EPRI-AP--2162

DE82 902096

Direct Flash Steam Geothermal Power Plant Assessment

AP-2162
Research Project 1195-1

Final Report, January 1982
Work Completed, February 1981

Prepared by

ARIZONA PUBLIC SERVICE COMPANY
411 North Central Avenue
Phoenix, Arizona 85004

Project Manager
T. E. Alt

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE. It
has been reproduced from the best available
copy to permit the broadest possible avail-
ability.

Prepared for

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
E. E. Hughes

Geothermal Power Systems Program
Advanced Power Systems Division

REPRODUCTION OF THIS DOCUMENT IS UNLIMITED *EB*

ORDERING INFORMATION

Requests for copies of this report should be directed to Research Reports Center (RRC), Box 50490, Palo Alto, CA 94303, (415) 965-4081. There is no charge for reports requested by EPRI member utilities and affiliates, contributing nonmembers, U.S. utility associations, U.S. government agencies (federal, state, and local), media, and foreign organizations with which EPRI has an information exchange agreement. On request, RRC will send a catalog of EPRI reports.

~~Copyright © 1982 Electric Power Research Institute, Inc. All rights reserved.~~

NOTICE

This report was prepared by the organization(s) named below as an account of work sponsored by the Electric Power Research Institute, Inc. (EPRI). Neither EPRI, members of EPRI, the organization(s) named below, nor any person acting on behalf of any of them: (a) makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report or that such use may not infringe privately owned rights; or (b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

Prepared by
Arizona Public Service Company
Phoenix, Arizona

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

EPRI PERSPECTIVE

PROJECT DESCRIPTION

This project for RP1195-1 was an investigation of the direct flash geothermal power plant at Cerro Prieto, Mexico. At the time of the study, which was performed largely in 1979 and 1980, over five years of operating experience had accumulated on the first two units at Cerro Prieto, each unit having a 37.5-MW(e) turbogenerator set. The assessment of the plant and its operating experience was based on both published and unpublished data. The most important information was provided by staff members of the operating utility, Comision Federal de Electricidad (CFE), and its supporting research institute, Instituto de Investigaciones Electricas (IIE). Several visits were made to the plant, and discussions were held with technical personnel (engineers, operators, and technicians) from both CFE and IIE. From these discussions, from documents provided by CFE and IIE, and from published information on the plant, the project staff developed the description and assessment presented in this report. The investigation was conducted in Spanish as well as in English.

PROJECT OBJECTIVE

The objective of the project was to analyze the capacity and availability factors of an operating direct flash geothermal power plant. The analysis was to include consideration of system and component specifications, operating procedures, maintenance history, malfunctions, and outage rate.

PROJECT RESULTS

The assessment is based on data from the period 1973 to 1979--the time from the startup of the first unit of 37.5 MW(e) until the startup of the third and fourth units in 1979. For the five full years of operation (from 1974 through 1978), the Cerro Prieto plant had an installed capacity of 75 MW(e) provided by the two 37.5-MW(e) units placed in operation in 1973. During this five-year period, the overall capacity factor was 84%, with the annual factor rising from 70% in 1974 to 91% in 1978. Availability was 93% over the five-year period and was 95% during the last three years, 1976 through 1978.

The most important factors contributing to the achievement of the excellent capacity and availability factors appear to have been care in materials selection, good maintenance practices, and installation of a retrofit to the wellhead steam separators during 1976. This retrofit consisted of increasing the height of the steam outlet line in each of the bottom-outlet cyclone separators. This change increased the moisture removal efficiency of the separators enough to significantly decrease the rate of scale formation in the steam turbines. As a result, the time interval between shutdown for major maintenance could be increased from a one-year period to an 18-month or even a two-year period. This change also improved the capacity factor by decreasing or eliminating the decline in maximum generating capacity (derating) that had been associated with scale formation in the turbines during the first two or three years of operation. The scale was primarily silica.

In 1979, subsequent to the period of operation covered by this report, two new units of 37.5 MW(e) were added. Diversion of steam from Units 1 and 2 during startup of the new units broke the trend of increasing annual capacity factors. For 1979, the capacity factor for Units 1 and 2 was 81%. Cooling-tower reconstruction, following a fire and an earthquake, severely limited the capacity factor for Units 1 and 2 during 1980. Unit 2 was out of operation for about seven months and Unit 1 for about two months. The capacity factor that year for the entire 150-MW(e) plant was 70%.

Evan E. Hughes, Project Manager
Advanced Power Systems Division

ACKNOWLEDGMENTS

Arizona Public Service Company expresses appreciation to all who contributed the success of the project. Particular thanks are extended to personnel of the Comisión Federal de Electricidad, Instituto de Investigaciones Electricas, Pacific Gas and Electric Company, and Lawrence Berkeley Laboratory.

Sr. Ing. Héctor Alonso Espinosa
Sr. Ing. Samuel Paredes Zarate
Sr. Ing. Alfredo Mañón M.
Sr. Ing. Francisco Vital B.
C. P. Benjamín Villicaña Alvear
Sr. Ing. José Alberto Castañeda E.
Sr. Ing. Fernando Ledesma Haro
Sr. Ing. Celso Acosta G.
Sr. Ing. Jorge Guiza L.
Charles E. Franks, PE
Dr. Marcelo J. Lippmann

CONTENTS

<u>Section</u>	<u>Page</u>
1 INTRODUCTION	
Flashed Steam Plants and Hydrothermal Resources	1-1
Project Description	1-2
Brief History of Mexico's Geothermal Development	1-3
History of Cerro Prieto Geothermal Development	1-3
2 CERRO PRIETO RESERVOIR	
General Description	2-1
Well Completion and Development	2-1
Well Head Separators	2-4
Well Location	2-4
Well Control, Start-up and Shutdown	2-4
3 PIPELINE GATHERING SYSTEM	
Steam Pipeline	3-1
Pipeline Operation	3-3
Separated Water Drain System	3-4
Steam Dryers	3-4
Advanced Technology	3-5
Summary	3-5
4 POWER PLANT	
Schematic Description of the Power Plant	4-1
Power Plant Equipment Layout and Description	4-3
Steam Turbine	4-3
Generator	4-3
Turbogenerator Unit Auxiliaries	4-6
Station Control Room	4-6
Barometric Condenser	4-10
Non-Condensable Gas Ejectors	4-12
Cooling Towers	4-12
Flashed Steam Geothermal Power Plant Operation	4-12
Power Plant Staffing	4-15

<u>Section</u>	<u>Page</u>
5 PLANT AVAILABILITY	
Cerro Prieto - Electric Output	5-1
Cerro Prieto Unit Outages	5-1
Forced Outages	5-2
Programmed Outages	5-3
Power Plant Equipment Failures	5-3
Summary of Reliability and Availability	5-3
6 POWER PLANT MAINTENANCE	
Equipment Material Selection	6-1
Steam Turbine Generator	6-1
Turbine Inlet Valves	6-1
Turbine Nozzles and Blading	6-1
Steam Turbine Spare Rotor	6-2
Steam Turbine-Generator Lubricating Oil Coolers	6-2
Generator Hydrogen Coolers	6-2
Barometric Condensers	6-5
Steam Jet Ejectors	6-5
Non-Condensable Gas Atmospheric Discharge	6-6
Cooling Tower	6-6
Station Electrical Apparatus	6-6
Power Plant Maintenance	6-8
7 GEOTHERMAL EXPANSION PROGRAM	
Expansion of Cerro Prieto Region	7-1
Power Needs Beyond Baja California	7-2
8 BIBLIOGRAPHY	
Spanish and English Translation	8-1
Proceedings from the Second United Nations' Symposium on the Development and Use of Geothermal Resources, May 20-29, 1975	8-1
Publications of Lawrence Berkeley Laboratory	8-2
Open File Data Bank	8-3
Informes (Well Reports), Reservoir Engineering Data	8-3
Memorias (Well Reports), Well Drilling and Completion Data	8-3
Additional Publications on Cerro Prieto	8-4

ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
1.1 Location Map of the Cerro Prieto Geothermal Field	1-5
2.1 Wellhead Valve Tree	2-2
2.2 Webre Centrifugal Separator	2-5
2.3 Location of Wells in the Main Part of the Cerro Prieto Geothermal Field as of March 1978	2-6
2.4 Production Well with Remote Manual Operator	2-7
2.5 Production Well Valve Tree with Drain Line Silencer in Background	2-8
3.1 Vapor Pipeline Arrangement for Units 1, 2, 3 & 4	3-2
3.2 Cerro Prieto Production Well Installation	3-6
3.3 Separated Liquid Drain Lines	3-7
3.4 Separated Liquid Drain Discharging into Evaporation Lagoon	3-8
3.5 Branch Lines at Power Plant	3-9
3.6 Branch Lines, Collection Header, Secondary Dryers	3-10
3.7 Collection Header and Dryers for Units 1 & 2	3-11
4.1 Flow Diagram Geothermal Flash Steam Power Plant	4-2
4.2 Plan View of Units 1 & 2 at Cerro Prieto	4-4
4.3 Elevation View of Units 1 & 2 at Cerro Prieto	4-5
4.4 Turbine-Generator Control Board	4-7
4.5 Turbine-Generator Control Board	4-8
4.6 Plan Area General Arrangement for Units 1 & 2 at Cerro Prieto 1978	4-9
4.7 Direct Contact Barometric Condensers	4-11
4.8 View of Cerro Prieto Power Plant	4-14

<u>Figure</u>	<u>Page</u>
6.1 Cerro Prieto Turbine House Floor with Spare Rotor Stored in Front of Unit No. 2	6-3
6.2 Front Standard Cerro Prieto Turbine Generator	6-4
6.3 Barometric Condenser for Units 1 & 2 Showing Non-condensable Gas Atmospheric Discharge	6-7
6.4 View of Steam Inlet to Power Plant, Cerro Prieto "Dark Hill" in Background	6-10
6.5 Steam Turbine Exhaust Duct to Barometric Condenser	6-11
6.6 Coolwater Supply Pump to Barometric Condenser	6-12
6.7 Barometric Condenser	6-13
7.1 Areas of Geothermal Development in Cerro Prieto Region	7-3

