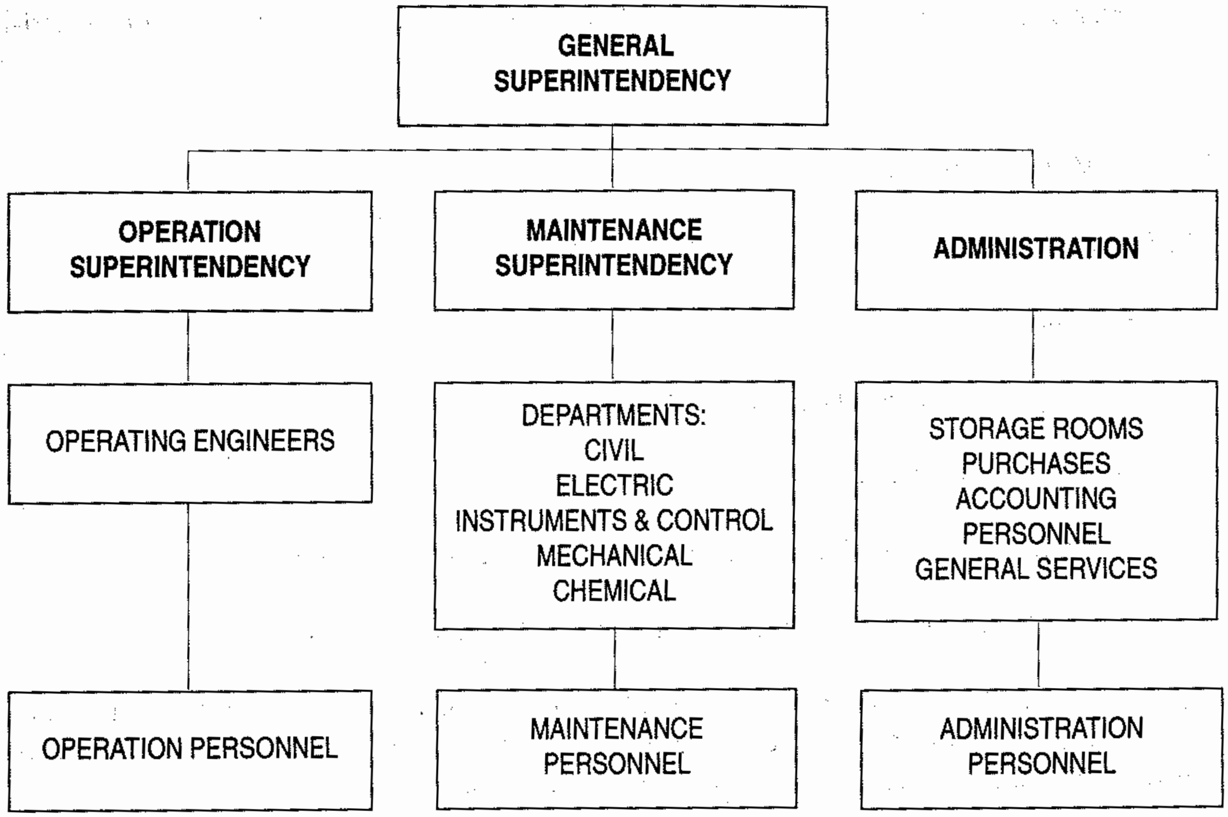

Figure 9.1 Organizational structure of a geothermoelectric plant

For better performance, this superintendency has two technical areas (operation and maintenance) and an administrative area.

9.4.2 Operation Superintendency

Its main functions are to:

- Plan the activities of this area.

- Develop the operation programs and procedures.

- Develop the operation records and controls.

- Coordinate and supervise the plant's operation.

- Assess the operation's outcomes and establish corrective actions.

This superintendency has the responsibility of keeping the plant operating continuously, efficiently and safely.

9.4.3 Maintenance Superintendency

The functions of this superintendency are the following:

- Plan the activities of this area.

- Develop the maintenance programs and procedures.

- Develop the maintenance records and controls.

