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Puna Geothermal Venture's Plan for a 25 MW Commercial Geothermal Power Plant on Hawaii's Big Island

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ABSTRACT

This paper will present Puna Geothermal Venture's plan to construct Hawaii's first commercial geothermal power plant - a 25 MW (net) twin turbine generator facility located in the east rift zone of the Kilauea Volcano in the southeastern portion of the Big Island of Hawaii.

INTRODUCTION

A 25 MW (net) geothermal steam field and power plant is proposed to be developed on the island of Hawaii on approximately 500 acres of the 816 acre sublease from the Kapoho Land Partnership (KLP) in the State-designated geothermal resource subzone. The sublease includes both surface and geothermal rights. KLP holds the surface rights to the parcels and has obtained a State of Hawaii geothermal resource mining lease. The KLP State lease was assigned to the Puna Geothermal Venture (PGV).

In March 1988, AMOR VI Corporation, a subsidiary of Ormat Energy Systems, Inc. (OESI), purchased a 25% working interest in the PGV. As of the completion date of this paper, July 1988, OESI was negotiating the purchase of the remaining interest in the PGV.

RESERVOIR

The Puna geothermal resource is situated along the east rift zone of the Kilauea volcano, which is one of the world's most active volcanoes. The rift zone is an underground conduit for lateral migration of molten basalt from Kilauea's crater. Well drilling data indicates that the Puna geothermal reservoir is a very high temperature, over 600^{o}F, two-phase vapor/liquid resource, one of the hottest in the world. The reservoir is believed to be maintained by a very high heat flow within the rift and by an effective overlaying shield which inhibit significant venting as conceptually modelled in figure 1.

The reservoir is characterized by a dike complex which increases in number with depth. The resource is maintained by these high temperature dikes and a suspected secondary magma chamber beneath the geothermal reservoir. The top of the reservoir occurs at a depth of about 4000' below the surface and is believed to extend to at least 7200' below the surface. A relatively impermeable cap seal extends upwards from the 4000' depth to approximately 2500' below the surface. A zone of vigorous groundwater flow extends from the top of the seal through porous and permeable basalt layers to the water table, which is approximately 600' below the surface. Four productive geothermal wells have been drilled into the geothermal reservoir: HGP-A, Kapoho State 1 (KS-1), KS-2 and KS-1A. HGP-A was drilled by a consortium of government agencies in 1976 and was a discovery well for the Puna geothermal resource. A power plant was developed between 1976-1981 as a research and demonstration project by the Federal government and the State of Hawaii. The HGP-A facility is capable of generating approximately 3 MW of electricity and has demonstrated the use of the geothermal resource as a source for electrical generation. KS-1, KS-2 and KS-1A were drilled by PGV subsequent to HGP-A.

PROPOSED POWER PLANT DESIGN

Geothermal Fluids

Geothermal fluids have been chemically characterized from samples obtained from the four wells within the vicinity of the project area. Table 1 lists the ranges of the chemical compositions. When the fluids reach the surface and flash, the majority of the dissolved minerals remain in the brine and any gases remain in the steam fraction. The design values for noncondensible gas content (3500 ppmw) are the maximum measured concentrations in the KS wells. The H_2S gas design concentration was established at 150% of the maximum measured concentration to assure a conservative design basis.

Wells, Well Pads and Steam Distribution System

The steam gathering system will deliver the steam, brine and condensate in three separate pipeline systems to the appropriate end point in accordance with design and construction practices which have been developed within the geothermal industry.

In addition to the existing well pads A and B, four additional well pad sites, C,D,E, and F, were selected on the basis of proximity to the power plant, current knowledge of reservoir extent, optimal drilling targets, directional drilling experience and reinjection needs. The steam gathering and fluid handling system process flow diagram is shown in figure 2. Each 400' x 300' well pad may accommodate up t four or five wells each along with the necessary rock and fluid separator(s) and associated piping necessary for the distribution of steam and brine. A single rock muffler at each wellpad will provide noise abatement during well testing and venting. Chemical abatement will be provided by a portable H_2S chemical abatement unit which will be moved to the appropriate well pad during venting.