TABLES

<u>Table</u>	<u>Page</u>
2-1 Casings Installed for Geothermal Wells	2-3
3-1 Pipeline Dimensions	3-1
5-1 Gross Generation Unit No. 1 and Unit No. 2	5-1
5-2 Outages Forced or Programmed	5-2
5-3 Electricity Production From Cerro Prieto Unit No. 1 and Unit No. 2	5-4
6-1 Operating Hours, Major Maintenance Schedule, Downtime	6-9
7-1 Geothermal Expansion Program	7-1
7-2 Planned Well Expansion	7-2

Aerial View of 150,000 KW(e) Cerro Prieto Flash Steam Geothermal Power Plant; Evaporation Lagoon Upper Right Background; Switchyard And Transmission Line Foreground, Pipeline Supplying Steam Seen At The Right

Source: CFE

Cerro Prieto Power Plant, August 1979

Source: CFE/APS

Cerro Prieto Power Plant, View Of Switchyard Side

Source: CFE

SUMMARY

Introduction

Geothermal power generation can be a significant national energy resource in the United States only if the liquid-dominated (rather than dry steam or vapor-dominated) hydrothermal resources are developed for commercial power plants. The first such plants in the U.S. were put into experimental operation during 1980. In order to provide the U.S. utility industry with a description and an evaluation of an existing hydrothermal power plant with significant operating history, the Electric Power Research Institute (EPRI) awarded a contract to Arizona Public Service Company (APS) to perform an assessment of a direct flash geothermal power plant. The plant selected for this investigation was the 75 MW(e) commercial power plant at Cerro Prieto, near Mexicali in Baja California, Mexico.

Objective

The project objective was to assess the operation and maintenance of a direct flash geothermal power plant based on actual operating experience. Specific objectives of the project included description of the plant and supporting geothermal field, characterization of the equipment and the operating experience with that equipment, documentation of the operating utility's procedure and experience in maintaining the plant, and an overall evaluation of the plant's reliability.

Approach

In order to characterize and assess the Cerro Prieto plant, a literature search was performed, and several visits to the plant site were made. The literature search revealed a substantial amount of published data on the Cerro Prieto reservoir and well systems. Several papers, presented at conferences and symposia, capably set forth information about the reservoir and the wells. The technical literature search uncovered little information on Mexico's geothermal power plant, compared to that available on the Cerro Prieto reservoir and wells. Interviews with key personnel of the operating utility, the Comision Federal de Electricidad (CFE), provided information on specific aspects of plant equipment and on the operating and maintenance experience with that equipment.

Resource Description

The Cerro Prieto hydrothermal reservoir has well-bottom temperatures from 250-340°C (482-644°F). It produces a 165°C (329°F) liquid and vapor mixture flow at the wellhead, about 20% steam and 80% liquid. The two-phase flow is separated into liquid and steam flows in a bottom outlet cyclone separator vessel at each wellhead. Flashed steam separated from the two-phase mixture contains about 1% by weight non-condensable gases, principally carbon dioxide and hydrogen sulfide. A typical chemical analysis of the separated flashed steam sent to the power plant is listed below:

Separated Liquid Sent to Drains (Well M-5)

	(ppm)		(ppm)
Na	9062	Cl	16045
K	2287	Br	31
Li	38	F	2
Ca	520	SO ₄	6
Mg	1	CO ₃	2
B	14	HCO ₃	74
SiO ₂	1250		
Fe	0.3	pH	7.7
NaCl	26442	Cond.	32200 mmhos

Steam to Plant (Well M-8)

	(ppm)
CO ₂	13000
H ₂ S	1300
NH ₃	120
Cl	16
Na	8.4
K	2.4
Ca	0.8
Mg	0.1
B	0.2
SiO ₂	1.1

Plant Description

The plant consists of two 37.5 MW(e) single inlet steam turbine-generator units and the associated steam supply, heat rejection, cooling and electrical systems. Each 37.5 MW(e) turbine, supplied by Tokyo Shibaura Electric Company (Toshiba), is rated as follows: rotation speed 3600 rpm, steam inlet pressure 5.3 kg/cm² (75 psia); steam inlet temperature 160°C (320°F), steam inlet flow 285,450 kg/hr (629,310 lb/h), exhaust pressure 89 mm Hg absolute (3.5 in. Hg absolute).

The electric generator close-coupled to the turbine was also supplied by Toshiba. The nameplate rating is 44 200 kva, 13800 volt, 60 hz, and 0.85 power factor. Each machine is hydrogen cooled at 2.0 kg/cm² (28.5 psi) pressure, with static self exciter with automatic voltage regulator. The stator is star connected with class B insulation code ASA-C50.

The auxiliary equipment supplied with each turbine generator is similar to that furnished to low pressure steam turbines in fossil fuel plants. The components are automatic steam seal system, main oil pump on shaft, A/C turning gear oil pump, turning gear, lubricating oil reservoir, two oil coolers, and front standard speed governor. The electric generator has a hydrogen seal system complete with oil pumps and gas vacuum pumps.

Electric output from each generator is conducted by enclosed fan cooled bus bars to the main step up transformer. Each main transformer is rated 41 MVA, 161 kV/13.8 kV, 60 hz, with star/delta connection. Power from the main transformer is sent to the switchyard, then to the Mexicali transmission line.

The plant has a barometric condenser built by Toshiba. This direct contact condenser is a vertical shell cylinder with spray nozzles and trays located in the upper part of the shell. The cooling water inlet design temperature is 32°C (90°F) and the cooling water flow is 10,710 tons per hour for each unit.

The cooling tower for Units 1 and 2 is a 12-cell design with standard cross flow and was supplied by Marley de Mexico. The condensed steam, mixed with the circulating water sprayed into the barometric condenser, flows from the tail pipe by gravity, through the covered hot water canal, to the hot water pump suction basin. Two 6950 m³/h (30,000 gpm) pumps raise the hot water to the top of the cooling tower.

Comparison to Other Types of Power Plants

Electric utility personnel accustomed to operating fossil fuel electric plants find the comparable operation of this geothermal steam plant relatively simple. Some comparisons to other types of plants are as follows:

- The equipment for the geothermal plant is similar to a fossil fuel plant in appearance, function, performance, and maintenance, e.g., steam piping, turbo-generator, circulating water system, cooling tower, instrumentation, air-ejectors, and condenser.
- The principal operating and maintenance difficulties associated with fossil fuel steam plants, involve the fuel handling, ash handling, combustion, and feedwater systems. The absence of these systems in the geothermal facility minimizes problems of steam supply to the turbine-generator compared to fossil fuel plants.
- Multiple wells, supplying steam to the geothermal plant, compared to a single boiler steam supply to the fossil fuel plant, are an advantage. Failure of a well may partially reduce the power output of a geothermal plant, if at all. However, failure of a pressure

part in the single boiler would usually require shutdown of the boiler and turbo generator unit in a fossil fuel steam plant.

- A flash steam geothermal plant and a hydroelectric plant are similar in their ease of operation. Both types of plant conduct the working fluid through a prime mover turbine; both obtain an energy supply from a large reservoir; both base load the generating units consistent with system electrical demand and reservoir ability to supply energy.

Reliability and Availability

During the five full years of operation of Units 1 and 2 at Cerro Prieto, from 1974 through 1978, the plant produced 2.75 billion kilowatt-hours (2750 GWh) of electricity. Taking the ratio of this production to the maximum production possible gives 0.84 as the overall capacity factor for those years. A year-by-year accounting of the plant production and losses from maximum possible production is as follows:

<u>Year</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>Total</u>
<u>Nameplate^a (GWh)</u>	657.0	657.0	657.0	657.0	657.0	3285.0
<u>Production (GWh)^b</u>	463.0	518.0	579.0	592.0	598.0	2750.0
<u>Losses (GWh)</u>						
Forced Outage	0.80	2.20	0.75	-0-	-0-	3.75
Scheduled Outage	2.11	4.11	1.95	1.12	1.24	10.53
Annual Maintenance	76.5	56.7	26.1	31.5	35.1	225.9
Unaccounted ^c	114.59	75.99	49.2	32.38	22.66	294.82
<u>Capacity Factor^d</u>	0.70	0.79	0.88	0.90	0.91	0.84
<u>Availability Factor^e</u>	0.88	0.90	0.96	0.95	0.95	0.93

^aNameplate GWh or maximum possible annual plant output is nameplate rating, 75 MW(e), multiplied by 8760 hours per year.

^bRead from totalizer meter at each unit.

^cIncludes effects of (1) decreased capacity of turbine due to scale formation, (2) demand limitations, and (3) lack of full steam supply.

^dCapacity factor is production GWh divided by nameplate GWh (i.e., $2750/3285 = 0.84$).

^eAvailability factor is approximated as 1.00 minus the ratio of forced, scheduled, and maintenance outage losses (GWh) to the nameplate (GWh), (i.e., 1.00 minus ratio of 240.18 divided by 3285 is 0.93).

The above data indicate that outages have not been a significant factor in reducing the availability of the plant. The actual number of outages could not be determined from the data supplied by CFE. None of the forced outages, i.e., the trips or unscheduled outages, was due to the plant's geothermal features. All of the forced outages were caused by electrical failures, most of them in the switchyard rather than in the plant. The major maintenance work now being scheduled at intervals of 18 or 24 months, has been the major source of lost availability and has been effective in keeping other outages at a low level.

Materials

CFE conducted approximately 1,000 tests on candidate materials for the critical parts of the plant, in order to select materials compatible with the vapor and liquid characteristics of the Cerro Prieto reservoir. Samples were exposed to geothermal steam and condensate for a period of 150 days. Most of the material selected has proved satisfactory. Some exceptions and the CFE actions to correct problems are named below in the description of operation and maintenance at the plant.

Steam and brine pipelines and valves in the production field are carbon steel. The only problems due to the geothermal operating environment in the production field have been due to scale formation rather than corrosion of the steel. Insulation on the exterior of the steam pipelines is being changed from magnesia block to a fiberglass material, due to the latter's greater resistance to H_2S corrosion as well as its lower cost.

