

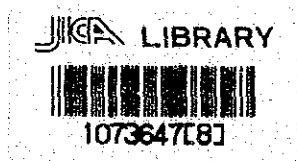
THE FEASIBILITY STUDY
ON
KERINCI GEOTHERMAL DEVELOPMENT PROJECT
IN
THE REPUBLIC OF INDONESIA
FINAL REPORT

MARCH, 1989

JAPAN INTERNATIONAL COOPERATION AGENCY

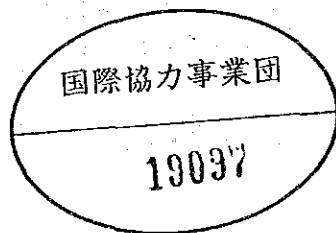
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マイクロ
フィルム作成

PREFACE

In response to a request from the Government of the Republic of Indonesia, the Japanese Government decided to conduct a survey on Kerinci Geothermal Development Project and entrusted the survey to the Japan International Cooperation Agency (JICA).

JICA sent to Indonesia a survey team headed by Mr. Tadahiko Shimoike, West Japan Engineering Consultants, Inc., from December, 1988 to February, 1989.

The team exchanged views with the officials concerned of the Government of Indonesia and conducted a field survey in West Sumatra area. After the team returned to Japan, further studies were made and the present report was prepared.

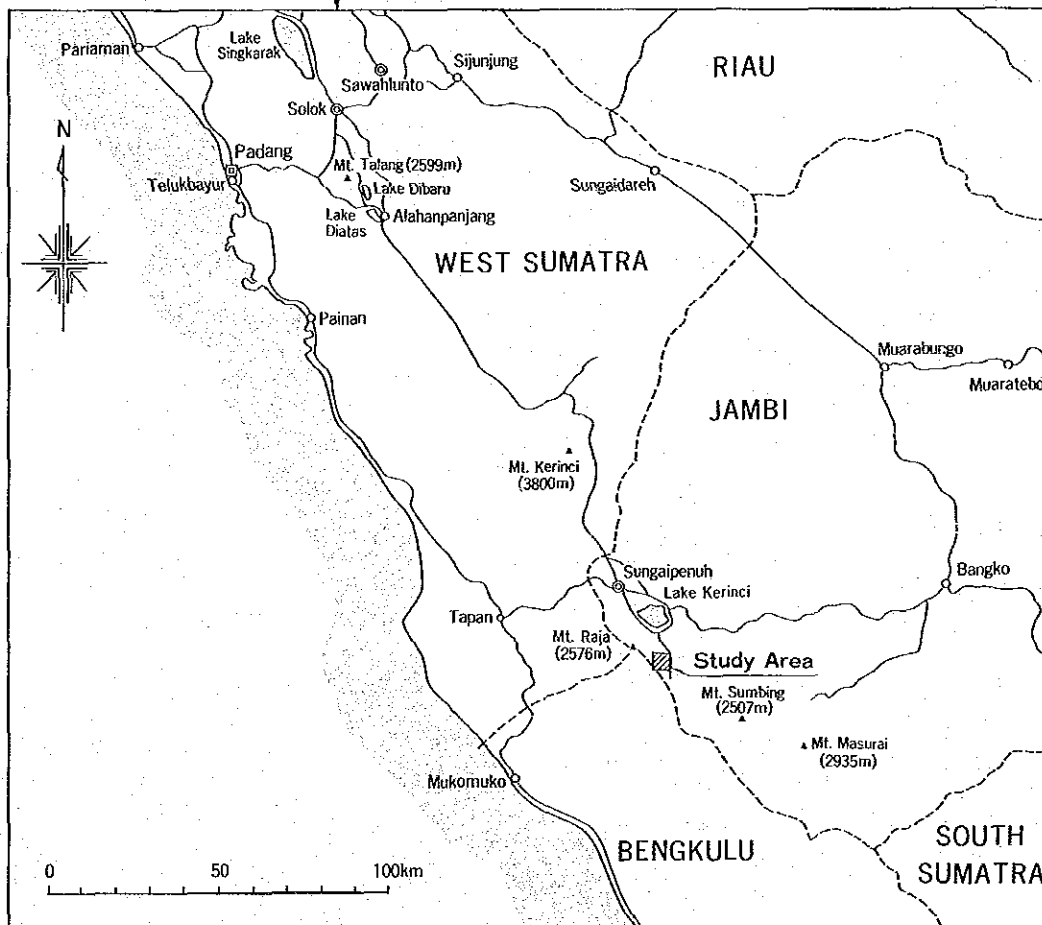
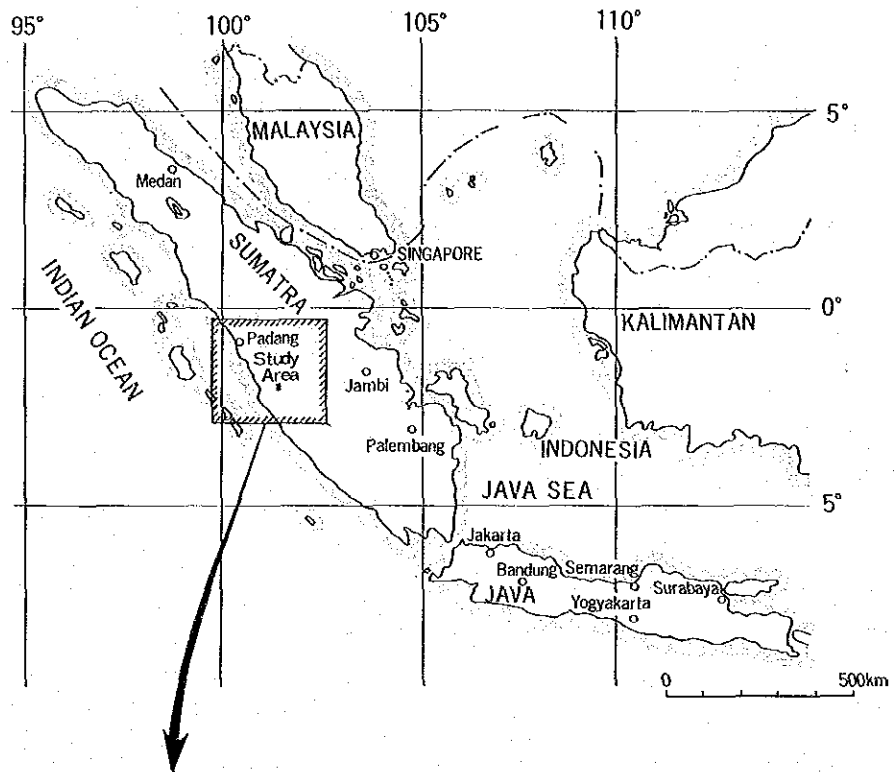
I hope that this report will contribute to the development of the Project and to the promotion of friendly relations between our two countries.

I wish to express my sincerest appreciation to the officials concerned of the Government of the Republic of Indonesia for their close cooperation extended to the team.

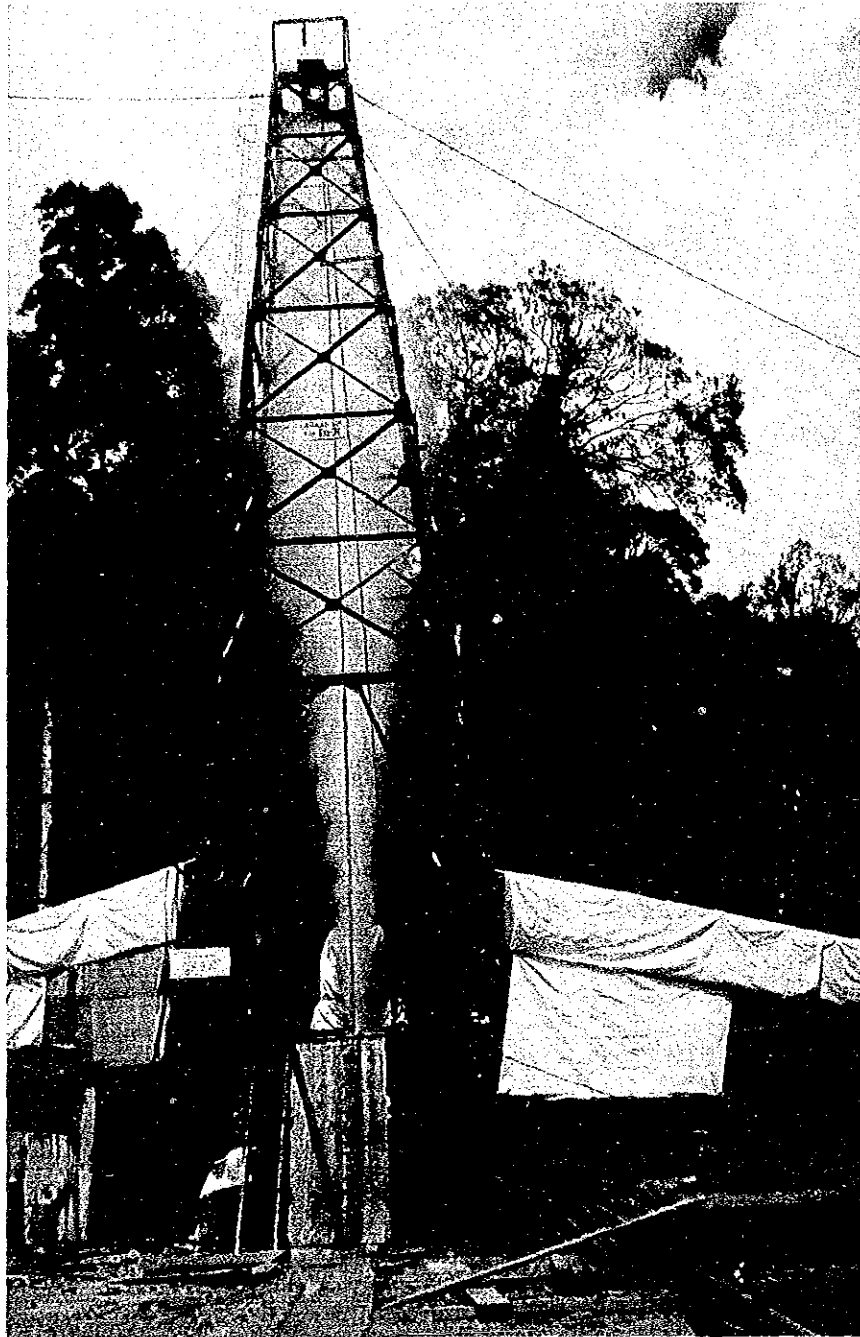
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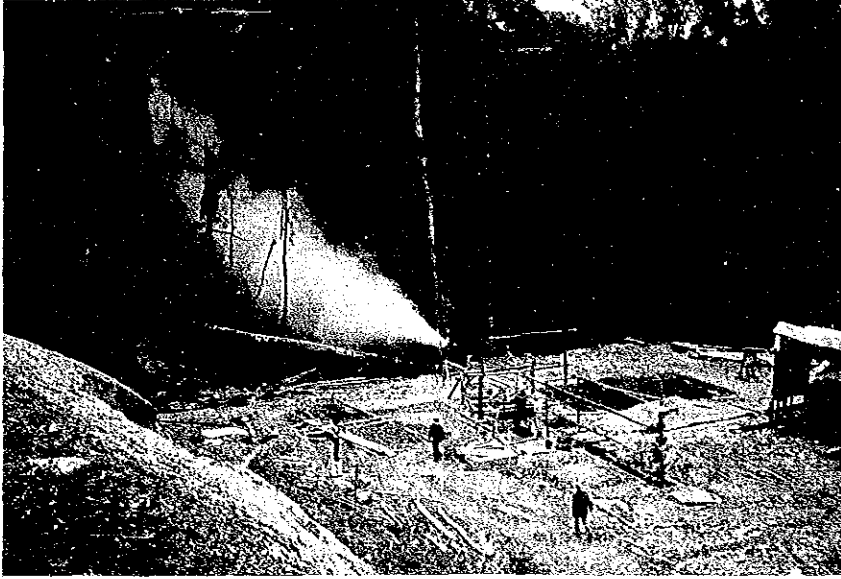
Kensuke Yanagiya
President
Japan International Cooperation Agency