- Coordinate and supervise the maintenance and repair tasks of the plant.

- Assess the maintenance's outcomes and establish corrective actions.

This superintendency has the responsibility of keeping the plant's facilities in good operating conditions by means of timely and adequate preventative and corrective maintenance activities that will ensure sustaining its operational characteristics.

It should have civil engineering, electric, instrumentation and control, mechanics and chemistry specialists to fulfil the maintenance needs in each one of these areas.

In important situations it may consult other manufacturers and jointly program and design improvements on the facilities.

9.4.4 Administration

This area has the purpose of providing administrative support to the technical areas in relation to storage, purchasing, accounting and costs, personnel and general services.

9.5 Materials and Equipments

It is of critical importance that the plant have a satisfactory stock of materials and replacements to cover operation and maintenance needs in a timely way.

The stock of replacements and spare parts that is needed is determined, in principle, by following the equipment manufacturers' recommendations and, secondly, by taking into consideration the plant's particular operating conditions and the difficulty of obtaining those parts.

In a geothermal power plant a wide variety of materials are used that should be classified and stored in such a manner that they can be found easily. Through the implementation of a computerized control system of storage rooms it is possible to keep updated information on stocks, consumption, costs, etc.

To optimize the use of resources a control system of maximum and minimal stock should be established based on the detection of needs of the users, the time for acquisition and economic repercussion. This system should be supported by the purchase department to replace the stock.

Replacement parts as well as other materials should be stored under suitable conditions to avoid deterioration and possible accidents.

The equipment needed to undertake the activities at this stage are the following:

- Office furniture and equipment.
- Computer equipment.
- Communication equipment.
- Laboratory equipment.
- Testing equipment.
- Workshop equipment.
- Cargo and handling equipment.
- Special tools.
- Maintenance tools.
- Transportation equipment.

9.6 Offices, Laboratories, Workshops and Transportation

The infrastructure required for the operation and maintenance stage of the plant should be foreseen in the project taking into account its projected final capacity, be it completed from the beginning or gradually by stages.

It is advisable that the operating personnel participate with the project staff in defining the needs of office space, laboratories, workshops, etc. with their respective equipments, based on the conceptual design of the project, the chosen equipment and both parties' experience in order to achieve maximum functionality.

The office and support service areas that should be considered are:

- Offices for the operating personnel.
- Administration offices.
- Rest rooms and dressing rooms.
- Dinning halls.
- Meeting room.
- Storage room for materials and replacement parts.
- Warehouse for maintenance tools and equipments.
- Storage room for paper and files.
- Storage place for cleaning utensils and supplies.
- Training halls.
- Security and hygiene office.
- Medical and care services.
- Guarding area.
- Parking lots.

Concerning laboratories and workshops, the following should be considered:

- Chemical laboratory.

- Instrument laboratory.
- Protection laboratory.
- Electric shop.
- Machinery and tools shop.
- Mechanic shop for major and minor pieces of equipment.
- Welding shop.
- Machinery and vehicle maintenance shop.
- Sand jet cleaning area.

Personnel transportation requirements are conditioned by the distance of the plant to the urban centers, and by the company's policies.

9.7 Personnel

9.7.1 Operating Personnel

The construction of a geothermal power plant poses the need of having personnel trained to operate and provide maintenance to its equipment. Operating personnel is special and should have specific technical preparation in accordance with the activities that are going to be undertaken and the particular equipment that has been installed.

To be able to determine the needs of operating personnel a detailed analysis should be carried out regarding the work that will be undertaken, identifying each of the activities, ordering and putting them into priority and establishing their frequency as well as the most convenient way of carrying them out.

A working unit or position is determined by all the activities that should be carried out by a single person. The number of workers should be equal to the number of positions identified.

Once all factors related with a position have been identified, a job profile or description can be developed, that is, the definition of the qualifications needed by the person who will hold the position. The job description sets the employee's functions and responsibilities, and should establish at least the following: knowledge level, practical experience, nature of the decisions that will be taken on the job, physical, visual and mental efforts that will be required, accountability for damages, management of materials, safety of others and one's own, environment, special conditions and contingencies.