The turbine rotors are fabricated from 1 Cr-1.25 Mo-0.25 V alloy steel forgings. The turbine blades are machined from 12 Cr alloy steel and are enclosed with a shroud band hand-riveted on the outer edges of the blades. The blades of the 6th row are fitted with stellite erosion shields and lashing wire. The nozzle partitions are of 12 Cr-0.2 Al alloy steel, and the stage labyrinth strips are of 15 Cr-1.7 Mo alloy steel. The outer and inner casings are made of carbon steel ASTM specification ASTM-A285. A spare turbine rotor, purchased as a backup at the time of turbine procurement, stands in the turbine hall at the plant. It has not been needed.

The condenser shell is of low carbon steel with an epoxy resin overlay. The condenser trays are stainless steel, SS-AISI/304L. The cooling tower structural members are AISI 4140 steel and the packing is redwood and fiberglass.

Operation and Maintenance

Maintenance to counteract corrosion has been a regular procedure and some corrosion problems have been solved by replacement with different materials. In liquid streams, exposure to condensate made corrosive by the CO_2 and H_2S gases in the steam has been a problem in aluminum tubes, carbon steel pipes, and concrete canals. These problems have been solved by the replacement of aluminum tubes by titanium or stainless steel tubes and by regular annual maintenance procedures. These procedures include repairing and recoating concrete canals and recoating carbon steel condenser parts with epoxy resin.

Carbon steel diffuser tubes in the gas ejectors were replaced by stainless steel after discovery of pinhole leaks caused by the corrosive gases being ejected from the condenser. Air-tight rooms, air conditioning, including activated carbon filtering, and use of aluminum cladding on exposed copper bus work have prevented H_2S corrosion of electrical wiring and connections. The air conditioning system includes activated carbon filters filled with impregnated potassium permanganate beads.

Major overall maintenance took place annually until 1976 and has been scheduled at longer intervals since then: 18 months or two years. The longer interval between major overhaul was made possible by an improvement in the wellhead steam separator that resulted in less moisture carryover into the turbines and much less need to clean scale from the first stage nozzles and blading of the turbines. This is the single most significant factor leading to the increased capacity and availability factors for 1976 through 1978. The scale formed in the turbines is primarily silica. The improvement was achieved by increasing the height of the steam outlet line coming down through the center of each wellhead separator. This change decreased the amount of liquid (containing dissolved silica) carried with the steam into the pipelines that supply steam to the turbines.

Maintenance to counteract scale formation has also included daily operation of the main turbine inlet valves, which are swing check type for quick closing as the stop valves. Frequent blowdown of the cooling tower controls the concentration of materials dissolved in the steam condensate. The cooling tower is monitored and repaired to correct problems of scaling and corrosion that impair performance and structural integrity.

Conclusion

The single-stage direct flash geothermal power plant at Cerro Prieto has an excellent capacity factor, 84 percent, sustained over the five-year period 1974-1978. The major causes for lost generating capacity have been downtime for major scheduled maintenance and decreased power output due to scale formation in the turbines. Improvement in steam separation at the wellheads in the production field has decreased both these losses of generating capacity. This has enabled the plant to achieve annual factors of 95 percent availability and 90 percent capacity.

Section 1

INTRODUCTION

Flashed Steam Plants and Hydrothermal Resources

The technology for flashed steam geothermal power plants has been well established in Mexico, New Zealand, El Salvador and Japan, producing more than 500 MW(e) in those countries. However, development of flashed steam geothermal systems has lagged in the United States, in part due to the lack of information on the reliability of these types of power plant. U. S. utilities have expressed the view that operational, reliability and maintenance data from one or more of the flashed steam power plants now in operation in other countries would be beneficial in assessing their own position relative to financial commitments to geothermal power extracted from hydrothermal (liquid dominated) systems.

Most of the known geothermal fields are of the hydrothermal type, producing a mixture of hot brines and steam. Despite the large quantity of available heat in hydrothermal resources, virtually all geothermal electric power in the United States at the present time is generated from vapor dominated systems. The production of geothermal electric power from hydrothermal (liquid dominated) reservoirs may be technically more difficult than from dry steam fields for the following reasons:

- Larger masses of fluids must be extracted to generate the same amount of electrical energy.
- Corrosion of well casing and surface piping may be greater compared to vapor-dominated areas.
- Deposition of minerals (scaling) from the brines may be greater in hydrothermal systems.

A number of high and moderate temperature hydrothermal systems being developed for electric power production in the United States are located in the Imperial Valley of California. Cerro Prieto, Baja California, Mexico, is within the same geologic province (Salton Sea - Sea of Cortez Trough) as the Imperial Valley.

An agency of the Republic of Mexico, the Comision Federal de Electricidad (CFE) began exploration efforts in the Mexicali region in 1959. Detailed geological and geophysical surveys undertaken during the years between 1962-1967 gave promising

results. This led to a decision to drill 14 production wells for supplying the Cerro Prieto geothermal power plant. Design and construction of the 75,000 kW(e) power plant began in 1969 with commercial operation of the flashed-steam geothermal power plant starting in 1973.

Project Description

In order to provide the U.S. utility industry with a description and evaluation of an existing hydrothermal power plant with a significant operating history, the Electric Power Research Institute (EPRI) awarded a contract to Arizona Public Service Company (APS) to perform an assessment of a direct flash geothermal power plant. The study was performed during 1979 and 1980.

The close proximity of the Cerro Prieto power plant to the Mexico-United States border, the level of activity in utilizing the hydrothermal reservoir for electric power production, plus the vast amount of reservoir information obtained by Mexican engineers, indicated to the contractor, APS, that the CFE Cerro Prieto project would be an ideal subject for the study called for by the contract. EPRI agreed with this choice.

The APS search for published material relating to the Cerro Prieto geothermal reservoir and plant showed many publications which are listed in the bibliography. Two publications provided the major part of the reservoir, well, and pipeline information contained in this report.

- The three volume proceedings of the "Second United Nations Symposium on the Development and Use of Geothermal Resources" contains eleven papers about Cerro Prieto.
- "Proceedings of the First Symposium on the Cerro Prieto Geothermal Field" sponsored by CFE and DOE. This volume of 450 pages contains 37 papers on Cerro Prieto with topics of Geology, Geochemistry, Subsidence, Geophysics, Reservoir Engineering and Reinjection.

The literature search revealed ample information on the reservoir, wells, and pipeline gathering system. However, there was very little written about the operation and maintenance of the power plant which is of major interest to the electric utilities.

APS made arrangements with the CFE Executive Coordinator at Cerro Prieto for visits to the geothermal plant to observe operation and maintenance activities and procedures. Several trips were made to Cerro Prieto for talks with key CFE personnel, and information obtained at the power plant is presented in Section 4 and 5 of this report.

Brief History of Mexico's Geothermal Development

In 1949 and 1950, the Comision Federal de Electricidad (CFE) sent a group of engineers and technicians to visit geothermal fields in Larderello, Italy. The CFE was interested in the possibility of extracting energy from the numerous geothermal manifestations throughout the Republic of Mexico and sought to acquire experience from the successful Italian operation. An inventory of Mexican geothermal sources was initiated as a result of that mission.

Special emphasis was placed on the Pathe area, in the state of Hidalgo, 120 km north of Mexico City. Surficial geological studies were carried out in this area; gradient wells were drilled and chemical analyses of the geothermal manifestations were performed. The first exploratory well was drilled between 1955 and 1956. This exploration well marked the beginning of geothermal technology development in Mexico. In 1959, a 3,500 kW(e) experimental unit was installed and operated for a period of 14 years. This unit was dismantled because the plant output decreased to a point where it was less than 500 kW(e).

The results obtained in Pathe encouraged geothermal exploration in other parts of the country. The geothermal field of Ixtlan de Los Hervores, in the state of Michoacan, was opened in 1956. Two wells were drilled with one of them producing hot water and steam to this date. Geothermal exploration undertaken in Los Negritos, Jalisco, is giving positive results. Exploration work began in the Cerro Prieto, Baja California, early in 1959.

History of Cerro Prieto Geothermal Development

From the geological surveys and chemical analysis at Cerro Prieto, in 1959 an exploratory well was drilled producing a water-steam mixture. Two more wells were drilled at a later date: one to 700 meters depth and the other to 450 meters depth. Promising temperatures were observed in both. As a result of this, a program of detailed geological, geochemical, and geophysical studies began in 1962. Subsequent to these studies, the first of four deep wells, M-3, was sited in 1964 and drilled to a depth of 2,500 meters. This well penetrated the granitic basement rock with some minor steam-liquid production at a depth between 700 and 900 meters.

Well M-4, about 18 km north of Well M-3, was drilled at a later date in an attempt to intercept an important fault. Well M-4 reached a depth of 2,000 meters, but with a disappointing bottomhole temperature. Well M-5, which is 2.5 km south of M-3, marked the discovery of the Cerro Prieto field with excellent production characteristics.

During the period 1966-1969, the CFE decided to drill 14 wells in order to supply geothermal steam to the first power plant. The plant would initially consist of two units, each rated at 37,500 kW(e). Power plant construction began in 1969. The units were placed in commercial operation in 1973 and have continued working satisfactorily since then with the plant factor increasing above 90%.

During the construction, design, and operation of the initial units, additional geophysical studies were carried out to the south and east of the present field. At the time, it appeared that the geological structure of the field is made up of a series of parallel faults. Based on this, it was decided to drill outside the initial production area. Well M-53, drilled to a depth of 2,000 meters, proved to have a production of about 100 tons per hour of steam and a bottomhole temperature of 340°C. This well, combined with Well M-51, situated to the south of the present field, expanded the possibilities of Cerro Prieto.

The new group of wells, some 14 in number and drilled in 1977-1978, lie east and south of the present field Figure 1.1. These wells have a greater energy potential than the wells supplying Units 1 and 2. The majority of the new group have bottomhole temperatures between 300 and 350 C and produce 80-140 tons of steam per hour per well.

Two additional generating units began operation in 1979 which added 75,000 kW(e) to the station output for a total of 150,000 kW(e).

Based on reservoir information acquired in 1977, the CFE decided to begin drilling wells in the eastern part of the present field to supply another power complex which will be called Cerro Prieto II. This power plant will be supplied initially by 26 wells. The construction of Cerro Prieto II is scheduled to begin in 1981. Commercial operation of the first unit is planned for 1983 and the second in 1985. There will be four units of 55,000 kW(e) each, for a total CP II plant output of 220,000 kW(e).