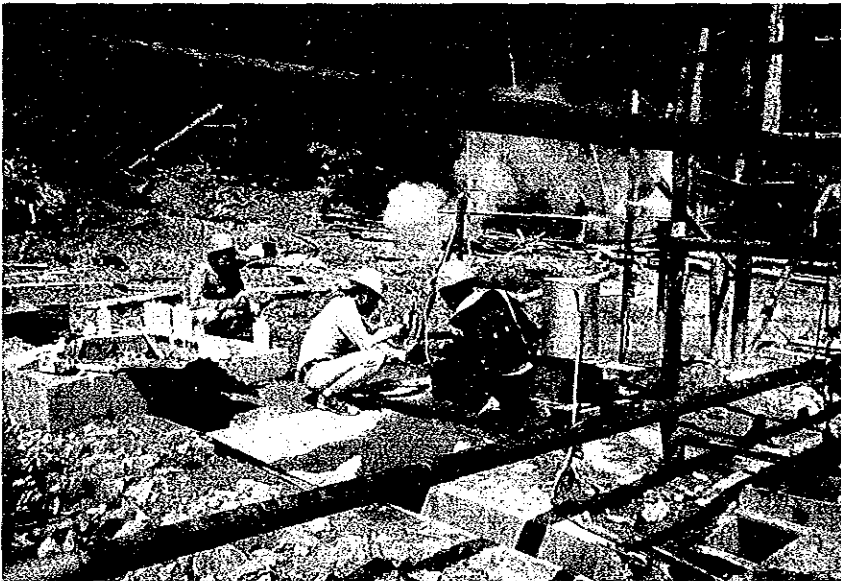
Location map of kerinci geothermal field



Exploratory well LP-2
(about 1hour after swabbing, 17February1988)



Discharging geothermal fluid from LP-2
(16 March 1988)



Gas sampling
(18 March 1988)

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Chapter 1. Conclusion and Recommendation

Chapter 1. Conclusion and Recommendation

1.1 Conclusion

The resource feasibility study confirmed that the Duabelas geothermal system has a potential for power generation of more than 5 MW. The following feasibility study for geothermal power plant, however, concluded that of 5 MW in the total potential, the development of 2.35 MW is appropriate for the time being to meet the power demand in the project area. Although the study revealed that the project is financially feasible and effective to alleviate the PLN's financial burden, the economic viability is not so sufficient. But in consideration that the project area is located in rural area remote from the PLN's transmission lines, the majority of the power demanders is residential customer, and the existing power sources are mostly diesel power units with a higher fuel cost due to long transportation from Padang, the study concludes that the project be continued for realization of geothermal power plant which will effectively utilizes the indigenous energy resources and contribute to economic and social development in the rural areas. The reasons for the conclusions and necessity of the project are summarized in the following.

1. Use of Available Geothermal Steam

The existing LP-2 well drilled as an exploratory well under the survey is producing the steam with an electricity energy of about 350 kW. It is advisable to formulate effective utilization of important geothermal energy as soon as possible. And the geothermal steam production by the production well is highly promised by a variety of the geothermal resource survey.

2. Power Demand

According to the demand forecast by PLN, the Kerinci area will need a new power source in addition to planned 2.5 MW x 2 units of new diesel power units before 1994 since PLN has no specific plan for interconnection of its Sumatra trunk line with the area. Introduction of the geothermal power plant to the area is significant for effective utilization of non-oil energy resource, or fuel saving amounting to 32,700 ton, or US\$545,000 annually (at US\$16/bbl.) and for diversification of power sources in the area. And the geothermal units formulated under the project can be properly operated as base load power units as a result of study on the estimated load curve.

3. Stable Power supply

The power supply in the Kerinci area relies mostly on diesel power sources with the fuel transported on the long, ragged road from Padang. In rainy seasons, the transportation route is occasionally closed by the land slide and that endangered the stable and reliable power supply in the area. And the higher fuel cost and low efficiency of these diesel power engines make the power rate in the area (about 103.38 Rp/kWh in 1988) higher than the average rate in the whole Indonesia (about 92.50 Rp/kWh). Since the geothermal power plant generates the power with the geothermal steam available in the area, the fuel supply is not effected by the natural weather conditions. Because the geothermal power unit is usually operated with carrying the base load in the area owing to the geothermal well characteristics, the higher the capacity factor, the cheaper the generating cost. That will advance the 24-hour operation of power supply in the whole Kerinci area while only Sungai Penuh power system attained 24-hour operation some years ago.

4. Promotion of Rural Electrification

The electrification rate in the Kerinci area in 1987 stands only 19% which is one of the lowest figure in the whole Indonesia. Of 54,000 households, only about 10,300 households could receive the electricity. Since this project will improve the financial conditions of power business in the area by lowering the generating cost and attain the stable power supply, the project will contribute to substantial increase of electrification rate followed by well being of people's livelihood. In the economic theory, the willingness to pay for the electricity increases and so the electrification rate rises as the price of electricity becomes lower.

5. Development from Rural Area

The government emphasized the economic development not only in the urban areas in Java Islands but also rural areas in the islands other than Java. It is said there scattered many geothermal resources mostly in the remote area from the major power transmission lines in Indonesia. The successful development of the geothermal power source in the Kerinci area will become a model case for electrification and modernization in the rural area by geothermal power development.

6. Economic and Financial Feasibility

The project financial evaluation registered its FIRR at 4.32% and the With/Without financial evaluation (a comparison between the case of Project implementation and the case without the project) at 6.37%. Both the FIRRs exceed the financial opportunity cost of capital at 3.61%. That means the project is financially viable. Especially, the With/Without evaluation reveals that the project implementation is well effective to lessen the financial burden in PLN's Sungai Penuh power system and to realize the cheaper power rate.

Meanwhile, the economic internal rate of return by comparison with the close alternative of diesel power unit did not provide a favorable figure at 3.78% mostly because of high project initial investment and low oil price. Regarding the oil price, the unfavorable affection to the project will be alleviated by increase of oil price since it is hard to believe that the current low oil prices will continue.

The sensitivity analysis of EIRR to the cost for power unit revealed that if the cost should be reduced, the EIRR becomes more favorable. The project will become economically feasible if the project cost estimate would be made more in detail toward the reduction of the project cost when the project implementation program will be prepared.

Though the project implementation will bring about somewhat hardship for PLN in view of financial conditions, PLN could solve this problem by seeking for the loans with the softest term and conditions. In order to attain further electrification at the same power rate as the average power rate in the whole Indonesia it is desired to advance the project as soon as possible.

1.2 Summary of the Study

1.2.1 Results of Resource Evaluation Stage

The Kerinci geothermal field is situated in the depression zone of which western margin is limited by the Great Sumatran Fault. This depression zone, which is an active Quaternary volcanism field, was resulted from subsidence of Pre-Neogene basement rocks, originated with the eruption of Neogene volcanic rocks. Geothermal manifestations such as fumarole and hot spring are recognized mainly along the Duabelas fault and along the Sikai fault. It is considered that geothermal activity in this field is mainly controlled by these faults. The geothermal features in this field are summarized as follows.

1. There are two geothermal systems, with a common heat source, of hydrothermal convection type, the Duabelas geothermal system along the Duabelas fault and the Sikai geothermal system along the Sikai fault. There are deep hot water reservoirs of neutral chloride type, with overlaying vapor-dominated zone, along the faults in both the systems.
2. The last eruption of Mt. Kunjit is considered to happen 0.06 million years ago, from the rock dating data. Therefore, it is considered that the heat source is the magma from which Kunjit volcanic rocks were resulted. Judging from the volume of Kunjit volcanic rocks, temperature of the magma is still as high as about 500°C.
3. The origin of deep hot water in the Duabelas geothermal system is meteoric water recharging from the southeastward area of the Duabelas area and a circulation time is more than 30 years. The origin of deep hot water in the Sikai geothermal system is also meteoric one, but its recharge area is not identified because there is no water sample from the deep reservoir.
4. Temperature of the deep reservoir in the Duabelas system is 200°C to 300°C and that in the Sikai system is more than 261°C. The deep reservoirs in both the systems are considered to be at nearly same horizon each others, their bottom and top are considered to be at the boundary between Pre-Neogene basement rocks and Neogene system and at about 800 m in elevation, respectively.
5. Although temperature of the vapor-dominated zone in the Duabelas system is relatively low (135°C to 160°C), that in the Sikai system is considerably high (about 224°C).

The results of the evaluation of geothermal resource in the Duabelas area are summarized as follows.

1. The extent of the geothermal reservoir is delimited as about 2 km² including Grao Duabelas, Grao Bujang and Grao Rasau, from the distribution of hydrothermal alteration zone, of mercury anomaly in soil and soil-gas, and of low resistivity.
2. Exploratory well LP-2 was drilled to 1,026.50 m in depth, and total lost circulation zones below 974.05 m in depth was considered as production zone. Well completion was succeeded to discharge geothermal fluid by swabbing method.
3. The characteristics of LP-2 is about 6 ton/hour of steam flow rate and 35 ton/hour of hot water flow rate at wellhead pressure of 5.2 ata. If the casing program of LP-2 were the production well size, the flow rates of steam and hot water are supposed to be about 4 or 5 times of measured flow rates.
4. Maximum generating output by the steam of LP-2 is estimated as 370 kW for back pressure steam turbine and 830 kW for condensing steam turbine, respectively.
5. Reservoir potential of Duabelas area is estimated by Volume Method and by Lumped Parameter Model Method, and both estimation show that exploitable potential is about 5 MW for 40 year's operation by back pressure steam turbine and about 5 MW for 90 year's operation by condensing steam turbine.

Duabelas area, which was selected as the most promising area in Kerinci geothermal field and was investigated in detail by exploratory wells, was evaluated as feasible to develop for the purpose of power generation from a viewpoint of resource development.

On the basis of the results of Resource Evaluation Stage, it is recommended to proceed the Study to Feasibility Study Stage.

1.2.2 Summary of Development Plan

1. Capacity of geothermal power plant

The demand forecast for this Project was prepared by categories of residential, commercial, public & others, and industry by the Planning Department of PLN, based on the past records of demand in PLN Sungai Penuh Sub-branch.

This demand forecast is a long-range forecast covering 1988 through 2000, and shows that the energy consumption at the consumer end will increase about four times from 6,043.7 MWh in 1987 to 24,385.2 MWh in 2000, and the required generation from 10,430.5 MWh to 31,669.0 MWh, or about 3 times, and the peak load is estimated to increase from 2,950 kW to 8,407.4 kW, or about 2.85 times.

As described in Chapter 3, approximately 5,000 kW of geothermal resources are confirmed in the Project Site, and it would be appropriate to build the geothermal power plant which utilizes the indigenous geothermal energy effectively to save the petroleum.

From the geothermal potential of the Project Site, an output of 5,000 kW can be expected, but in view of the advisability of operating the geothermal power plant as the base load supplying plant, it is planned to develop half of the assumed potential, or a total of 2,350 kW, of geothermal power plant will be built, in consideration of the load conditions in Kerinci Area.