The basic role of the operating personnel is to watch over and operate the equipments that take part in the process of generating and delivering electric power to the distribution network. Due to the nature itself of the operating function, the personnel should labor through continuous shifts if it is not and automated plant.

The main responsibilities of this personnel are to:

- Verify that the systems and equipments under their care operate normally, and carry out normal and emergency operations.

- Verify that the operating parameters are within established limits.

- Keep operating records.

- Communicate the operating conditions of the equipment under their care and any abnormality occurred during the shift.

- Comply with and watch that others comply with the established instructions and rules for the personnel and equipment's safety.

For safety reasons only the operating personnel is authorized to operate the equipments. Any other person that needs to work on a piece of equipment at the plant should procure a license or an expressed authorization issued by the person responsible for the operating shift.

Due to the special qualifications that the operating personnel should have, it is important to have carefully selected the candidates for each position.

For a worker to be able to fulfil his/her responsibilities satisfactorily, he/she should have the knowledge, ability and skills demanded by the job description. Since the specific knowledge that is required is not provided by the normal education system, it is necessary that the company develop its own training program.

Since this personnel will be in charge of keeping watch over the equipment and carrying out the operations from the very beginning of the plant's service, their hiring should be programmed beforehand so they will be ready when this stage begins.

The number of personnel required for its operation depends on the size of the units, the plant's total capacity and its level of automation. As an average, a single worker is needed for each 4 to 8 MW of installed capacity in medium-capacity plants and with a certain degree of automation.

Training of the personnel at all levels should continue during the whole operating life of the geothermal field, being supported by external consultants.

9.7.2 Maintenance Personnel

The role of the plant's maintenance department is that of carrying out all preservation activities required to keep the equipment at its best working conditions. Proper maintenance of any piece of equipment is the key to extending its lifetime and avoiding a failure.

The responsibilities of a maintenance team are:

- To plan the maintenance activities.
- To program the tasks.
- To develop budgets for materials and labor.
- To carry out and supervise the jobs.
- To keep record of the maintenance provided and assess it.

To achieve maximum efficiency of each worker it is necessary to establish:

- The working load generated by each facility.
- The most cost-effective working method.

The maintenance working load is comprised by:

- Repetitive tasks.
- Nonrepetitive tasks.

The load of repetitive tasks can be established based on the preventative maintenance program, while the nonrepetitive working load may only be estimated based on the history of previous maintenances or by an engineering evaluation.

Once the repetitive and nonrepetitive working loads have been determined, the working hours required for each position can be estimated.

It is important that the maintenance be carried out by qualified personnel that besides having the specific specialized knowledge also is familiar with the functioning of the equipment and its relationship with the system, its maintenance requirements and the correct way of performing it.

To be able to carry out a good maintenance job it is essential to have the information of the project on hand, such as drawings and specifications, as well as the installing, operation and maintenance instructions for the equipments.

For a good quality outcome the work needs to be competently supervised also.

When putting a maintenance team together, the possibility of hiring part of the work by contract should also be analyzed.

In new facilities it is advisable to begin work with a small working group and increase its size according to the increase of the permanent tasks that are needed. It should be taken into account that the working load will be greater at the beginning of the plant's operation and will gradually decrease with the adjustments that are made on each system until a stable operation is achieved. As an average, one maintenance worker will be needed for each 6 to 10 MW of installed capacity.

Training of the personnel at all levels should continue during the whole operating life of the geothermal field, being supported by external consultants.

9.8 Consultants

To accomplish better results of the activities carried out by the personnel, and with the purpose of complementing its training, it is desirable and advisable to have the support of external consultants for most of the more complicated activities such as efficiency and acceptation tests, improvements on facilities, repairs, maintenance and operation of equipments, as well as studies to adapt the plant to the changes that occur at the reservoir. A consulting period of up to one year after the plant service has began is advisable.

The consultants jointly with the plant's personnel should develop the procedures to carry out the main activities.

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