The CFE has begun geological gravimetric, magnetic and electrical resistivity studies north and south of the present field. In the southern portion, about 17 km from the present field, there have been interesting resistivity anomalies, which if productive, could extend the energy possibilities of the Cerro Prieto field.

Some thermal gradient wells have been drilled in the area called Tule Check, approximately 40-50 km southeast of the Cerro Prieto field. The information to date

Figure 1.1 Location Map Of The Cerro Prieto Geothermal Field

Source: CFE

is scarce, but irrigation wells drilled in the same region have temperatures of around 50⁰C for depths of 100-150 meters.

Section 2

CERRO PRIETO RESERVOIR

General Description

The Cerro Prieto geothermal field presents hydrothermal surface manifestations in an area of about 30 km². The production zone located in this region has more than 50 deep wells drilled to a depth ranging from 700 - 2,000 m (2296-6561 ft.) with bottomhole temperatures of 250 - 340 C (482-644 F). The maximum well head pressure noted to date is 90 kg/cm² (1280 psi).

The geothermal fluid as it ascends through the production well casing to the well head partially flashes into vapor. The two phase mixture, 20 percent vapor, 80 percent liquid (by weight), flows from the well head valve system (Christmas tree) shown in Figure 2.1, to a centrifugal Webre type gas-liquid separator.

The vapor separated from the mixture is discharged to the steam pipeline gathering system. The liquid from the mixture flows to a silencer. Drains from the silencer are conducted through the drainline system of trenches, canals and closed pipes to the evaporating ponds.

Production from the wells varies between 20 to 80 tons per hour of vapor. The number of reservoir wells to supply steam to the power plant is determined by the CFE power plant operators and CFE Coordinator for the resource on the basis that the average flow from one well is equivalent to 5 Mw(e).

Well Completion and Development

More than 55 wells have been drilled in the Cerro Prieto field in depths for a total linear distance exceeding 80 km. Well drilling activities span almost 19 years with six stages of geothermal well development.

General comments on the completion of the various wells drilled in each stage plus modifications in developing the wells are presented in several reservoir engineering papers. We direct your attention to the Spanish and English text of "Well Completion and Development at Cerro Prieto" plus "Physical and Thermodynamic Changes Observed in the Cerro Prieto Geothermal Reservoir".

Figure 2.1 Wellhead Valve Tree

Source: CFE

The information in these papers include:

- technical data on drilling and well completion
- tube profiles of 53 wells
- well casing details
- well repair details
- well logs of several wells
- evolution of Christmas tree well heads
- variations in production well characteristics

The published information on file at the CFE or Lawrence Berkeley Laboratory (LBL) is the most extensive documentation available to anyone interested in the Cerro Prieto reservoir. The CFE and LBL intend to update the information on an annual basis.

Table No. 2-1 gives general information about the reservoir well dimensions.

Table No. 2-1

CASINGS INSTALLED FOR GEOTHERMAL WELLS

Diameter cm (in)	Depth	
	Exploration m	Production m
50.8 (20)	0 - 50 (C)	0 - 20 (C)
34.0 (13 3/8)	50 - 1000 (A)	20 - 300 (S)
24.4 (9 5/8)	1000 - 2500 (P)	300 - 1000 (I)
		1000 - 3000 (P)

Casing Type: (C) Conducting, (A) Anchor, (P) Production
(S) Surface/Anchor, (I) Immediate

Well Head Separators

Webre centrifugal separators are installed at each well head. The quality of the steam leaving each separator is monitored by noting the liquid level in the "integral water tank" shown in Figure 2.2. The level is controlled by orifices installed in the water outlet flow lines. During operation of the well, liquid level is held at the mid point of the indicator which signifies that the separated liquid is flowing to drain and the vapor leaving the Webre is relatively dry.

This indirect method of monitoring the vapor quality has not been entirely satisfactory. There has been brine carryover in the steam to the turbine nozzles and blading. The scaling from solids in the liquid can cause a reduction in unit output by closing the turbine flow passages. This blockage was corrected by cleaning out the turbine nozzles once a year during the annual internal inspection.

CFE personnel took action to improve the quality of steam leaving the separators. The internal vapor lines of the separators were modified by extending the length of the vapor line. This extension improved the separation process and the output quality of the steam which in turn resulted in cleaner nozzles and blading. The load reduction was removed and finding cleaner turbine internals during overhauls prompted the CFE to extend the time between overhauls from 8,000 to 12,000 then 16,000 hours.

Steam quality monitors at each well head could give a more positive indication of quality. However, monitors are expensive and the CFE opted for annual overhaul cleaning instead of installing costly instrumentation. Continuous steam quality monitoring is being evaluated for the new units planned for Cerro Prieto II.

Well Location

Location of wells in the main part of the Cerro Prieto geothermal field as of March 1978, is shown on Figure 2.3.

Well Control, Start-Up and Shutdown

All control valves on the well head are operated manually as shown in Figures 2.4 and 2.5.

Figure 2.2 Webre Centrifugal Separator
Source: CFE

Figure 2.3 Location Of Wells In the Main Part Of The Cerro Prieto Geothermal Field as of March 1978

Source: CFE

Figure 2.4 Production Well With Remote Manual Operator
Source: CFE

Figure 2.5 Production Well Valve Tree With Drain Line Silencer In Background
Source: CFE

Section 3

PIPELINE GATHERING SYSTEM

Steam Pipeline

The network of steel piping that conveys vapor from the wells to the power plant is illustrated in Figure 3.1. The design concept, as originally planned, was to connect several wells to a branch line leading on to the power plant. For Unit No's. 1 and 2, the reservoir wells are grouped in four branches which connect to the power plant. The diameters of the piping that connects the wells to the branch lines vary in size from 30 cm (12 in.) to 41 cm (16 in.). On an average, five wells are connected to each branch.

The four pipeline branches as they extend from each group of wells to the power plant, vary in size from 46 cm (18 in.) up to 86 cm (34 in.). The increase is to accommodate additional flow as wells are added to the branch. Table No. 3-1 displays dimensions of the pipelines installed at Cerro Prieto to convey vapor from the well separators to the power plant.

Table No. 3-1
PIPELINE DIMENSIONS

Diameter	Lengths	
	Units 1 & 2	Units 3 & 4
cm (in)	m	m
30.48 (12)	1456	1278
40.64 (16)	4206	1278
45.72 (18)	2429	3329
48.26 (20)	136	1228
60.96 (24)	560	498
66.04 (26)	584	970
76.20 (30)	1236	1930
81.28 (32)	-	1926
86.34 (34)	1896	-
Total	10607	12437

Figure 3.1 Vapor Pipeline Arrangement For Units 1, 2, 3 & 4
Source: CFE

Pipeline Operation

The operation of the pipeline gathering system is simple and relatively free of maintenance. APS found no history of pipeline difficulties during talks with the CFE power plant operators or the CFE Cerro Prieto Coordinator group that is responsible for the reservoir.

Management of the Cerro Prieto facility is a joint function of the CFE Operations Department and the CFE Executive Coordinator for Cerro Prieto. The Coordinator is responsible for procurement, construction, operation, and maintenance of the reservoir wells. The CFE Coordinator estimates the number of wells needed to furnish steam to the power plant. The Coordinator makes sure the wells are drilled, casings installed, wells blown clear, and available for service.

The CFE Operations Department advises the Coordinator about the power plant's steam requirements so that sufficient production wells are made available to deliver steam to the plant.

When the wells and pipeline are in operation sending steam to the power plant, the only flow control available to the power plant personnel are remote operated pressure relief blow-off valves in the pipeline. These electric motor operated valves are opened in the event that a turbine trip occurs to avoid over pressure of the pipeline. However, with the valves open vapor escapes to the atmosphere and steam continues to flow from the wells. This can be a substantial loss of energy.

The power plant operators notify the CFE personnel responsible for the reservoir operation if the turbine shutdown will be of long duration. The Coordinator group can close the wells to a standby production status. A small flow of steam (5-10% of full flow) from the well will keep the production casing close to normal operating temperature during the standby, to avoid extreme thermal stress in the casing. During total shutdown of a well, the cooling and contraction of the well casing has resulted in some instances of casing fractures.

Once placed in operation, the branch pipeline remains continuous in service flowing steam and under pressure. Although the well steam may contain minute amounts of grit plus dissolved chemicals, the annual maintenance examinations show few scale deposits. These deposits are considered to be of no consequence because flow through the line is not restricted and the scale is easily removed during the annual overhaul.

The original thermal insulation on the exterior of the steam pipelines was magnesia block. Sections of this insulation are being replaced with a fiber glass material which has a cost advantage compared to magnesia block, requires less labor to install, and is more resistant to damage from H_2S corrosion.

Separated Water Drain System

The major difficulties encountered in the field piping at Cerro Prieto concerns the drain conduits from the well head separators out to the evaporation lagoons. The chemicals suspended in the separated liquid precipitate and deposit in the drain lines. This may result in plugging or stoppages in the drain conduits so that the conduit lines require frequent mechanical cleaning or possible replacement. Two classes of drain conduit lines are used at Cerro Prieto, open or closed.

The CFE prefers closed piping systems for drains to the evaporation lagoon rather than open canals or trenches. The hot brine liquid in the open canals partially flash to vapor. This lowers the temperature of the brine and the salt saturated water deposits scale. The scale or deposited chemicals require frequent maintenance cleaning of the canals.

The brine in closed conduits maintains a higher pressure and temperature than in open canals, with very little flashing. The rate of scaling in the closed system is much less relative to the open system. This permits longer operating intervals between cleanings which is a principal reason for the CFE preference of a closed drain system.

Steam Dryers

Steam from the four branch pipelines is collected in two headers. These headers have secondary separators or dryers to remove condensate that may have formed in the branch lines. The internal baffles in the dryers have suffered structural failure and collapsed. Efforts to reinforce the internal baffles have not met with success. However, since CFE testing indicates that the steam quality to the turbine is acceptable, dryers remain as originally installed, but without the baffle internals in the shell.