2. Unit capacity

The system load and influence to the system by the unit shut-down at troubles or periodical overhaul are the major items for determination of the unit capacity.

a. System load

The peak load in 1994 when some new power sources will be needed is forecasted to be about 6 MW. From the view point that the unit capacity will be about 10 to 20 percent of the peak load, the unit capacity of the additional power source lies in a range from 600 kW to 1,200 kW. And the geothermal power unit is usually operated as a base load power plant for maximum use of geothermal energy. Finally, it is judged from the minimum load of Sungai Penuh system as referred to the daily load curve appeared in Chapter 5 that the unit capacity of 1,000 to 1,200 kW is appropriate.

b. First unit

In order to use steam produced from the exploratory well of LP-2 as early as possible, first, a power unit with the backpressure turbine of 350 kW, which is cheaper in the initial investment than the condensed type, will be installed.

c. Second and third units

The generating cost of each unit capacity of geothermal power plant when the plant is operated with a capacity factor of 80% as a base load plant is calculated with the result of 48.30 Mills/kWh, 31.26 Mills/kWh, and 34.30 Mills/kWh for 350 kW, 1,000 kW and 2,000 kW units. The 350 kW unit becomes highest because of high equipment cost for its small unit capacity. The cost of 350 kW unit is cheaper by only 10% than that of 1,000 kW unit. While the cost of 2,000 kW condensed unit is nearly double of that of 1,000 kW back pressure unit. It is judged that the 1,000 kW unit is the most economic one.

3. Outline of the Project

This Project includes production well drilling, civil works, construction of power generating facilities and high voltage distribution line. Outline of the Project is as follows.

1) Production well drilling

- a. LP-3 drilling and wellhead equipment : 1,200 m of drilling depth
- b. LP-4 drilling and wellhead equipment : 1,200 m of drilling depth

2) Civil works

- a. Access road : Width 4 m x 7,000 m
- b. Land reclamation : 1,189 m², 1,800 m², 1,800 m²
- c. Foundations : 1 lot for turbine generator, etc.
- d. Powerhouse : 1 lot
- e. Intake and water pipe line : Length 600 m

3) Power generating facilities

- a. Silencer : 3 sets
- b. Steam/water pipe line: 1 lot
- c. Separator : 3 sets
- d. Turbine generator : 350 kW x 1
(Backpressure turbine)
1,000 kW x 2
(Backpressure turbine)
- e. Electrical equipment : 1 set
and control panel
- f. Transformer : 437.5 kVA x 1
1,250 kVA x 2

4) High voltage distribution line

- a. Wiring system : 20 kV x 1 cct, 50 Hz, 3-phase
3 wiring system
- b. Conductor : AAAC 240 mm²
- c. Length : 40 km
- d. Interconnected : Sungai Penuh switching station
switching station

4. The project development schedule is formulated taking into account the earliest possible use of LP-2 which has already been producing geothermal steam, matching the power demand increase in Kerinci area, and the shorter construction period.

The project development schedule in which the commissioning of No. 1 Unit using the existing LP-2 is set in June 1993, and commissioning of No. 2 and No. 3 Units using the new production wells of LP-3 and LP-4 is set in September 1993 and December 1993 respectively.

5. Cost estimate

(Unit: 1,000 US\$)

<u>Items</u>	<u>FC</u>	<u>LC</u>	<u>Total</u>
1. Well Drilling and Wellhead Eqt.	<u>1,846</u>	<u>462</u>	<u>2,308</u>
2. Power Plant			
Power generating eqt.	4,946	-	4,946
Installation	438	-	438
Civil/Arch. works	-	423	423
Subtotal	<u>5,384</u>	<u>423</u>	<u>5,807</u>
(Unit cost per kW)			(2,471 US\$/kW)
3. HV Distribution	-	<u>615</u>	<u>615</u>
4. Engineering Fee	<u>769</u>	-	<u>769</u>
5. Total	<u>7,999</u>	<u>1,500</u>	<u>9,499</u>
6. Contingency	<u>1,192</u>	<u>231</u>	<u>1,423</u>
7. <u>Grand Total</u>	<u>9,191</u>	<u>1,731</u>	<u>10,922</u>

1.2.3 Summary of Financial and Economic Evaluation

1. Financial evaluation

a. FIRRs

The project is financially feasible since the obtained FIRR at 4.32% exceeds the opportunity cost of capital at 3.61%. However, the financial conditions will be deficit for about 8 to 10 years after commissioning. Though the Project will become profitable finally, this project will be a hard project. Though the Project FIRR does not show an implicit financial feasibility of the Project, the With/Without FIRR registered 6.56% over the case without project implementation. The value well clears the WMCC at 3.61% and this shows that the implementation of the project is highly effective and feasible to minimize the financial deficit of PLN's Ranting Sungai Penuh.

b. Sensitivity of FIRR to project cost

Because the project initial investment is greater than that of other type of thermal and internal combustion power plant, the sensitivity of FIRR to the project cost is tested in a range of plus and minus 15%. If the cost should increase by about 8 to 9 percent, the FIRR value can not exceed the hurdle rate of 3.61%. This study also reveals that one percent variation of the cost affects approximately 0.1 percent FIRR value.

c. Financial statements

The project income and cashflow statements show that the net profit of the project at the final year after repayment of loans will stand at US\$1,243 thousand, or over Rp.2 billion. If the net profit at the final year is

compared with that of Without case, the profit of PLN, or decrease of PLN's financial deficit will approximately amount to US\$12,961 thousand or Rp.22 billion.

2. Economic evaluation

The economic feasibility of the Project was evaluated by Economic Internal Rate or Return (EIRR) Method between the project and its close alternative, diesel power units.

a. EIRR and sensitivity analysis

The obtained EIRR registered as low as 3.68% which is not sufficient as compared with the economic opportunity cost of capital at 9%. This insufficient EIRR is derived from a substantially higher construction cost of the project than that of the alternative since the project cost includes cost for access road and special design for small scale geothermal power units to meet the Kerinci geothermal field. The sensitivity of EIRR to project cost reveals that variation of the project cost greatly affects EIRR and if the project cost is reduced, the EIRR becomes more favorable. Therefore, if the project should be continued and the subsequent units constructed, the total project EIRR will become very favorable over the alternative.

b. Fuel save

As the Project will provide the electricity generated by geothermal energy, if it is implemented, it will save the consumption of fuel amounting to about 32.7 thousand barrel per year, or about US\$545 thousand per year, or increase export value of about US\$545 thousand per year at an unit oil cost of 16 \$/bbl.

c. Rural development

Since Sungai Peruh area is located at high elevation of about 800 m a.s.l. and surrounded by the mountain ranges, the transportation route of the fuel oil is sometimes closed due to the land slide especially in the rainy season. These conditions make the power supply unstable at present. The Project, on the contrary, using the local energy, could provide the stable and reliable electricity to the society. In addition, the stable and reliable power supply will lead to the industrization of the agriculture and forestry and develop the rural areas. This will accord to the government policy of equalized development of the country.

d. Summary

Though the EIRR obtained is not sufficient, since the Project will provide said merits with the rural society and country, and the development and use of non-exportable and indigenous energy resource is a national objective, the implementation of this project should be determined in the stand point of national economy.

1.2.4 Technical Transfer

The JICA team carried out the Study in close cooperation with Indonesian counterparts. Through the Study, the JICA Team transferred geothermal exploration technologies to their Indonesian counterparts, such as purpose, analyzing method and interpreting method of each survey, in addition to operating system and maintenance method of equipments donated by JICA. The Indonesian counterparts now understand fully the methods and technologies needed to carry out geothermal development by themselves in other areas in Indonesia.

The Study contributed to the improvement geothermal exploration techniques in Indonesia, and will then effectively promote geothermal development in Indonesia.

1.3 Recommendation

1.3.1 Recommendations from Resource Evaluation Stage and Feasibility Study Stage

As results of Resource Evaluation Stage, the Duabelas geothermal system, which is the most promising area in Kerinci geothermal field and is explored in detail by surface survey and exploratory wells, is evaluated to have enough potential to develop a geothermal power plant of 5 MW.

As results of Feasibility Study stage, it is concluded that the optimum capacity of power plant at the Duabelas geothermal system is about half of 5 MW, which is the initial objective of the Project, by considering that the Project area is located at mountain area, its power supply system is isolated from the PLN's trunk lines, its power demand is limited and is almost for house lighting, and there are no factories. However the capacity is supposed to increase to 5 MW responding to the increase of power demand in the future.

1.3.2 Recommendation prior to the power plant development

The project is recommended to continue to install a portable packaged unit (back pressure type) of 350 kW by utilizing the steam of LP-2, to drill production wells LP-3 and LP-4, and then to install a portable packaged unit (back pressure type) of 1,000 kW at each site of production well.

The following items should be implemented prior to execute the Project.

1. Preparation of the Project budget

It is recommended to procure foreign currency of low interest such as OECF soft loan, in considering that FIRR of the Project is as low as 4.32%.

2. Projection well drilling

It is recommended to arrange the organization among PLN, VSI and PERTAMINA, prior to allocate the budget.

3. Meteorological Survey

Meteorological survey of rainfall, atmosphere temperature, humidity, wind direction, wind velocity at the Project site is recommended to design the detailed layout of the power plants, especially for considering the H₂S gas diffusion.

4. Monitoring of well characteristics of LP-2

It is recommended to continue the monitoring of well characteristics of LP-2, because well characteristics are basic data for power plant designing and are usually changing with time.

Chapter 2. General

Chapter 2. General

2.1 Project Background

The Republic of Indonesia (hereinafter referred to as "Indonesia") is developing the country in accordance to the Five Year National Developing Plan (PELITA) to improve the living standards. Main purposes of the plan are to prevent the increasing population of big city and then to transmigrate the population from the overpopulated areas to the unpopulated areas.

For these purposes, the Government is improving the infrastructures such as road, irrigation facilities, water resource, power source, school, hospital and communication system (including radio and television network) and is promoting the local industries such as tea, coffee, coconut, tobacco, rubber, etc. at the unpopulated area.

Energy policy of Indonesia is also based on the PELITA and its main objects are as follows,

1. Oil and gas are main products to gain foreign currency
2. Energy resources for domestic demand depend on hydro, coal and geothermal.

Indonesia is one of the world-famous volcanic countries, in which most of volcanos and associated geothermal fields are distributed on Sumatra, Java, Nusantara islands and Sulawesi, and the potential of geothermal resource is estimated as 8,000 - 10,000 MW in total.

With this background, the Government of Indonesia requested the Government of Japan to implement the Pre-Feasibility Study on geothermal project at Kerinci area, West Sumatra.

In response to the request of the Government of Indonesia, Japan International Cooperation Agency (JICA) dispatched the Survey Team composed of West Japan Engineering Consultants, Inc., Nittetsu Mining Consultants Co. and Nikko Tankai Co. to implement the surface surveys and to drill an exploratory well (LP-1) at Lempur, Kerinci, West Sumatra from 1981 to 1983.

This well was located at the boundary of prospective geothermal reservoir because of restraints of access road, and the characteristic of producing fluid (steam flow rate 3.5 t/h at wellhead pressure 0.58 atg) was not suitable for the purpose of power generation.

The Survey Report recommended that the potential of Duabelas area is estimated as more than 30 MW and it is preferable to carry out further field surveys and feasibility study to develop mini geothermal power plant of 5 MW.

In accordance to this recommendation, the Government of Indonesia requested the Government of Japan to continue the project to the next stage, and simultaneously conducted additional surveys, monitoring the well characteristics of LP-1 and preparation of access road.

In response to the additional request from the Government of Indonesia, JICA carried out the preparatory study to continue the project in October 1986, then decided to implement the project with cooperation of Volcanological Survey of Indonesia (VSI) and State Electricity Corporation (PLN).

2.2 Project Objective

The objective of the study is to prepare an optimum developing program of geothermal resource at Kerinci area, West Sumatra, and to implement a feasibility study to develop a mini geothermal power plant such as 5 MW, and then to contribute to an electrification program at isolated villages.

The Study consists of two stages; namely the Resource Evaluation Stage and Feasibility Study Stage.