Well head separators and pipeline dryers were built by SWECOMEX, SA. The manufacturer is continuing an investigation of the internal baffle failure but to date there has been no suggestion toward remedial action. The CFE with assistance of the IIE are studying alternative methods of steam condensate separation.

Advanced Technology

There has been some preliminary study of two-phase flow in pipelines extending a distance of more than 1 km. We understand the results are encouraging and indicate a subject of investigation that can benefit design consideration for additions to the power plant. Two-phase flow would convey a greater mass flow in a new pipeline similar to the existing system. This improvement would reduce the material and capital cost for the next pipeline installation.

Summary

The vapor and liquid pipeline systems are relatively simple to operate. Once the both systems are placed in service the only problems seem to be in the liquid drain lines. The only moving parts involve valving. The vapor blow off valves are used to protect the pipeline if a turbine trips, but that operation is infrequent. The operating history shows good availability for the pipelines.

Figure 3.2 shows a production well installation including the well head valve tree, Webre centrifugal separator, twin silencers, vapor branch line, and separated liquid drain piping.

Figures 3.3 and 3.4 show the separated liquid drain lines extending from the power plant area to the evaporating lagoon area.

Figures 3.5, 3.6, and 3.7 show the pipeline branches connected to secondary dryers and power plant steam inlet header.

Figure 3.2 Cerro Prieto Production Well Installation

Source: CFE

Figure 3.3 Separated Liquid Drain Lines
Source: CFE

Figure 3.4 Separated Liquid Drains Discharging Into Evaporation Lagoon

Source: CFE

Figure 3.5 Branch Lines At Power Plant
Source: CFE

Figure 3.6 Branch Lines, Collection Header, Secondary Dryers
Source: CFE

Figure 3.7 Collection Header And Dryers For Unit 1 & 2

Source: CFE

Section 4

POWER PLANT

Schematic Description of the Power Plant

Figure 4.1 is the schematic flow diagram for a geothermal power plant showing a single turbine close coupled to the electric generator. Steam gathered from the production wells passes through a dryer or secondary vapor/liquid separator before being admitted into the steam turbine.

The turbine double flow exhaust passes into a direct contact barometric condenser. Cool water is sprayed into the exhaust steam in the condenser shell. The vapor after transferring heat to the cool water is condensed. The mixture flows by gravity to the sump of the hot water pumps adjacent to the cooling tower.

The hot water mixture is distributed atop the cooling tower. Within the tower some water evaporation occurs as heat is rejected to the atmosphere. Cooled water falls into the tower basin and is conveyed by canals to the cold water pumps. The pumps raise the cool water to the top of the barometric condenser for direct mixing with the turbine exhaust, thus completing the flow path of the circulating water system.

Water lost from the circulating water cycle by evaporation in the cooling tower is replenished by condensed vapor from the turbine exhaust. This addition to the cooling water mass balance enables the power plant personnel to operate the Cerro Prieto units without external makeup.

Non-condensable gases in the turbine exhaust steam are removed from the barometric condenser by two stage steam jet ejectors. The gases are discharged to the atmosphere.

Figure 4.1 Flow Diagram Geothermal Flash Steam Power Plant

Source: CFE

Power Plant Equipment Layout and Description

All four units have the same plan arrangement as shown in Figure 4.2 and equipment elevation as shown in Figure 4.3.

Steam Turbine

The steam turbines are of the single-cylinder, horizontal shaft, double-flow type with six stages of impulse - reaction blades in each flow. The turbines were supplied by the Tokyo Shibaura Electric Company (Toshiba).

- Name plate capacity 37,500 kW(e)
- Velocity, rotation 3600 rpm, CCW
- Inlet steam pressure 5.3 kg/cm² (75 psi)
- Inlet steam temperature 160°C (320°F)
- Inlet steam flow 285, 450 kg/hr (629,310 lb/hr)
- Exhaust pressure 89 mm Hg. abs (3.5 in)
- Maximum blade length 508 mm (20 in)

The turbine rotors are fabricated from 1 Cr-1.25 Mo-0.25 V alloy steel forgings. The turbine blades are machined from 12 Cr alloy steel and are enclosed with a shroud band hand-riveted on the outer edges of the blades. The blades of the 6th row are fitted with stellite erosion shields and lashing wire. The nozzle partitions are of 12 Cr-0.2 Al alloy steel, and the stage labyrinth strips are of 15 Cr-1.7 Mo alloy steel. The outer and inner casing are made of carbon steel ASTM specification ASTM-A285.

Generator

The electric generator close-coupled to the turbine was also supplied by Toshiba. The nameplate rating is 44 200 kva, 13800 volt, 60 hz, and 0.85 power factor. Each machine is hydrogen cooled at 2.0 kg/cm² (28.5 psi) pressure, with static self exciter with automatic voltage regulator. The stator is star connected with class B insulation code ASA-C50.

Figure 4.2 Plan View of Units 1 & 2 At Cerro Prieto
Source: CFE

Figure 4.3 Elevation View Of Units 1 & 2 At Cerro Prieto

Source: CFE

Turbogenerator Unit Auxiliaries

The auxiliary equipment supplied with each turbine generator is similar to that furnished to low pressure steam turbines in fossil fuel plants. The components are automatic steam seal system, main oil pump on shaft, A/C auxiliary oil pump, D/C emergency oil pump, A/C turning gear oil pump, turning gear, lubricating oil reservoir, two oil coolers, and front standard speed governor. The electric generator has a hydrogen seal system complete with oil pumps and gas vacuum pumps.

Station Control Room

The control room common to all four units is furnished with bench type panel board. The board has all the control elements necessary to operate the station. Vertical panels contain instrumentation to monitor temperatures, pressures, flows (velocities), voltage, amperage, vibrations, differential expansion and, to remotely control electric circuit breakers for the power plant and switchyard.

The panels are listed in order of appearance starting from left side and moving to the right as shown in Figures 4.4 and 4.5.

- Turbine Controls Units 1 & 2
- Generator Controls Units 1 & 2
- Transmission Line Controls Units 1 & 2
- Hidalgo Transmission Line (Future)
- Generator Controls Units 3 & 4
- Turbine Control Units 3 & 4
- Panel Space Unit 5 (Future)

Electric output from each generator is conducted by enclosed-fan cooled bus bars to the main step up transformer. Each main transformer is rated 41 MVA, 161 kV/13.8 kV, 60 hz, with star/delta connection. Power from the main transformer is sent to the switchyard then to the Mexicali transmission line shown in Figure 4.6.

Figure 4.4 Turbine-Generator Control Board Source: CFE

Figure 4.5 Turbine-Generator Control Board
Source: CFE

Figure 4.6 Plan Area General Arrangement For Units 1 & 2 At Cerro Prieto 1978

Source: CFE

Each unit has an auxiliary service transformer rated 7500 KVA, 60 hz, 13.8 kV/4.16 kV, and wye to wye connected.

Barometric Condenser

The steam exhausts downward from the turbine through a large circular duct installed on the turbine house floor, flows to the exterior of the turbine house building where the duct makes a 90° turn and rises vertically to the upper inlet of the barometric condenser. Design steam flow to the condenser is 286,160 kg/hr.

The barometric condenser was built by Toshiba, Ltd. The direct contact condenser is a vertical shell cylinder with spray nozzles and trays located in the upper part of the shell. The shell diameter is 6.7 m (22 ft.). The shell height is 26.5 m (86 ft.). The diameter of the tail pipe within the condenser is 2.0 m (6.6 ft.) and 13.9 m (45 ft.) in length. The steam inlet to the condenser is 3.6 m (11.8 ft.) in diameter. Refer to Figure 4.7.

The shell is of low carbon steel with an epoxy resin overlay. The trays are SS-AISI/304L.

The cooling water inlet design temperature is 32°C (90°F) and the cooling water required flow is 10,710 tons per hour for each unit.

The condensed steam plus the circulating water that was sprayed into the condenser, collects in the tail pipe and flows by gravity to the hot water canal. The canal conveys the hot water to the suction of the hot water pumps adjacent to the cooling tower basin. The hot water pumps pass the water to the distribution boxes on top of the cooling tower. The water falls through an air stream which is drawn through the tower air louvres by the induced draft fans.

The cooled water which rejected its heat to the atmospheric air stream, flows by gravity back toward the power plant. The cool water pumps force the liquid into the barometric condenser spray nozzles and trays to complete the circulating water cycle.

Figure 4.7 Direct Contact Barometric Condenser
Source: CFE/Toshiba

Non-Condensable Gas Ejectors

Three two-stage steam jet air ejectors remove non-condensable gases from the barometric condenser. Each ejector has 5.3 kg/cm^2 (75 psi) operating steam pressure. Each set has a barometric condenser, inter, and after cooler. Gas removal capacity is 3990 kg/hr and steam consumption is 24200 kg/hr with suction pressure of 80 mm hg. abs. During normal running, two of the three sets are in operation.

Cooling Towers

The cooling tower for Units 1 & 2 is situated 100 m south of the turbine house. The tower is 12 cell design, 146 m (480 ft.) long, 25 m (82 ft.) wide, and 18 m (59 ft.) in height. The design capacity is to cool $27300 \text{ m}^3/\text{hr}$ of water with a temperature range of 16°C .

Marley de Mexico supplied the standard cross flow tower. Structural members are A151 4140 steel and the packing is red wood and fiber glass.

The cooling tower for Units 3 & 4 has 10 cells instead of the 12 cells supplied for Units 1 & 2. Based on operating experience with Units 1 & 2, the CFE decided that 10 cells would supply the required cooling flow.

The condensed steam mixed with the circulating water sprayed into the barometric condenser flows from the tail pipe by gravity, through the covered hot water canal to the hot water pump suction basin. There two $6950 \text{ m}^3/\text{hr}$ pumps raise the hot water to the top of the cooling tower.

Flashed Steam Geothermal Power Plant Operation

Operation of the Cerro Prieto flash steam geothermal electric generation units is relatively simple compared to fossil fuel steam electric plants. Steam flows to the power plant via the pipeline, enters the prime mover (turbine), exhausts to the barometric condenser, is condensed, and the condensate plus circulating water flows to the cooling tower.

The amount of water evaporated during the heat rejection process (lost to atmosphere) in the cooling tower is balanced by the amount of geothermal steam condensed (added to circulating water system) in the power plant. Therefore, no makeup to the circulating water system is needed. The power plant operators blowdown the circulating water system as needed to control the salt concentration.

Based on flow tests of the production wells, the CFE reservoir operators and CFE power plant personnel estimate the number of wells needed to furnish full load steam flow to the generating unit. The CFE considers that the average equivalent output of each production well is 5 MW(e). Several wells are put in operation sending steam to the power plant pipeline.

The turbine is rolled, brought up to speed, and synchronized to the electrical system. The unit is loaded to nameplate rating, 37500 KW(e), in accordance with standard operating procedures.

Additional wells are put into service in case the reservoir flow is not sufficient for full power output.

The turbine steam flow is controlled by the speed governor apparatus similar to the type one would encounter in any steam electric turbine driven power plant. The front standard of the steam turbine is similar to steam turbines of fossil fuel plants. Steam inlet line control is a butterfly disc valve operated through a rack and pinion gear. With the turbine generator at base load the control valve mechanism only travels in a narrow band during most of the operating period. Each day the control valves are exercised to be sure that the valves will function full stroke when required to do so.

The CFE Operations Department load the Cerro Prieto units to the maximum possible, subject to the Baja California Division electrical demand. Load following responsibility is assigned to the fossil fired steam plant installed near Tijuana. During the early years of Cerro Prieto operation, 1973-1975, the electrical output had to be reduced in the winter months to satisfy the operating requirements of the system. This reduction affected the plant capacity factor during the early years.

The geothermal steam plant is relatively simple to operate compared to a fossil fired steam plant because several steam wells offer more reliability and flexibility as a multiple steam supply, than the single source supply such as a fossil fuel fired boiler.

The turbines operate near full load condition from start up following major overhaul until shutdown for the next annual major overhaul. Internal inspections during the overhaul revealed no major defects in the turbines. Therefore, the CFE was confident that periods between overhauls could be extended from 12 months to 18 months or more.

Figure 4.8 View Of Cerro Prieto Power Plant
Source: CFE

Power Plant Staffing

The CFE operates the four Cerro Prieto units with a full staff of operators each shift: shift supervisor, control room operator plus one auxiliary operator for each unit. This staffing procedure follows the CFE policies in fossil fuel steam plants. In contrast, The Geysers power plant of Pacific Gas and Electric Company is operated with a partial staff. Many of the geothermal generating units are in operation without attendants. This staffing policy appears to follow the PG&E practice for hydro electric plants.

The reliable operation of Cerro Prieto is shown by annual plant factors of: 0.87 - 1976, 0.90 - 1977, 0.91 - 1978. This record has initiated CFE and IIE interest in more automation and data collection for the existing plant as well as future units. The CFE is studying remote monitoring and control of the next units scheduled for installation during the 1980's.

Section 5
PLANT AVAILABILITY

Cerro Prieto - Electric Output

Unit No. 1 and No. 2 entered into commercial operation in 1973. Data for Table No. 5-1 were obtained from CFE published information. The plant annual gross generation is the accumulation of kWh for each unit read every hour during the year.

Table No. 5-1
GROSS GENERATION
UNIT NO. 1 & UNIT NO. 2

<u>Year</u>	<u>GWh</u>	<u>Plant Factor</u>
1973	193	0.63
1974	463	0.74
1975	518	0.79
1976	579	0.88
1977	592	0.90
1978	<u>598</u>	0.91

Total 2943

Calculation of Plant Factor for 1974 and Subsequent Years:

$$\text{Plant Factor} = \frac{\text{Plant Gross Output} - \text{GWh}}{\text{Plant Rating Output} - \text{GWh}}$$

$$\begin{aligned}\text{Plant Rating Output} &= \text{Nameplate Rating} \times 8760 \text{ hrs, i.e.,} \\ &75,000 \text{ kW(e)} \times 8760 \text{ hr} = 657 \text{ GWh}\end{aligned}$$

Cerro Prieto Unit Outages

APS personnel had an opportunity during visits to the geothermal plant to examine plant operation and maintenance data with key CFE personnel. Our review helped to clarify the nomenclature and explain any practices that appeared to differ from the customary procedures in the United States.

We gathered information about the hours when a unit was shutdown, off-line and not available for load. These outage hours (shutdowns) did not include the period when the unit was out of service during the annual overhaul. The findings are tabulated in Table No. 5-2.

Table No. 5-2

OUTAGES
FORCED OR PROGRAMMED

<u>Year</u>	<u>Unit No.</u>	<u>Forced Outage(A) (hours)</u>	<u>Program Outage(B) (hours)</u>	<u>Total Outage (hours)</u>
1974	1	9	12	21
1974	2	8	41	49
1975	1	29	20	49
1975	2	18	83	101
1976	1	2	35	37
1976	2	14	14	28
1977	1	-0-	22	22
1977	2	-0-	6	6
1978	1	-0-	7	7
1978	2	-0-	24	24

Information from Comision Federal de Electricidad.

(A) Forced Outage -- Unit non-scheduled shutdown.

(B) Programmed Outage -- Unit controlled shutdown.

Forced Outages

Forced outages at Cerro Prieto are usually initiated by an electrical relay operation. The relay protective device trips the unit from the line without giving the plant operator time to take action. The CFE considers that all of the forced outages were electrical problems. At Cerro Prieto, the switchyard is accounted for as an integral part of the power plant. Some of the electrical trips may have been faults in the switchyard, but the data did not make a clear definition of the fault origin.

Programmed Outages

Programmed outages were scheduled shutdowns usually to correct a mechanical problem. For example, replacement of aluminum tubing in the No. 2 generator hydrogen coolers accounted for most of the 83 hours accumulated in 1975. The scheduled shutdown can be arranged with very little disturbance to the system. Power plant operators prefer to control a shutdown rather than have a "trip" take the unit from service.

Power Plant Equipment Failures

The forced or electrical outages were zero for the years 1977 and 1978 which agreeably coincides with the CFE's decision to extend time between overhauls to 16,000 hours. The mechanical outages are low in number because of some redundancy in equipment installation. This equipment redundancy is consistent with steam plant auxiliary design practice in the United States.

Some of the initial equipment problems were due to the purchased material not being compatible with the corrosive elements in the geothermal steam. Most of those problems were corrected during the early years of operation. Those problems that persist are in the nature of mechanical-structural design troubles. We have commented about the type of problem in Section 6 on Power Plant Maintenance.

Summary of Reliability and Availability

Table 5-3 summarizes the quantitative measures of plant reliability and availability for each of the five full years of operation 1974-1978. The capacity factor has been high, averaging 84% and exceeding 90% over the last two years of the period. The only significant contributors to lost electricity production are the downtime for annual maintenance and the failure to generate at full nameplate capacity at times. Information was not available for determining the extent to which the units ran below capacity due to demand limitations rather than due to scale formation in the turbines or lack of full steam supply.

The decline in turbine output attributed to scale formation is given at 2.5 MWe out of 37.5 MWe over a one-year period. (See page 6-1 below.) This rate of decline in generating capacity would account for lost production of about 22 GWh per year for the 75 MWe plant. This would account for all of the otherwise unaccounted lost production in 1978, but would accumulate to only about one-third of the otherwise unaccounted lost production for the five-year period.

The availability of the plant has been high, nearly 93% over the total five-year period and about 95% during each of the last 3 years, 1976-1978. Major ("annual") maintenance accounts for nearly all of the lost availability.

Table No. 5-3
ELECTRICITY PRODUCTION FROM CERRO PRIETO UNITS 1 AND 2

Year	Nameplate ^a (GWh)	Production ^b (GWh)	Losses of Potential Production (GWh)				Capacity Factor ^d	Avail- ability Factor ^e
			Forced Outage	Scheduled Outage	Annual Maintenance	Unaccounted ^c Losses		
1974	657	463	1	2	76	115	70%	88%
1975	657	518	2	4	57	76	79%	90%
1976	657	579	1	2	26	49	88%	96%
1977	657	592	0	1	32	32	90%	95%
1978	<u>657</u>	<u>598</u>	<u>0</u>	<u>1</u>	<u>35</u>	<u>23</u>	<u>91%</u>	<u>95%</u>
Total	3285	2750	4	10	226	295	84%	93%

Notes and Definitions:

^aNameplate GWh is maximum possible plant output, i.e., nameplate rating 75 MW(e) multiplied by 8760 hours per year.

^bProduction of electricity is read from totalizer meter at each generating unit.

^cUnaccounted includes effects of (1) decreased capacity of turbine due to scale formation, (2) demand limitations, and (3) lack of full steam supply.

^dCapacity factor is production GWh divided by nameplate GWh, e.g., $2750/3285 = 0.84$.

^eAvailability factor is calculated as 1.00 minus the ratio of the sum of forced, scheduled and maintenance outage losses to the nameplate GWh, e.g., $1.00 - 240/3285 = 0.93$.

Section 6

POWER PLANT MAINTENANCE

Equipment Material Selection

The CFE conducted approximately 1,000 tests on candidate materials for the critical parts of the plant, to determine those compatible with the vapor and liquid characteristics of the Cerro Prieto reservoir. Samples were exposed to geothermal steam and condensate for a period of 150 days. Although most of the material selected has been satisfactory, there were some problems as reported in this section.

Steam Turbine Generator

Turbine Inlet Valves

The main stop valves are swing check type for quick closing. Stuffing box leakage has been a problem since initial operation in 1973. Erosion of the shaft supporting the disc and stuffing box scaling require frequent maintenance. The valves are exercised each day to assure correct functioning. One spare set of replacement valves are on order. When these valves are installed in one unit the removed valves can be overhauled and made ready to replace the other sets of main stop valves. This should reduce the outage rate associated with main stop valve problems.

Turbine Nozzles and Blading

Scaling of the first stage nozzles and blading has occurred in each turbo-generator unit. Liquid carryover in the steam leaving the well head separators deposited salts in the nozzles and on the blading. The deposit restricts steam flow and reduced the unit output about 2.5 Mw(e) over the course of a year's operation.