Resource Evaluation Stage and Feasibility Study Stage consist of the following items respectively;

Resource Evaluation Stage

1. Collection and compilation of well characteristics records of LP-1
2. Electrical survey (Misc-a-la-masse and CSAMT methods)
3. Supplementary survey for geology and geochemistry
4. Drilling of the exploratory well LP-2
5. Well Logging and core analysis
6. Well test
7. Well chemical characteristic test

Feasibility Study Stage

1. Power situation in Project area
2. Socio-economic survey
3. Power development plan
4. Project development plan
5. Economic and Financial evaluation

2.3 Survey Team and Schedule

In accordance with the Scope of Work, the following organization were in charge of the Study.

<u>Japan</u>	<u>Indonesia</u>
Japan International Cooperation Agency (JICA)	Ministry of Mines and Energy
West Japan Engineering Consultants, Inc. (JICA Team)	Volcanological Survey of Indonesia (VSI)
	Perusahaan Umum Listrik Negara (PLN)

JICA Team, VSI and PLN were organized into the following staff to carry out the Study.

JICA Team

Project manager	Tadahiko *(Tamotsu)	SHIMOIKE IWAKI)
Geologist	Hideo	AKASAKO
Geochemist	Kanichi	SHIMADA
Reservoir engineer	Tetsuya	YAHARA
Geophysicist	Shigeo Yusuke Mitsuru	MATASAKA MATSUDA HONDA
Drilling engineer	Yoshikazu Toyomatsu Kyuya	SUEYOSHI SUGAWARA FUJII
Generating equipment	Masakazu	NAKAMOTO
Generating and Transmission Equipment	Ginjiro	MATSUO
Economic and Financial	Kenji	FUJII

* From December 1986 to January 1988

VSI

Coordinator	W. Subroto	MODJO
Geologist	Nikmatul Dang	AKBAR ASWIN
Geochemist	Djoko Abdul	HADISUDEWO SOMAD
Geophysicist	Firdausj Yanes	DJAZULI SIMANJUNTAK
Drilling engineer	Kartijoso A. BARIDJI Komar	SOEMODIPOERO DJAYAPERMANA BSc
Reservoir engineer	Susilo Reighman	BACHRI SIHONBING

PLN

Coordinator	Vincent T.	RADJA
Geologist	Sigit Dermawan Chairul	WITONO HASRI
Electrical engineer	WIDODO Poerba	HUTAPEA
Mechanical engineer	PURWANTO Sapto	TRIONO
Civil engineer	SIHABUDIN Budi	SUKMANA
Padang office	Andy Syahril	SUNARYO MULUK

The Study was implemented in two steps in accordance with the Scope of Work.

Table 2-1 Progress of the survey

		1986	1987	1988	1989
		F. Y. 1986	F. Y. 1987	F. Y. 1988	
Resource evaluation stage	Data collection and compilation of well characteristics records of LP-1	15Dec. 1Feb. 28Dec. 6Feb.			
	Electrical survey	7 Jan.	1 Jun.		
	Supplementary survey for geology and geochemistry	28Mar. 26Feb. 28Mar.	30 Jul. 1 Jun. 18 Jul. 1 Jul. 24 Jul.		
	Preparation of progress report		18Jul. 27 Jul. 24Jul. 5Aug.		
	Drilling of LP-2			6 Mar. 5Mar. 31Mar.	
	Well logging and core analysis		5 Jan. 3Feb. 24 Jan. 28Feb.	9 May. 30 May.	
	core analysis		22Dec. 3Feb. 14Jan. 28Feb.	9 May. 30 May.	
	Well test			9 May. 30 Jun.	
	Well chemical characteristic test			26 Feb. 26Mar. 9 May. 30 May.	
	Integrated analysis and preparation of interim report			1 Jun. 4 Jul. 30Jun. 13Jul.	
Feasibility study stage	Electric power survey			1 Aug. 31Aug. 30 Sept.	
	Socio-economic survey			1 Aug. 31Aug. 30Sept.	
	Formulation of optimum power output			1 Sept. 30 Sept.	
	Selection of optimum site			1 Aug. 31 Aug. 30 Sept.	
	Feasibility design			1 Oct. 28 Dec.	
	Cost estimation			1 Dec. 28 Dec.	
	Formulation of Implementation schedule			1 Dec. 28 Dec.	
	Economic and Financial analysis of the project			1 Dec. 31 Jan.	
	Comprehensive evaluation			4 Jan. 31 Jan. 15Feb.	
Report	Inception report	16 Dec.			
	Field report	25 Mar.	12 21 26 2 Jan. Jan. Feb. Mar. 21 Mar.	30 Aug	
	Progress report		28 Jul.		
	Interim report			2 Jul.	
	Draft final report				2 Feb.

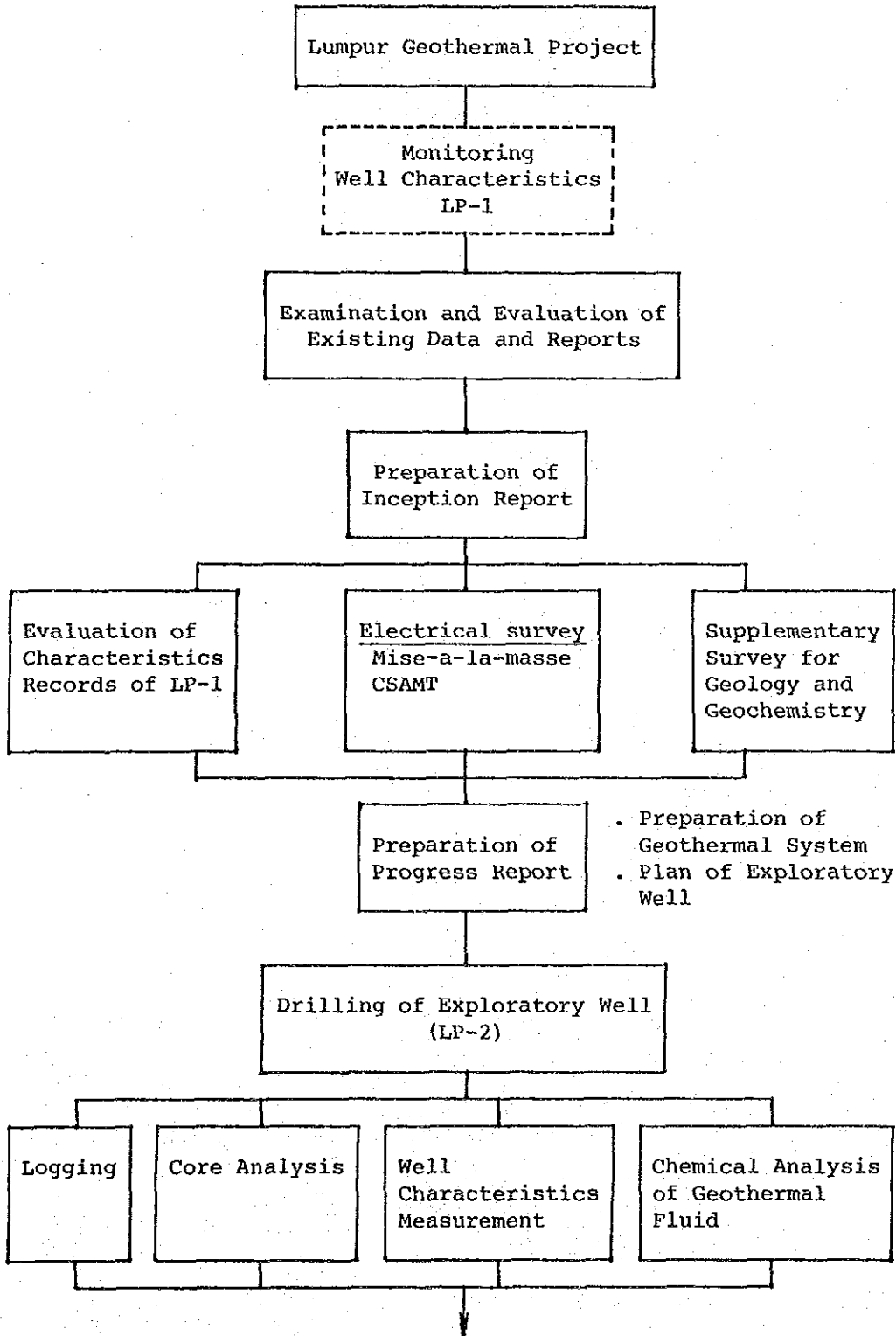
■ : Works in Indonesia. □ : Works in Japan.