Water washing with the turbine in service, to remove the deposits, has not been satisfactory. During the annual overhaul internal cleaning by sand blasting removed the deposits. The expense of annual cleaning plus the output kW loss were concerns of the CFE. Investigations were made to reduce carryover. Modification of the well head separators, as explained in the section on well operation improved liquid separation. The quality of the

steam improved and resulted in reduced scaling in the turbine. This convinced the CFE operating department that time between overhauls could be extended since turbine deposits for two years were no greater than deposits previously acquired in one year. The rate of scaling was reduced by 50%.

The turbine internals cleaned by sandblasting are examined each overhaul by dye penetrant tests. No fissures or fractures in the blading or nozzles has been found which gives support to the decision to extend the number of hours between overhauls.

Steam Turbine Spare Rotor

At the time of the purchase of the turbine generators for Units No. 1 and No. 2, the CFE acquired a spare rotor for the turbine. It was thought that the turbine would experience rotor difficulties due to corrosion or erosion from the steam. The manufacturer recommended that the CFE acquire a spare turbine rotor. See Figure 6.1.

The spare rotor is mounted on wooden blocks on the turbine house floor at Cerro Prieto. It has its original part number markings and the only "maintenance" is to occasionally remove some of the dust that collects on it. The turbine generator units have been relatively free of any maintenance needs as shown by the unused spare rotor.

Steam Turbine-Generator Lubricating Oil Coolers

The lubricating oil coolers were originally supplied with aluminum tubing. Leaks began to appear in the first months of operation due to the corrosive nature of the cooling water (high CO_2 and H_2S content). Repair procedures were to plug leaky tubes until tube bundle pressure drop became excessive, then replace entire bundle with stainless steel tubing. Units 1 and 2 tubing were all changed by mid-1979. Units 3 and 4 were furnished with stainless steel tube bundles as original equipment.

Generator Hydrogen Coolers

Aluminum tubing in the hydrogen coolers was gradually replaced with titanium tubing beginning in 1974 for Unit 1 and 1975 for Unit 2. The tube bundles had to be changed with the unit out of service. This replacement work was a major part of the programmed outage for mechanical maintenance noted in the outage table. Change out was completed by 1976 in both the original units.

Figure 6.1 Cerro Prieto Turbine House Floor With Spare Rotor Stored In Front Of Unit No. 2

Source: CFE

Figure 6.2 Front Standard Cerro Prieto Turbine-Generator
Source: CFE

Based on the experience with Units 1 and 2, the material specifications for the hydrogen coolers were amended. Units 3 and 4 are furnished with titanium tubing as original equipment in the coolers.

Cooling water supply and return lines to hydrogen cooler headers and valves were furnished as low carbon steel. The CFE had furnished stainless steel headers for water supply to hydrogen coolers but Toshiba had recommended and supplied carbon steel piping. These lines all had to be replaced with stainless steel piping. Operation of the Cerro Prieto has furnished material experience information that can be useful in the design of a flash steam geothermal facility.

Barometric Condensers

The steel shell interior is inspected during each major maintenance overhaul. Some random "blisters" appear in the epoxy paint overlay and these damaged areas are cleaned, the surrounding overlay removed, and a new patch applied to the affected area. There has been no indication of pitting damage to the shell surface beneath the overlay.

The exterior surface of the tailpipe (barometric leg) corrodes at the "water line". This occurs at the level in the hot water canal where the tailpipe is sealed. Non-condensable gases, released from the hot water in the canal, combine with atmospheric oxygen to attack the wetted surface of the tailpipe; annual cleaning and heavy application of epoxy paint retards the corrosion.

Metal canal covers have been replaced with concrete covers that appear to better resist the gases corrosive attack. PVC inserts in the concrete covers are effective options against the corrosion attack.

Steam Jet Ejectors

Each barometric condensing unit has three sets of two stage steam jet ejectors to remove non-condensable gases. The ejector diffuser tubes were made of carbon steel. Frequent pinhole leaks developed from the corrosive gases extracted by the ejectors and discharged to the atmosphere. This problem caused programmed outage because the shut-off valves for isolating each set failed to function and the unit had to be shutdown to make repairs to the ejectors.

The diffuser tubes were changed to stainless steel in Units 1 and 2. However, an oversight by the manufacturer resulted in Units 3 and 4 being furnished with the carbon steel original material as 1 and 2. These steam jet ejector sets will be modified during the first annual major maintenance of the new units.

Non-Condensable Gas Atmospheric Discharge

The non-condensable gases discharged from the steam jet ejectors are conveyed to an atmospheric stack discharge above each unit. These stacks can be seen in the plant photograph Figure 6.3. There are occasions when the ambient conditions around the power house permit the toxic gases to collect at grade level. This condition is dangerous to the well being of plant personnel. The stacks were modified by the installation of a "tee" connection near the roof. The gas discharge can go vertically to atmosphere or be diverted through the side outlet of the "tee" to a pipe descending to grade level, then going to the evaporation lagoon. This conducts the toxic corrosive gases to an area remote from the power plant.

Cooling Tower

The problems in the cooling tower originate with the corrosive character of the cooling water. The CO_2 and H_2S contained in the steam mix with the cooling water sprayed into the barometric condenser. The make-up to the cooling water system is continually being fed by condensed turbine exhaust and the chemical concentration increased. Frequent blowdown controls the concentration level.

Steel and wood supports, metal fastenings and fill material all suffer attack by the cooling water. The sulphur contained in the cooling water deposits in water distribution boxes. Minerals deposits cause overflows and poor water distribution. Tower structural failures can occur due to overweight conditions caused by salt deposit.

The H_2S in the hot water flowing in the return canal attacks the concrete of the tunnel "covered" roof. The low pH water causes spalling of concrete. This results in sand and gravel being leached into the water. This leached grit accelerates pump wear and adds to basin cleaning problems. Sand blast cleaning and application of new concrete plaster are being used to protect the affected tunnel areas. PVC plates are being studied as another method for protective coating.

Station Electrical Apparatus

The electrical equipment is susceptible to corrosive attack by hydrogen sulfide. Precautions taken to protect the equipment include switchboards and electrical relay equipment being installed in air tight rooms. There are rooms provided with air conditioning systems that have activated carbon filters filled with impregnated potassium permanganate beads. This air

Figure 6.3 Barometric Condensers For Units 1 & 2 Showing Non-condensable Gas Atmospheric Discharge

Source: CFE

system provides an artificial atmosphere relatively free of dust and corrosive H_2S .

Exposed copper bus work is protected by aluminum cladding which appears to give satisfactory protection against corrosive atmosphere attack.

Power Plant Maintenance

The CFE staff the power plant with a group of skilled craftsmen who take care of the preventive maintenance. This group usually is on call for repairs during the Programmed Outages. The CFE labor forces used to construct all thermo-electric plants in Mexico are available as a pool of skilled craftsmen to augment the plant staff during major overhauls. In fact, the technical personnel often transfer between Construction and Operations during their assignments at Cerro Prieto.

The open layout and spacing of power plant gives adequate access to most of the installed equipment as noted in Figures 6.4, 6.5, and 6.6.

CFE Operating personnel supplied the data in Table No. 6-1. The "hours between overhaul" number is the accumulative reading since the last overhaul period or outage of the unit.

CFE Operating personnel supplied the data in Table 6-1. The "hours between overhaul" number is the accumulator reading since the last overhaul period or outage of the unit. The accumulator records the number of hours the unit is synchronized to the grid during the period from the end of the last major overhaul to the beginning of the next unit major overhaul.

The major maintenance period ranged from a minimum of 27 days to a maximum of 43 days, with an average period of 35 days. The CFE completes the Cerro Prieto overhauls on a forty hour work week schedule. This productivity of the labor force at the geothermal facility compares favorably with labor forces in the USA relative to steam plant overhauls.

The experience gained by CFE personnel during the first five years of operation of Cerro Prieto, will be of significant help in the planning for the Cerro Prieto II especially in equipment and material selection. This report can also assist all electric utilities that are developing geothermal electric production plants.

Table No. 6-1
OPERATING HOURS, MAJOR MAINTENANCE SCHEDULE, DOWNTIME

<u>Unit No.</u>	<u>Running Time Between Overhaul hours</u>	<u>Maintenance Period</u>		<u>Overhaul Downtime days</u>
		Begin	End	
2	Start Operation 4/1973			
1	Start Operation 9/1973			
2	8325	19-04-74	28-05-74	40
1	9380	23-10-74	04-12-74	43
2	7533	09-04-75	06-05-75	28
1	7937	03-11-75	05-12-75	33
2	7169	08-03-76	03-04-76	27
1	12119	26-04-77	28-05-77	33
2	15596	16-01-78	21-02-78	37
1	16943	07-05-79	12-06-79	37

Figure 6.4 View Of Steam Inlet To Power Plant, Cerro Prieto "Dark Hill" In Background

Source: CFE

Figure 6.5 Steam Turbine Exhaust Duct To Barometric Condenser

Source: CFE

Figure 6.6 Coolwater Supply Pump To Barometric Condenser
Source: CFE

Figure 6.7 Barometric Condenser
Source: CFE

Section 7

GEOHERMAL EXPANSION PROGRAM

Expansion of Cerro Prieto Region

The CFE program of electric sector investment projects has estimated dates for placing in operation additional geothermal electric power production units. Overall, this would increase the electrical output at Cerro Prieto from the present 150 MW(e) to 400 MW(e) by the end of 1984. The following tabulation, Table No. 7-1, lists units and estimated operating dates:

Table No. 7-1
GEOHERMAL EXPANSION PROGRAM

<u>Unit No./Plant</u>	<u>Capacity MW(e)</u>	<u>Date</u>
1 CP I	37.5	4/73
2 CP I	37.5	9/73
3 CP I	37.5	3/79
4 CP I	37.5	5/79
5 CP I	30.0	5/82
1 CP II	55.0	5/82
2 CP II	55.0	5/82
3 CP II	55.0	5/84
4 CP II	55.0	5/84

Source: Comision Federal de Electricidad

The objective of the above program is to satisfy the electric demand for the system "Tijuana - Mexicali". This area is supplied principally by two power plants, the fossil fired steam electric plant at Rosarita and the geothermal power plant at Cerro Prieto. Normally all of the output of the geothermal power plant can be used in the Baja California electric system so the units are operated at base load.