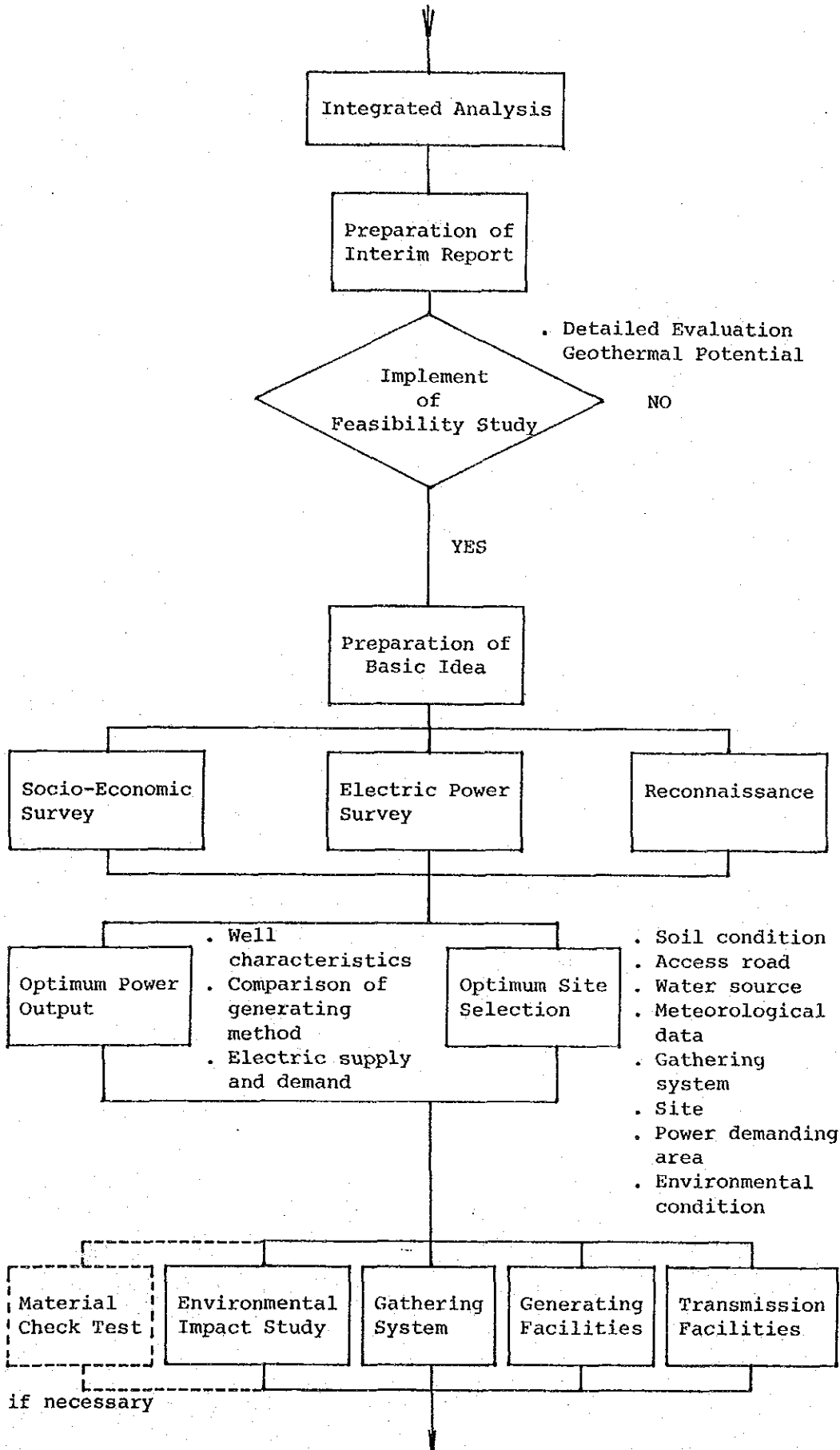
2.4 Procedure of the Project

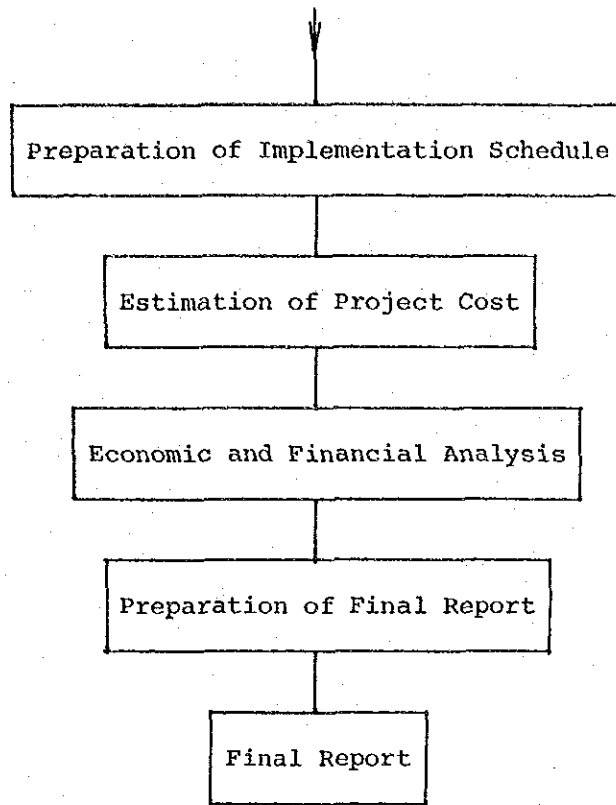
The Project was planned in accordance with the result of Lumpur Geothermal Project (1981 - 1983, by Japan International Cooperation Agency and Volcanological Survey of Indonesia), and proceeded step by step in accordance with the Flow Chart of the Study (Fig. 2-1) which was formulated to evaluate the exploitable potential of the Duabelas geothermal system in Kerinci geothermal field by supplementary surveys and drilling exploratory well, and then to implement a Feasibility Study to construct a portable packaged generating unit of 5 MW. Outlines of each stage are as follows;

Fig. 2-1 Flow Chart of the Study

Survey Flow for the Feasibility Study on
Kerinci Geothermal Development Project







1. Resource Evaluation Stage

Prior to the Study, the Inception Report was prepared in accordance with Scope of Work and by reviewing of existing data and reports, and then Evaluation of Characteristics Records of LP-1, Electrical survey, Supplementary survey for Geology and Geochemistry, and drilling of exploratory well LP-2 were conducted. As a result of Resource Evaluation Stage, it is concluded that Duabelas geothermal system has enough potential to proceed to Feasibility Study Stage.

2. Feasibility Study Stage

Prior to Feasibility Study Stage, Basic Idea of Feasibility Study was prepared, and then reconnaissance for Socio-Economic Survey, Electric Power Survey was conducted. Developing program and Economic/Financial evaluation of the Project were implemented.

It is concluded that the Project is not suitable to develop a conventional geothermal power plant such as 30 MW or 50 MW from points of electrical power demand of the Project area, and then the Project has difficulties from points of economic and financial view, however the development of portable package type power units is recommended in consideration of geographical and social conditions of the Project area.

2.5 Acknowledgement

JICA Team wish to express their sincere appreciation of the supports and assistance given by Mr. Soebadi M. SANYOTO, Director of Bureau of Foreign Cooperation, Dr. Adjat SUDRADJAT, Director of VSI, Ir. Mohd SINGGIH, Director of Planning of PLN, and Dr. Nengah SUDJA, Deputy Director of Planning of PLN.

The readiness to provide available data and information and the efficient cooperation given during the Study were very valuable. Without their supports and assistances, it were hardly possible to complement the Study successfully.

Chapter 3. Geothermal Resource

Chapter 3. Geothermal Resource

3.1 Geothermal Development in Indonesia

Indonesia is one of the world-famous volcanic countries, and almost half of these volcanoes bear evidence of geothermal activities, such as fumaroles and surface activities. Up to now, development of geothermal resource in Indonesia is divided into four stages.

1. First stage (Before World War II)

In 1926, scientific research on geothermal resource started at Kamojang field in West Java, and then at Dieng field in Central Java. Several exploratory wells were drilled at both areas, and one of these wells in Kamojang field is still producing dry steam.

2. Second stage (Between 1964 and 1974)

In 1964, Volcanological Mission of UNESCO visited Indonesia to reconnoiter the geothermal fields.

In 1968, French team sponsored by French government conducted preliminary survey and made recommendations of further investigation.

In 1970 - 1972, the United States Agency for International Development, with Geological Survey of Indonesia and Power Research Institute of PLN conducted preliminary survey in Sumatra, Java, Bali, Sulawesi, etc., and reported the high potential of Dieng field.

3. Third stage (Between 1974 and 1984)

In 1974, based on Presidential Decree, PERTAMINA was appointed to undertake exploration and development of steam fields, and PLN was appointed to generate power. Six fields, namely Kamojang, Banten, Cisolok, Dieng, Salak, in Java and Bali, were given the priority of exploration.

In 1975, the Kamojang Geothermal Project was started with New Zealand government fund and 41 wells were drilled and its installed capacity is 140 MW (30 MW x 1 unit, 55 MW x 2 units). PERTAMINA has drilled 11 production size exploratory wells at Dieng field.

In 1982, PLN started the survey for the site selection of power plant at Dieng field.

4. Fourth stage (up to 2000)

Preliminary inventories have been carried out by the Volcanological Survey of Indonesia (VSI) and Pertamina for: Nusatenggara, 9 areas; Mollucos, 4 areas; Bali, 1 area; Sumatera, 18 areas; Java, 29 areas; and Sulawesi, 16 areas. Geothermal resources that could be developed for electrical power generation between 1995 and the year 2000 are estimated to be 550 MW, especially from Dieng, Ijen (Java), Kotamobagu (Sulawesi), Bali, Flores (Nusatenggara), Kerinci and Souh (Sumatera). In line with the government energy diversification policy, the electric energy generated from geothermal resources would reach nearly 1,500 MW in the year 2000.

However, due to a shortage of funds, the development of several fields in Java will be carried out mainly through a Joint Operation and Energy Sales Contract with foreign contractors. Joint Operation and Energy Sales Contracts were made with Union Geothermal of Indonesia for Salak field in 1982, and Amoseas for Darajat field in 1984.

3.2 Resource Evaluation of Kerinci Geothermal Field

3.2.1 Geological Model

1. Tectonics around the Sumatra Island

Indonesia is a world-famous volcanic country. The islands, from Sumatra to Sumba, constitute the island-arc system on the margin of the Southeast Asia plate, where the Indian Ocean plate is subducting. Around the Sumatra Island, a typical double island-arc system is observed as shown in Fig. 3-1. There is the Sunda trench, deep sea exceeding 6,000 m and extending from the northwest to the southeast, in the southwestward from the island. The outer arc is composed of the islands between the Sumatra Island and the Sunda trench, from Simeulue to Enggano, and any Quaternary volcanism cannot be observed. There is large-scale strike-slip fault, Great Sumatran fault, in the western part of the Sumatra Island. Quaternary volcanism is recognized on the eastern side (inner arc) of this fault and is not recognized on the western side where Pre-Quaternary basement rocks (mainly Tertiary) crop out extensively. Therefore, the volcanic front is considered to correspond nearly with this fault. In the western part of the inner arc, a depression zone was resulted along the Great Sumatran fault by tectonic movement which began in Miocene and there became active Quaternary volcanism field. Eleven Quaternary volcanos are recognized in the depression zone and arranged along some rows trending nearly in the direction of E-W. This trend intersects obliquely with the volcanic front (and also with the Great Sumatran fault), forming a so-called clock-wise volcanic row. This is characteristic features of volcanic row in the tectonic field where the plate is subducted obliquely to the extending direction of trench. Judging from the above condition, there is a high geothermal potential in the depression zone, because it is considered that there is very active magmatism resulted from subduction of the Indian Ocean plate under the Southeast Asia plate in a

deep part in the depression zone. The study area, Kerinci geothermal field, is just situated in this depression zone. In the eastern part of the inner arc, there is a world-famous oil field.

2. Geology around Kerinci geothermal field

As shown in Fig. 3-2, the study field is covered widely by Quaternary volcanic rocks (Tua volcanic rocks, Raja volcanic rocks, and Kunjit volcanic rocks). Fan deposits and alluvium are also distributed widely in the northeastern part of the study field, with a relatively flat place. Neogene acidic volcanic rocks (mainly composed of rhyolite, dacite, and andesite) and Pre-Neogene sedimentary rocks (mainly Mesozoic) crop out in the surrounding area. Therefore, these rocks are considered to be distributed widely under the Quaternary volcanic rocks in this field.

Tua volcanic rocks are recognized at the lowest horizon among the Quaternary volcanic rocks observed in the study field, and composed mainly of hornblende-pyroxene andesite lava, pyroxene andesite lava and tuff breccia. These volcanic rocks are abundant in joints. Tua volcanic rocks around Grao Duabelas are strongly altered. According to the data from LP-1 and LP-2, thickness of these volcanic rocks is more than 1,000 m.

Raja volcanic rocks are distributed widely, covering upon Tua volcanic rocks. These volcanic rocks are mainly composed of two pyroxene andesite lava and tuff breccia. Raja lava is very hard compact rock, as a whole. The lava cropping out along R. Lolo is relatively dominant in joints. The lava cropping out along R. Rasau shows relatively young age (0.17×10^6 Year).

Kunjit volcanic rocks are composed of Kunjit lava dome, Kering lava, Lempur pyroclastic flow, and Rawang-Sipedjani pumice gravel bed. Kunjit lava dome is observed at the top of Mt. Kunjit, Mt. Setangis, westward hill from Lolo-ketjil, northward from Lolo-hilir, and southward hill from Lempur in the distance of about 3 km. This lava dome is mainly composed of pyroxene-hornblende dacite lava dome. In the lava at Mt. Setangis, certain amount of xenolith are observed. The age of this lava was deduced to be 0.06×10^6 Year to 0.25×10^6 Year from rock dating by fission track method in the supplementary survey of this study. Especially, the lavas cropping out at the top of Mt. Kunjit (0.06×10^6 Year) and at Mt. Setangis (0.07×10^6 Year) are very young.

Kering lava is distributed on the eastern slope of Mt. Kunjit in a tongue-like shape. Although petrological characteristics of this lava are nearly same as those of Kunjit lava dome, Kering lava is different from the latter in the point that it is composed of lava flows.

Lempur pyroclastic flow is mainly distributed in the southward area from Mt. Kunjit and on the northward plateau from Mt. Kunjit. This pyroclastic flow is mainly composed of pyroxene-hornblende dacitic volcanic breccia and ash bed.

Rawang-Sipedjani pumice gravel bed is distributed around the basis of R. Rasau, R. Lolo, and R. Suman, of which elevation is lower than 1,200 m. This bed is mainly composed of dacitic pumice and silt, and considered to be resulted from sedimentation in water.

As shown in Fig. 3-3, NW-SE trending faults and NNE-SSW trending faults are significantly recognized in this field. The fault of fl estimated from CSAMT survey is considered to correspond with the Daubelas fault. The trend of the former is nearly same as that of the volcanic row composed of Mt. Raja, Mt. Kunjit, Mt. Sumbing and Mt. Masurai. However, geothermal manifestation is not recognized along the faults of this

trend, though alteration zone is recognized along the Aur fault. The trend of the latter is nearly same as that of the Great Sumatran fault. Active geothermal manifestation and alteration zone are recognized along the Duabelas fault and the Sikai fault, of this trend. Moreover, high concentration areas of Hg and CO₂ in soil air are recognized along the Sikai fault, the Duabelas fault and the fault of f2. Therefore, it is considered that these three faults control geothermal activity in this field.