Power Needs Beyond Baja California

In the CFE Baja California Division, construction programs for geothermal plants are contingent on the demand for electric energy. The electrical system in that region is an isolated grid and supplied by two power plants; one located south of Tijuana and the other in Cerro Prieto. To justify power stations whose capacities go beyond the needs of the northern zone, the CFE is contemplating a connection from the existing Baja California system to the national grid, approximately 700 km distant. This interconnection of the Tijuana-Mexicali electric system to the Sonora-Sinaloa system would increase the demand for geothermal output capacity to a total of 1,000 MW(e).

Another factor to consider in the potential demand for electricity from the Cerro Prieto plant is the U.S. demand. Both San Diego Gas and Electric Company and Southern California Edison Company have executed contracts to purchase electricity from CFE. As a result, CFE intends to expand the generating capacity at Cerro Prieto faster than required by demand growth in Baja California and to sell the product of the excess capacity to the U.S. utilities until internal demand requires the full capacity.

Recent Cerro Prieto field studies divide the region into six areas as illustrated in Figure 7-1. These areas have had exploratory drilling and show good potential for production wells.

Table No. 7-2 indicates the number of wells planned, the estimated capacity of the wells, the estimated geothermal electric output and a comment as to whether the area has been proven or has a high probability for production.

Table No. 7-2
PLANNED WELL EXPANSION

<u>Area</u>	<u>Wells</u>	<u>Megawatt/Well</u>	<u>Output MW(e)</u>	<u>Remarks</u>
I	30	6	180	Proven
II	30	10	300	Proven
III	20	5	100	Proven
IV	16	6.2	100	Proven
V	20	10	200	Probable
VI	16	7.5	120	Probable

- Completed Exploratory Wells

Figure 7-1 Areas Of Geothermal Development In Cerro Prieto Region

Source: CFE

Section 8

BIBLIOGRAPHY

Spanish and English Translation

Many publications about the Cerro Prieto geothermal facility are listed with Spanish and English titles. The reader is advised to refer to the native language publication of the principal author for diagrams, graphs and tabulations. The translation copy usually does not contain the graphic information contained in the original.

Proceedings from the Second United Nations' Symposium on the Development and Use of Geothermal Resources, May 20-29, 1975 San Francisco, CA., Vols. 1-3

- H. Alonso E., "Potencial Geotermico de la Republica Mexicana," Vol. 1, pp 17-20; "Geothermo Potential of Mexico," Vol. 1, pp 21-24.
- E. Tolivia M., "Evaluacion del Potencial Geotermico de Cerro Prieto, Baja California," Vol. 1, pp 275-278; "Evaluation of The Geothermal Potential of Cerro Prieto," Vol. 1, pp 279-281.
- S. Mercado G., "Migracion de Fluidos Geotermicos y Distribucion de Temperaturas en el Subsuelo del Campo Geotermico de Cerro Prieto, Baja California, Mexico," Vol. 1, pp 487-492; "Movement of Geothermal Fluids and Temperature Distribution in the Cerro Prieto Geothermal Field," Vol. 1, pp 492-494.
- E. Paredes A., "Informe Preliminar Sobre la Geologia Extructural del Campo Geotermico de Cerro Prieto, Baja California, Mexico," Vol. 1, pp 515-517; "Preliminary Report on the Structural Geology of the Cerro Prieto Geothermal Field," Vol. 1, pp 518-519.
- M. J. Reed, "Geology and Hydrothermal Metamorphism in the Cerro Prieto, Baja California, Mexico," Vol. 2, pp 1003-1009; "Geoelectric Study of the Cerro Prieto Geothermal Area," Vol. 2, pp 1009-1011.
- S. Mercado G., "Proyecto Geotermoelectrico de Cerro Prieto: Contaminacion y Proteccion Basica," Vol. 2, pp 1385-1393; "Cerro Prieto Geotermoelectric Project: Pollution and Basic Protection," Vol. 2, pp 1394-1398.

- B. Dominguez A. and F. Vital B., "Reparacion y Control de Pozos Geotermicos en Cerro Prieto, Baja California, Mexico," Vol. 2, pp 1483-1495; "Repair and Control of Geothermal Wells at Cerro Prieto," Vol. 2, pp 1495-1499.
- B. Dominguez A. And F. J. Bermejo de la Mora, "Metoda Actual para la Apertura e Inicio de Explotacion de Pozos en el Compo Geotermico de Cerro Prieto, Baja California, Mexico," Vol. 3, pp 1619-1628; "Present methods of Opening and Starting Production in Wells at Cerro Prieto Geothermal Field," Vol. 3, pp 1629-1633.
- E. Tolivia M., J. Hoashi, and M. Miyazaki, "Corrosion of Turbine Materials in Geothermal Steam Environment in Cerro Prieto," Vol. 3, pp 1815-1820.
- J. Guiza L., "Generacion de Energia Electrica en el Campo Geotermico de Cerro Prieto," Vol. 3, pp 1973-1975; "Power Generation at Cerro Prieto Geothermal Field," Vol. 3, pp 1976-1978.

Publications of Lawrence Berkeley Laboratory

At the Second United Nations Symposium on the Development and Use of Geothermal Resources, May 1975, a discussion between CFE personnel and the Lawrence Berkeley Laboratory (LBL) initiated ideas for an international program of cooperative investigations and technology exchange to study the Cerro Prieto geothermal field. Follow-up meetings were held in Mexicali, Mexico City, D.F.; and Washington D.C. during the period June 1975 to early 1977 between representatives of CFE, LBL, and the United States Energy Research and Development Administration (ERDA), now the United States Department of Energy, (DOE).

An official agreement was signed in Mexico City on July 21, 1977 by the CFE and the United States Embassy on behalf of ERDA (DOE). The many tasks to be covered in the five-year agreement include geologic, hydrogeologic, geophysical, geochemical, subsidence and reservoir engineering studies. Data from these studies are published in reports by the CFE and LBL.

The agreement stipulates that a symposium is to be held each year on the subject of the Cerro Prieto geothermal field. These symposia update many of the studies. The meeting location alternates between the United States and Mexico. The first symposium was held in San Diego in 1978, the second in Mexicali in 1979 and the third in San Francisco in 1981. The Proceedings/Actas of these meetings are a valuable source of information on the Cerro Prieto geothermal field.

LBL-7095, P. A. Witherspoon, H. Alonso E., M. J. Lippmann, A. Manon M., and H. A. Wollenberg (August 1978), "Mexican-American Cooperative Program at the Cerro Prieto Geothermal Field," 15 pages with an appendix that describes the "agreement between the Comision Federal de Electricidad of the United Mexican States and the U.S.A. Energy Research and Development Administration."

LBL-8603, "Geothermal Exploration Technology Annual Report" (1978), pages 26-42 contain information on Geophysical Studies at Cerro Prieto.

LBL-7019, A. Manon M., E. Mazor, M. Jimenex, A. Sanchez, J. Fausto, and C. Zenizo (1977), "Extensive Geochemical Studies in the Geothermal Field of Cerro Prieto.

LBL-6321, M. J. Lippmann, D. Dominguez A., H. A. Wollenberg, and P. A. Witherspoon (April 1977), "Open File Data on the Cerro Prieto Geothermal Field," 10 pages.

Open File Data Bank

Most of the CFE data collected at Mexicali and Cerro Prieto are primarily internal reports (written in Spanish later translated into English), internal memoranda, maps, and well logs. Individuals wishing to obtain copies of the above are encouraged to contact the LBL Open File Data Bank and arrange for its reproduction.

Informes (Well Reports), Reservoir Engineering Data

The "informes" include: well repair information, description of the wellhead installation, temperature and pressure surveys, plots of wellhead pressure vs production rates, and well production rates.

Memorias (Well Reports), Well Drilling and Completion Data

The "memorias" indicate the location of the well, describe drilling, logging, completion repair activities, and list installed casings and wellhead equipment. To each report there are attached curves giving temperature profiles, completion data, lithologic column, electric log, and location map.

Proceedings/Actas, First Symposium on the Cerro Prieto Geothermal Field, sponsored by DOE/DGE and the CFE, September 20-22, 1978, San Diego, California. One volume, 455 pages. Two papers that can supply answers to any technical questions about the wells are listed below:

- B. Dominguez A., "Terminacion y Desarrollo de Pozos en Cerro Prieto," Vol. 1, pp 265-293; "Well Completion and Development at Cerro Prieto," Vol. 1, pp 293-299.
- F. J. Bermejo M., C. Cortez A., y A. Aragon A., "Cambios Fisicos y Termodinamicos Observados en el yacimiento Geotermico de Cerro Prieto," Vol. 1, pp 300-329; "Physical and Thermodynamic Changes Observed in the Cerro Prieto Geothermal Reservoir," Vol. 1, pp 329-332.

Program and Abstracts/Programa Y Resumenes, Second Symposium on the Cerro Prieto Geothermal Field, sponsored by the CFE and the DOE/DGE, October 17-19, 1979, Mexicali, Baja California, Mexico. 55 pages.

Abstracts/Resumenes, Third Symposium on the Cerro Prieto Geothermal Field, sponsored by the U.S. DOE/DGE in cooperation with CFE, March 24-26, 1981, San Francisco, California. 45 pages.

Additional Publications on Cerro Prieto

S. Mercado G., (1976), "Cerro Prieto Geothermal Field, Wells and Plant Operation," International Congress on Thermal Waters, Athens, 15 pages.

Alonso E., H., et al, "Recent Activities at the Cerro Prieto Fields" - Fourth Workshop, Geothermal Reservoir Engineering, December 1978, Stanford University.

Alonso, E., H., et al, "Update of Reservoir Engineering Activities at Cerro Prieto" - Fifth Workshop, Geothermal Reservoir Engineering, December 1979, Stanford University.

DiPippo, R., 1978, "Geothermal Power Plants of Mexico and Central America," Report No. CATMEC/18, D.O.E. No. C00/4051-26.

Alt, T. E., "Assessment Flash Steam Geothermal Plant," Report 1195-1, EPRI 3rd Annual Geothermal Workshop, June 1979.

Alt, T. E., "Performance Assessment of Flashed Steam Geothermal Power Plant" - EPRI 4th Annual Geothermal Conference, June 1980.