3. Geothermal manifestation and alteration zone in Kerinci geothermal field

As shown in Fig. 3-4, geothermal manifestation is recognized at Grao Kunjit and Grao Sikai in the Sikai area and at Grao Duabelas, Grao Bujang, Grao Rasau, Grao Bulan and Abang hot spring in the Duabelas area. Grao Kunjit and Grao Sikai, in the Sikai are, are situated on the Sikai fault and there are active fumaroles which discharge considerable amount of steam and gas. Hydrothermal alteration zone is recognized in considerably wide extent at Grao Kunjit, surrounding the fumaroles. Hydrothermal alteration zone is also recognized at Grao Sikai but its extent is relatively narrow, comparing the geothermal activity.

In the Duabelas area, geothermal manifestation is recognized mainly along the Duabelas fault, though Grao Bulan is not situated on the Duabelas fault, as shown in Fig. 3-4. Hot water with temperature of about 60°C is flowing out at Abang hot spring but hydrothermal alteration zone is not recognized there. At Grao Bulan, there is fumaroles and the alteration zone, but the extent of the alteration zone is narrow. At Grao Duabelas, Grao Bujang and Grao Rasau, there are active fumaroles and boiling mud pools, accompanied with the alteration zone of relatively wide extent. Especially, at Grao Duabelas, many fumaroles and mud pools are scattered in a relatively wide area.

In the Duabelas area and its southward, there are three alteration zones without geothermal manifestation such as fumarole and hot spring. One of them is in the southward of the Duabelas area, Kering alteration zone along the Aur fault. The others are in the Duabelas area, Abang alteration zone along R. Abang and Rasau alteration zone along the valley between Grao Bujang and Grao Rasau. As a whole, alteration zone in the Duabelas area is mainly distributed along the Duabelas fault.

4. Geological model of Kerinci geothermal field

From the above geological conditions, geological model of this field was estimated as shown in the cross sections of Figs. 3-5 and 3-6. Fig. 3-5 is the geological cross section in the direction of ENE to WSW, passing LP-2 and Grao Kunjit. Fig. 3-6 is the geological cross section in the direction of NNE to SSW, passing LP-1 and LP-2. The Duabelas fault is represented as a nearly horizontal line in Fig. 3-6, because this section is nearly parallel to the strike of the Duabelas fault.

Kerinci geothermal field is situated in the depression zone of which western edge is limited by the Great Sumatran fault. This depression zone is considered to be resulted from subsidence of Pre-Neogene basement rocks, which began with the eruption of acidic volcanic rocks (Neogene system, cropping out in the surrounding area). This volcanic rocks accumulated thickly on the basement rocks.

Basic to neutral magma of high fluidity was extruded in the Quaternary. Tua volcanic rocks were resulted from this magma and covered widely Neogene system in the early to middle Pleistocene. Judging from the data of LP-1 and LP-2, thickness of Tua volcanic rocks in the Duabelas area is considered to be more than 1,000 m. In the middle to late Pleistocene, Raja volcanic rocks covered them.

Thereafter, composition of the magma became acidic one. Kunjit volcanic rocks were resulted from this acidic magma in the late Pleistocene. Mt. Kunjit, Mt. Setangis and other dome-shaped volcanos had been resulted from this volcanism. The remained magma after this volcanism is regarded to be the heat source of the geothermal system in this field.

For the geothermal system in this field, it is considered that NNE-SSW trending faults in the Duabelas area (Duabelas fault and the fault of f2 estimated from CSAMT survey) and the Sikai area (Sikai fault) are the most important geological structure; they are considered to control geothermal activity. And the Quaternary volcanic rocks in this field are relatively rich in joints and hydrothermal alteration is sometimes recognized along them. Therefore, it is considered that the joints are additional factor to control the geothermal activity in this field.

3.2.2 Model of Geothermal System

1. Detected exploratory data on the ground surface

In the Kerinci geothermal field, geothermal manifestations, such as fumarole and hot spring, are recognized mainly along the Sikai fault and the Duabelas fault and geothermal activity is controlled by these faults, the fault of f2 and joints, as mentioned before. Some characteristic features, indicating that there is active geothermal system, are detected along these faults by some explorations; high concentration of Hg and CO₂ in soil air by 1 m depth survey, low resistivity zone (less than 3 ohm-m) by CSAMT survey, alteration zone resulted from acidic hot water (occurrence of kaolinite and/or alunite) by supplementary survey for geology and so on, as shown in Fig. 3-7.

From the difference in noncondensable gas concentration in the steam from the fumaroles and LP-1, it is identified that there are two geothermal systems in this field, the Duabelas geothermal system along the Duabelas fault and the Sikai geothermal system along the Sikai fault, though the concentrations suggest that there are deep reservoirs of water-dominated type in the both systems. And LP-1 was drilled to this deep reservoir in the Duabelas geothermal system.

Chemical composition of hot water from LP-1 indicates that the deep reservoir in the Duabelas geothermal system is composed of hot water of neutral chloride type which is available for geothermal development. Hydrogen isotope ratio of geothermal fluid from LP-1 and of cold water in and around this field indicates that the origin of the hot water in this deep reservoir is meteoric water recharging from the southeastward area of the Duabelas area (see Fig. 3-7). And the temperature of the hot water in this reservoir is estimated to be 200°C to 300°C from chemical composition and isotope ratio of geothermal fluid from LP-1 and of gas from the fumaroles in the Duabelas area. Judging from minor gas ratios and carbon

isotope ratio in carbon dioxide of gas discharging from the fumaroles, it is considered that geothermal gases (such as carbon dioxide), which are mixtures of magmatic origin gas and organic gas generating from the Pre-Neogene basement rocks (sedimentary rocks), come up through the basement rocks and come into this deep reservoir. And gas isotope thermometers indicate that the temperature of the basement rocks or around the heat source is 332°C to 480°C. From the rock dating data, the heat source is considered to be remained magma after the volcanism resulting Kunjit volcanic rocks and its temperature is estimated to be about 500°C.

Isotope ratios of hydrogen and oxygen of the steam from the fumaroles in the Duabelas area indicate that these steam are derived from the deep water reservoir. It is considered that there is vapor dominated zone above the deep reservoir and temperature in this zone is estimated to be 135°C to 160°C from isotope ratio of hydrogen and oxygen in steam. In the Duabelas area, alteration zone resulted from acid hot water is recognized with considerably wide extent, from Grao Duabelas to Grao Rasau, along the Duabelas fault and it is surrounded by montmorillonite zone (resulted from neutral to alkaline water at a low temperature). The mechanism of hydrothermal alteration near the surface in the Duabelas area is explained as the followings. Secondary acidic hot water is resulted near the surface from upflowing steam and geothermal gas through the fault and joints from the deep reservoir, heating of ground water near the surface by the steam and oxidation of the gas (mainly hydrogen sulphide). Hydrothermal alteration along the Duabelas fault, between Grao Duabelas and Grao Rasau, is derived from this secondary hot water. The temperature of this hot water decreases during lateral flowing and its pH condition changes to neutral or alkaline one by interaction with surrounding rocks. According to this physical and chemical change of secondary hot water during lateral flowing, montmorillonite zone is resulted in the marginal part of the alteration zone.

In the Duabelas area, neutral bicarbonate type hot water is flowing out at Abang hot spring. From chemical composition of this hot water, it is considered that there is water reservoir of neutral bicarbonate type at a shallow level and it is resulted from percolation of the upflowing steam into ground water aquifers. And the temperature of this reservoir is estimated to be 145°C to 168°C.

Judging from the distribution of low resistivity zone detected by CSAMT survey, alteration zone and estimated reservoir temperature, the center of geothermal activity in the Duabelas geothermal system is in the part along the Duabelas fault and between Grao Duabelas and Grao Rasau. And it is also deduced that LP-1 and Abang hot spring are situated in the marginal part of the geothermal activity. This is supported by chemical composition of hot water discharging from LP-1 in earlier stage, which indicates that mixing of hot water of relatively low temperature with deep hot water was occurred around LP-1. Therefore, the drilling site of LP-2 was located between Grao Duabelas and Grao Bujang, southward from LP-1 with distance of about 1.5 km.

For the Sikai geothermal system, detailed chemical characteristics of deep hot water are uncertain, because there is no water derived directly from the deep water reservoir. However, similarity in chemical composition between fumarolic gas in the Sikai area and the Duabelas area indicates that the deep water reservoir in the Sikai area is also neutral chloride type. Moreover, as same as in the case of the Duabelas geothermal system, it is considered that geothermal gases upflowing from a deeper part come into the deep reservoir, and that they are originated from the common source with the Duabelas system. The temperature of the deep water reservoir is estimated to be not lower than 261°C, by gas isotope thermometer. And the elevation of this deep reservoir is considered to be nearly same as that of the reservoir in the Duabelas geothermal system, from the electrical survey in the previous works.

It is considered that there is vapor-dominated zone, above the deep reservoir, resulted from upflowing steam from the reservoir, as same as the Duabelas geothermal system. However, the temperature of this zone is considerably higher than that in the Duabelas system, it is estimated to be about 224°C, from isotope ratio of hydrogen and oxygen in steam from Grao Sikai. At Grao Sikai, it is considered that there is no large-scale secondary hot water aquifer above the vapor-dominated zone, even if there are some local secondary hot water aquifers. This is supported by relatively narrow alteration zone around Grao Sikai. On the other hand, secondary hot water of acid-sulfate type (steam heated type) is recognized at Grao Kunjit. Alteration zone with considerably wide extent, observed around Grao Kunjit, is considered to be resulted from interaction of this secondary acidic hot water with surrounding rocks. Estimated evaporation temperature by isotope ratio of hydrogen and oxygen in steam and hot water from Grao Kunjit is 92°C and it is approximately same as the boiling temperature on the ground surface. Therefore, it is deduced that most of steam discharging from Grao Kunjit are originated from the reservoir of secondary acidic hot water near the surface.

2. Data from the exploratory well

The exploratory well, LP-2, was drilled at the site between Grao Duabelas and Grao Bujang. The site was located near the center of geothermal activity in the Duabelas area, estimated from the electrical survey and supplementary survey for geology and geochemistry. However, the location is not just at the center of geothermal activity, because the problem concerning with access road to the site is also considered at the site selection and it is located beside the access road which had been prepared.

As shown in Fig. 3-8, LP-2 was drilled to 1,026.5 m in depth. Identified secondary minerals in core samples from LP-2 indicate that hydrothermal alteration by neutral to alkaline hot water is dominant around LP-2, except near the surface.

Although hydrothermal alteration by acidic water is recognized near the surface, it is limited in the part shallower than 50 m. Hydrothermal alteration in the part shallower than 670 m is more intensive than that in the deeper part but the high concentration of mercury in the rocks (indicating high geothermal activity) is recognized in the part deeper than 620 m. Judging from the occurrence of hydrothermal veins and fractures, it is considered that fractures in the shallower part around LP-2 was already filled by secondary minerals and geothermal activity became weak. On the other hand, fractures in the deeper part are not yet filled by secondary minerals and it is considered that geothermal activity is high and still young. Estimated alteration temperature from the occurrence of secondary minerals in the part deeper than 620 m is lower than the estimated one from fluid inclusion measurement; the former is 100°C to 200°C and the latter is more than 200°C. This phenomenon can be explained by young geothermal activity; mineral assemblage in the deeper part around LP-2 is not yet reached to the equilibrium under the present temperature condition.

The estimated vertical temperature profile at LP-2 site, from the fluid inclusion measurement, is as the followings; it is about 100°C at about 230 m, 150°C at about 420 m, 200°C at about 600 m and about 224°C from 970 m to 990 m.

The density of upper Tua volcanic rocks is relatively smaller than those of middle Tua volcanic rocks and lower Tua volcanic rocks. On the contrary, the porosity of the former is larger than those of latter. However, there is not significant difference in density and porosity between middle Tua volcanic rocks and lower Tua volcanic rocks. Averaged values of density, porosity and thermal conductivity of upper Tua volcanic rocks are 2.4 g/cm³, 12% and 4.8x10⁻³ cal/cm sec °C, respectively (containing the data from LP-1). And those of middle Tua volcanic rocks and lower Tua volcanic rocks are 2.5 g/cm³, 10% and 5.5x10⁻³ cal/cm sec °C.

As shown Fig. 3-8, lost circulation happened frequently during the drilling. However, the most important lost circulation as a production zone of geothermal fluid is the one which began from 974.05 m, judging from the amount of the lost and temperature condition. Relatively many open fractures with nearly vertical dips are recognized from 975.60 m to 985.00 m and core recovery is very bad in this range. And it is considered that LP-2 crosses the Duabelas fault in this range. From the logging data, the main lost circulation in this range. From the logging data, the main lost circulation in this lost circulation zone is considered to happen at 983 m and it is deduced that the permeability of this lost circulation zone is considerably large. From pressure logging, the reservoir pressure is estimated to be about 48 ata.

Chemical composition of geothermal fluid from the above production zone indicates that hot water in the reservoir is meteoric origin and chloride type, and that geothermal fluid discharging from LP-2 is derived from the deep water reservoir of the Duabelas geothermal system, as same as the case of LP-1. However, concentrations of chemical components dissolved in the water from LP-2 and estimated temperature from them (silica and Na-K-Ca-Mg thermometers) are relatively high, comparing with the data of LP-1. This means that LP-2 is situated near the center of geothermal activity, compared with LP-1, and confirms that model estimated at the site selection of LP-2. The estimated temperature of the reservoir around LP-2 is about 220°C. This value is concordant with the temperature estimated from fluid inclusion measurement (224°C). Therefore, it is deduced that reservoir temperature around LP-2 is about 224°C. However, isotope geothermometer indicates a little higher temperature, 238°C to 271°C, than the above temperature. This temperature condition may be that in the deeper part of the reservoir than the depth of LP-2. Of course, this does not mean the temperature condition under the bore hole bottom of LP-2 but means that of deeper part along the Duabelas fault, considering the geological structure as mentioned before.

Judging from tritium concentration in the hot water (1.0 T.R. to 1.8 T.R.), circulation time of hydrothermal convection system in the Duabelas area is estimated to be more than 30 years. And the recharge area is deduced to be the southeastward area of the Duabelas area from the isotope ratio of hydrogen in the hot water; this result is same as that of supplementary survey for geochemistry.

Concentration of noncondensable gas in the steam discharging from LP-2 is considerably low, such as 0.078 vol.%. This is very suitable for condensation type power generation with condenser at the outlet of the turbine. Moreover, chemical composition of hot water from LP-2 indicates that scale problem is not serious for the geothermal development, concerning the deep water reservoir in the Duabelas area. Therefore, it is deduced that the deep water reservoir in the Duabelas area is very suitable for geothermal power generation.

3. Model of geothermal system

From the above data, the model of geothermal system in the Kerinci geothermal system is estimated and it is shown in Figs. 3-9 and 3-10, as a cross section. And the model is also given in Fig. 3-11, as a three-dimensional model.

There are two geothermal systems in the Kerinci geothermal field; the Duabelas geothermal system along the Duabelas fault and the Sikai geothermal system along the Sikai fault. The both systems are considered to be hydrothermal convection system resulted from water of meteoric origin and upflowing heat and gases from the remained acidic magma after the volcanism, from which Kunjit volcanic rocks were resulted. And the temperature of the magma is estimated to be about 500°C.

For the Duabelas geothermal system, recharge area of meteoric water is in the southeastward area of the Duabelas area.

Recharged meteoric water is considered to flow toward the west or the northwest upon the Pre-Neogene basement rocks. The flowing meteoric water will be heated by conductive heat from the magma and change to neutral chloride type hot water by interaction with surrounding rocks. This hot water will contain upflowing gases from basement rocks and flow up along the Duabelas fault and the fault of f2. And this hot water is considered to be reserved mainly in a fracture zone along the faults. The data from LP-2 indicate that circulation time of water from the recharge area to the reservoir is more than 30 years. Temperature of this reservoir is estimated to be 200°C to 300°C. On the other hand, temperature of the basement rocks or around the heat source is estimated to be 330°C to 480°C in the Duabelas area. Solubility of silica increases with increasing temperature of solution until 320°C, but it decreases inversely with the increasing temperature in the condition of higher temperature than 320°C. Therefore, it is considered that silica deposition (silica sealing) occurs at the bottom of this reservoir, presumably near the boundary between the Neogene system and the Pre-Neogene basement rocks, and the deepest part of the reservoir is limited by this sealing zone because liquid phase cannot flow across this zone.

It is also considered that sealing zone is resulted from deposition of secondary minerals around the reservoir, near the top of the reservoir, due to the change of physical and chemical conditions by the effect of ground water. This sealing zone is regarded to be upper limit of the reservoir. Judging from the data of LP-2, the level of this upper limit is considered to be about 600 m in depth. According to chemical data of hot water from LP-1, it is considered that this sealing zone around LP-1 is not complete and hot water of relatively low temperature come into the reservoir from a shallower part. Moreover, it is considered that the northern limit and the southern limit in the lateral extent of the reservoir are respectively around LP-1 and around Grao Rasau, judging from the distribution of temperature estimated by

geochemical thermometers, from distribution of alteration zones on the surface and from distribution of low resistivity zone detected by CSAMT survey.

The vapor-dominated zones reaching the fumaroles such as Grao Duabelas, Grao Bujang, and Grao Rasau are resulted by steam flowing up through sealing zone. Temperature of steam in the vapor-dominated zone is estimated to be 135°C to 160°C. A secondary acidic hot water is resulted near the ground surface from ground water heated by upflowing steam and oxidation of gases such as hydrogen sulphide upflowing together with steam. Especially, acid-sulfate water is induced around the fumaroles. Alteration near the surface is brought about by interaction of these secondary acidic hot water with surrounding rocks and by deposition of secondary minerals from the hot water. Alunite zone is produced around the fumaroles by the acid-sulfate water and kaolinite zone is produced around the alunite zone by acidic water. According to the data from LP-2, this acidic water around LP-2 is considered to exist in the part shallower than 50 m. Temperature of acidic water decreases in lateral flowing and halloysite zone is produced around kaolinite zone. Moreover, acidic water changes to neutral one in lateral flowing by interaction with surrounding rocks and montmorillonite zone is produced around halloysite zone.

There is reservoir of neutral bicarbonate type water at a shallow level in the Duabelas area. This reservoir is considered to be the secondary one resulted from percolation of the upflowing steam from the deep reservoir into ground water aquifers. The hot water from this secondary reservoir flows out at Abang hot spring. Temperature of this secondary reservoir is estimated to be 145°C to 168°C, from silica content in the hot water from Abang hot spring.

For the Sikai geothermal system, although its detailed characteristics are not clear (for example, recharge area, circulation time of water and so on), because there is no well in the Sikai area and water sample from the deep water reservoir cannot be collected, nearly same condition of the geothermal system as that of the Duabelas geothermal system is considered from chemical composition of fumarolic gas. Meteoric water flowing upon the basement rocks is heated by conductive heat from the same heat source as that of the Duabelas geothermal system and changes to hot water of neutral chloride type by interaction with surrounding rocks. This hot water flows up along the Sikai fault and the deep water reservoir is resulted in a fracture zone along the fault. Geothermal gases upflowing from the basement rocks is considered to come into this reservoir. Gas isotope thermometer indicates higher temperature condition (more than 261°C) of the deep reservoir than that of the Duabelas geothermal system. It is considered that sealing zone is resulted around the top of the reservoir by deposition of secondary minerals. The top of the reservoir is considered to be at nearly same elevation as the top of the reservoir in the Duabelas area from the electrical survey data in the previous works. Judging from the distribution of alteration zone, it is considered that overlaying rocks above the reservoir are relatively poor in fractures and upflowing of steam along the fault occurs only at limited parts, at Grao Sikai and around Grao Kunjit. And there are vapor-dominated zones above the reservoir at Grao Sikai and around Grao Kunjit. Temperature of this zone is estimated to be about 224°C. Around Grao Kunjit, there is a secondary reservoir of acid-sulfate type near the surface. This secondary reservoir is resulted from ground water heated by upflowing steam from a deeper part and from oxidation of hydrogen sulphide upflowing together with steam. Temperature of this reservoir is about 100°C. Large-scale alteration around Grao Kunjit is considered to be resulted from this acidic hot water.

4. Promising prospect in the Kerinci geothermal field

There are two geothermal systems in this field, with nearly same characteristics. One is the Duabelas geothermal system along the Duabelas fault. The other is the Sikai geothermal system along the Sikai fault. In the both systems, there are deep water reservoirs of neutral chloride type and overlaying vapor-dominated zones. Judging from estimated reservoir temperature, it is deduced that the deep reservoirs in the both systems have enough potential for geothermal development. Moreover, identified quality of the geothermal fluid from LP-1 and LP-2 is available for power generation; considerably low concentration of noncondensable gas and not serious scale problem. Therefore, the main target for the geothermal development in this field is the deep water reservoirs of neutral chloride type in the Duabelas area and the Sikai area. Although the vapor-dominated zone in the Duabelas area is not available for geothermal development because of low potential (temperature is considered to be 135°C to 160°C), the vapor-dominated zone in the Sikai area has relatively high potential (estimated temperature is about 224°C). Therefore, the vapor-dominated zone can be regarded as an additional target for geothermal development in the Sikai area.

From some exploratory data, it is considered that the deep water reservoir exists along the Duabelas fault between around Grao Duabelas and Grao Rasau and along the fault of f2 from around Grao Duabelas to the valley between Grao Bujang and Grao Rasau, in the Duabelas area. And in the Sikai area, the reservoir is considered to exist along the Sikai fault, at least from Grao Sikai to Grao Kunjit. The existence of the reservoir along the Duabelas fault is already confirmed by LP-1 and LP-2, though those along the fault of f2 and along the Sikai fault are not yet confirmed by the drilling of exploratory well. Therefore, promising areas in this field are summarized as shown in Fig. 3-12. The most promising area is in the Duabelas area and along the Duabelas fault, because it

is already confirmed by the exploratory wells. Its northern limit is around Grao Duabelas and the southern limit is around Grao Rasau. And it is considered that the top of the reservoir is at the elevation of about 800 m and its bottom is at the level of boundary between the Pre-Neogene basement rocks and the Neogene system. In the Duabelas area, there is also promising area on the eastern side of the above promising area. This area is along the fault of f2, but it is not yet confirmed. Although the bottom of the reservoir is also considered to be at the level of the boundary between the basement rocks and the Neogene system, its top is considered to be at a lower level than that along the Duabelas fault. In the Sikai area, although it is not yet confirmed, the area from Grao Sikai to Grao Kunjit, along the Sikai fault, is considered to be promising. The top of the reservoir is considered to be at about 800 m in elevation and its bottom is around the boundary between the basement rocks and the Neogene system. In this promising area, it can be expected that there is production zone (vapor-dominated zone, mentioned before) above the deep water reservoir.

3.2.3 Evaluation of Geothermal Resource

The objective of geothermal resource evaluation is to estimate the possible resource from the quantity of heat and fluid stored in geothermal reservoir. The data obtained from LP-1 and LP-2 drilled in the Duabelas geothermal system are not enough to evaluate the structure and physical characteristics of geothermal reservoir. Consequently, the Volume method and the Simulation method using Lumped Parameter Model were applied for the evaluation of this field.

1. Resource evaluation by Volume method

The Volume method is convenient and is usually adopted at the beginning stage of geothermal development. The possible resource from the hydrothermal convection system reservoir defined by Nathenson. M is calculated from the following equation.

$$Q_R = \int C v (t - t_{ref}) R_f \dots\dots\dots (1)$$

where,

- Q_R : Possible resource (heat energy), (KJ)
- $\int C$: Volumetric heat capacity of rock and water (KJ/m³.°C)
- V : Geothermal reservoir volume (m³)
- t : Geothermal reservoir temperature (°C)
- t_{ref} : Reference temperature (15°C)
- R_f : Recovery factor

The promising reservoir for geothermal development in the Duabelas geothermal system was synthetically discussed from the results of geological survey, geochemical survey and electrical survey. Consequently the area and the thickness of promising geothermal reservoir was inferred to be 2 km² (1 km x 2 km) and 800 meters (the center of reservoir is 1,000 meters above sea level), respectively as shown in Fig. 3-11 and Fig. 3-12.

The temperature, rock density and porosity of geothermal reservoir were inferred as shown in the following by the measurement of homogenization temperature of fluid inclusion, geochemical thermometer, core analysis and well logging.

Geothermal reservoir temperature:	224°C
Rock density	: 2,500 kg/m ³
Hot water density	: 850 kg/m ³
Porosity	: 10 %

The heat capacity of rock and water including in the eq. (1) became about 2,400 kJ/kg°C assuming the volumetric heat capacity of rock and water to be 900 J/kg°C and 4,600 J/kg°C, respectively.

The heat energy recoverable by geothermal development is not all but a portion of the heat energy stored in geothermal reservoir. Nathenson, M. suggested the recovery factor based on the sweep process without the supply of heat, which is the model that the reinjection water and meteoric water filters in the porous zone in the reservoir and is recovered with the heat energy of rock. However, as a matter of fact, the hot water stored in the reservoir does not behave ideally. Consequently the reasonable recovery factor is generally considered to be 25 percents. As the results of above-mentioned discussion, the recoverable resource (heat energy) is 2.0×10^{14} (kJ).

In case of utilize the steam for generation the recovery efficiency of energy recovered from production steam, which means the rate between the produced steam energy and the produced fluid energy, and the conversion efficiency of recovered heat energy to electric power must be considered.

In case of separating the hot water of 1 ton with the enthalpy of 230 kcal/kg (224°C) at the wellhead pressure of 5.2 ata, which was inferred as the optimum turbine inlet pressure, only the steam of 0.15 ton with the enthalpy of 656 kcal/kg contribute to the generation of electric power because the quality of steam at the wellhead is 0.15. Accordingly the recovery efficiency becomes 0.43.

The conversion efficiency depends on the system of electric power generation. In case of using the non-condensing turbine with the inlet pressure of 5.2 ata, the outlet pressure of 1.1 ata and total generation efficiency of 0.8, the rate between the heat energy contributing to the generation of electric power and that of the steam of 1 ton (conversion efficiency) is 0.077. Further the conversion efficiency in case of using the condensing turbine with the inlet pressure of 5.2 ata, the outlet pressure of 0.1 ata and total generation efficiency of 0.8 is 0.172.

Consequently the recoverable heat energy to contribute to the generation of power supply in non-condensing turbine system is as follows.

$$\begin{aligned} 2.0 \times 10^{14} \text{ (kJ)} \times 0.43 \times 0.077 &= 6.62 \times 10^{12} \text{ (kJ)} \\ &= 1.58 \times 10^{12} \text{ (kcal)} \end{aligned}$$

Further, the recoverable heat energy in condensing turbine system is 3.54×10^{12} (kcal).

Accordingly the possible operation period for 5 MW in non-condensing turbine system and condensing turbine system becomes 42 years and 94 years, respectively.

The heat supplied from reinjection water, the outer side and the bottom of promising reservoir for development are out of consideration in this method. Therefore, the inferred operation period may be prolonged.

2. Resource evaluation by Simulation with Lumped Parameter Model

i. Equations

The change of pressure and temperature in geothermal reservoir can be calculated using the following equations.

Mass Balance

$$M_t = M_o - M_p + M_w + M_r \quad \dots\dots\dots (2)$$

Energy Balance

$$\begin{aligned} M_t U_t + V(1-\phi) \int_r \cdot Cr \cdot T_t \\ = M_o U_o + V(1-\phi) \int_r \cdot Cr \cdot T_o - M_p \cdot h_p + M_w \cdot h_w + M_r \cdot h_r \end{aligned} \quad \dots\dots\dots (3)$$

where,

- Mt: Fluid mass stored in the reservoir at a certain time
- Mo: Initial fluid mass stored in the reservoir
- Mp: Production mass flow
- Mw: Reinjection mass flow
- Mr: Recharge mass flow
- Ut: Internal energy of reservoir fluid at a certain time
- Uo: Initial internal energy of reservoir fluid
- hp: Enthalpy of production fluid
- hw: Enthalpy of reinjection fluid
- hr: Enthalpy of recharge fluid
- Tr: Reservoir temperature at a certain time
- To: Initial reservoir temperature
- V: Reservoir volume
- ϕ : Porosity
- \int_r : Rock density
- Cr: Specific heat capacity

Once the geothermal fluid produces, the reservoir pressure decreases gradually. On that occasion the hot water stored outside the reservoir boundary is recharged into the reservoir in accordance with the pressure gradient. This recharged mass flow can be calculated from the following equation.

$$M_r = 2 \pi r_e h \rho \frac{k}{\mu} \left. \frac{\partial P}{\partial r} \right|_{r=r_e} \dots\dots\dots (4)$$

where,

M_r : Recharge mass flow

r_e : Reservoir radius

h : Reservoir thickness

ρ : Fluid density

k : Permeability

μ : Viscosity

$\left. \frac{\partial P}{\partial r} \right|_{r=r_e}$: Pressure gradient

The above equation is based on the cylindrical reservoir model. Though the area and height of the promising reservoir in the Duabelas geothermal system was inferred to be 2 km² (1 km x 2 km) and 800 meters, respectively, the cylindrical reservoir model with the same volume with the real reservoir is applied to this simulation.

The pressure gradient at the reservoir boundary as shown in Fig. 3-13 is calculated from the following equation in consideration with the fluid flow in the outer area of reservoir.

$$\frac{\partial^2 P}{\partial r^2} + \frac{1}{r} \frac{\partial P}{\partial r} = \frac{\phi \mu C}{k} \frac{\partial P}{\partial t} \dots\dots\dots (5)$$

where,

P : Reservoir pressure

r : Distance from reservoir boundary

t : Time

C : Compressibility of fluid

ii. Model and condition for simulation

The reservoir model and condition necessary for simulation were assumed as mentioned below.

Reservoir model

- 1) Reservoir radius : 800 meters
- 2) Reservoir thickness : 800 meters
- 3) Reservoir temperature : 224°C
- 4) Reservoir pressure : 48.5 ata
(at 400 meters above sea level)
- 5) Reservoir permeability : 5 md - 10 md

Condition for calculation

- 1) Power output : 5 MW
- 2) Turbine type : non-condensing turbine
- 3) Initial production flow : Steam flow 85 ton/hour
Water flow 475 ton/hour
- 4) Initial reinjection flow : 475 ton/hour

The reservoir permeability calculated from the permeability-thickness product of 16 darcy m measured in well LP-2 is 20 md assuming the reservoir thickness of 800 meters. This value is largely effected by the sectional lost circulation zone with large permeability and is not average permeability of reservoir. Consequently, the average permeability of reservoir was assumed to be 5 md to 10 md.

Though the turbine type for generation will be discussed in detail at the step of the engineering feasibility study, the non-condensing turbine type was adopted as this simulation condition for severe evaluation. Because the steam flow rate necessary to keep the this power output in non-condensing turbine is larger than that in condensing turbine.

The steam and hot water flow rate necessary for the power output of 5 MW in non-condensing turbine system were estimated from the actual production flow rate from LP-2.

iii. Calculation results

The results calculated by above conditions are shown in Fig. 3-14 and Fig. 3-15. These figures shows the results with and without the reinjection condition, respectively. Further the calculation results in case of the permeability of 1 md in addition to 5 md and 10 md is also shown.

In case of reinjection condition, the drop of reservoir pressure becomes bigger according as the reserver permeability is smaller. Though the hasty pressure drop in the reservoir with the permeability of 5 md and 10 md occurs in the initial five years, the reservoir pressure on and after ten years is almost stable. The reservoir temperature changes in unrelation to the reservoir permeability and decreases in accordance with the elapsed time. This drop of reservoir temperature is cased by much more reinjection water flow than the recharging water flow.

In case of no reinjection the change of reservoir pressure shows that the fluid in the reservoir with the permeability of 1 md and 5 md becomes to be two phase state of steam and hot water and the fluid in the reservoir with the permeability of 10 md maintain the hot water state. The change of the fluid pressure in the reservoir with the permeability of 10 md is large even after 30 years elapsed. This indicates that the recharging flow rate is smaller than the production flow rate. The reservoir temperature is almost stable because of no reinjection. A little drop of the fluid temperature in the reservoir with the permeability of 1 md as revealed in Fig. 3-13 is caused by the change of saturation pressure in the two phase state.

The evaluation of possible power output needs to judge whether the production from the well is possible or impossible in accordance with the change of reservoir pressure and temperature. The production flow rate from well depends on not only the reservoir temperature and pressure but also the permeability of lost circulation zone, the diameter of casing and the well depth and so on. Consequently it is difficult to determine the minimum reservoir temperature and pressure necessary to produce the geothermal fluid from well generally. Therefore, the only minimum reservoir temperature necessary for production was assumed to be 200°C based on the experience. (In fact this temperature depends on the pressure.)

Though the reservoir temperature in case of no reinjection hardly changes, the pressure drawdown even in the reservoir with the permeability of 10 md is 17 at and is large. Therefore, it is predicted that the number of production well necessary to keep the constant power output becomes large even if the production is possible. Because the production flow rate per one well becomes small. Accordingly the execution of reinjection is desirable for the long utilization and the cultivation of reservoir.

The reservoir temperature in case of reinjection becomes 200°C at 38 years later. At this time the production is considered to be possible because of the low pressure drawdown; for example pressure drop in the reservoir with the permeability of 5 md and 10 md is 6 kg/cm² and 4 kg/cm², respectively. Accordingly the possible operation period with reinjection and non-condensing turbine system for 5 MW is inferred to be about 40 years.

The steam and hot water flow rate necessary for generating 5 MW in the condensing turbine system is about 45 percents of that in the non-condensing turbine system. In addition, the drop speed of reservoir temperature in the condensing turbine system is considered to change in accordance with the rate of reinjection flow rate. Therefore, the possible operation period with reinjection and condensing turbine system for 5 MW is inferred to be about 90 years.

3. Inference of possible operation period

As the results of analysis by the Volume method and the simulation method with the Lumped Parameter Model, the possible operation period in case of non-condensing turbine system for the power output of 5 MW was estimated to be 42 years by the Volume method and about 40 years by the simulation method. Further the possible operation period in case of condensing turbine system was estimated to be 94 years by the Volume method and about 90 years by the simulation method. As above mentioned the possible operation period estimated by two kinds of analysis method is almost same to each turbine system. Accordingly the possible operation period in case of non-condensing turbine system and condensing turbine system with reinjection was inferred to be about 40 years and 90 years, respectively.

These analysis methods include many unknown factors; for example the development area and depth, porosity, reservoir temperature and the possibility of fluid production and so on.

The Volume method takes no account of the heat supply of reinjection water and recharging hot water, and that from the side boundary and the bottom of reservoir. Therefore, the inferred power output or operation period is inferred to be prolonged.

The simulation method with the Lumped Parameter Model also takes no account of the heat supply from the bottom of reservoir. Consequently the possible operation period in this method is inferred to be also prolonged. Accordingly the estimated operation period by these method is considered to be minimum.

Therefore, this estimated operation time should be reconsidered as the reservoir model and reservoir characteristics becomes more clear by new survey.