The piping system will be designed to separate the fluid into steam and brine. Control and measurement of the flow rate will be at the wellhead. The current plant calls for six production wells, three injection wells and eleven make-up wells, a total of twenty wells over the 35 year life of the project. Currently, KS-1 and KS-2 wells are suspended with cement plugs in their bores due to drilling problems. KS-1A is presently being maintained in a shut-in mode until a pipeline connection can be made to the HGP-A plant and thereafter a production flow test conducted. Some or all of these wells may be used for the PGV project.

All wells will be drilled to the depth of the geothermal resource, which will vary between 4000' to 7000;. Wells will consist of 13-3/8" standard steel casing down to about 2500' and 9-5/8" casing will extend to about 4100'; a 7" perforated liner will be installed from the bottom of the 9-5/8" casing to the bottom of the well. All casings will be steel and will be joined with premium threaded couplings and cemented to assure the structural integrity of the well casing. A special well casing procedure has been developed and approved to safely contain and produce the geothermal resource and to protect human health, the ground water and the environment.

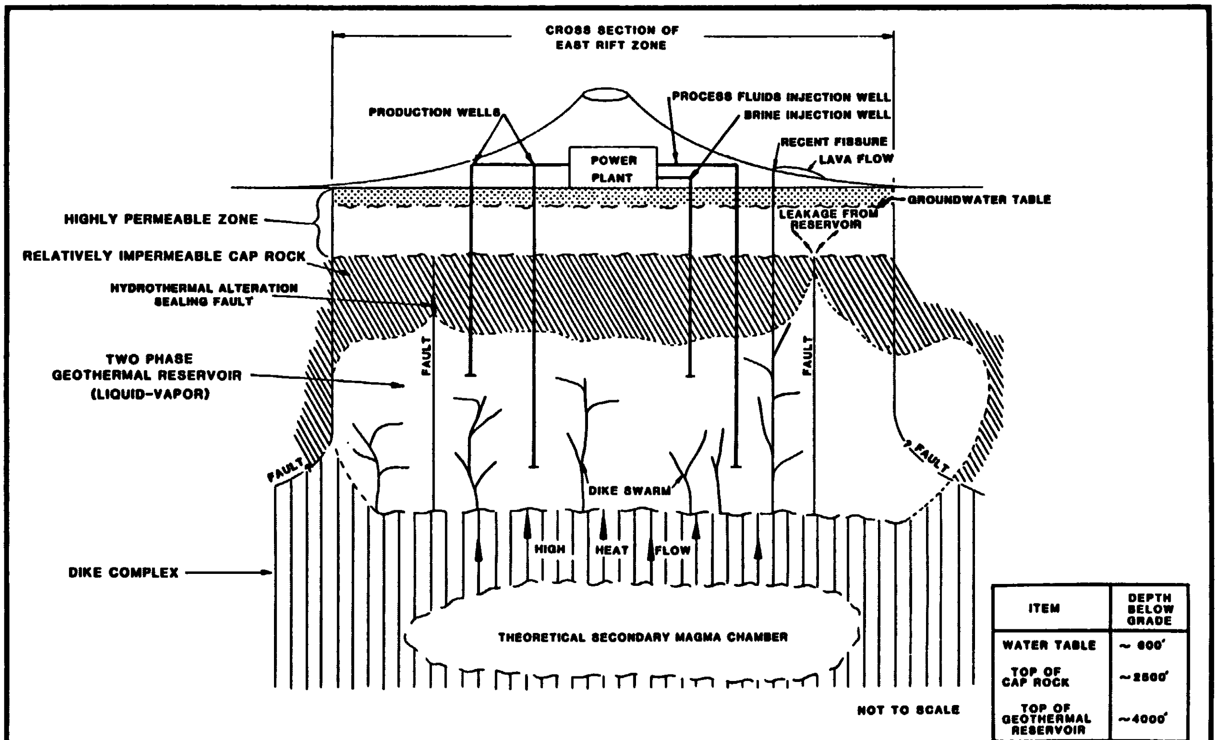
Each production well is anticipated to have an average flow rate of 90,000 lb/hr steam deliverable to the pipeline at wellhead flowing pressures in the range of 160-180 psig and wellhead temperatures in the range of 370^{o}-380^{o}F.

Injection

Fluids generated in the operation of the PGV well field and power plant will be reinjected into the reservoir below 4000'. The two fluid streams, the brine and plant process fluids, will have two separate injection systems having different handling requirements as follows:

a. Process Fluids

Steam condensate and other collected liquids will contact the noncondensible gases in an absorber to dissolve the H_2S and CO_2 and thereafter the liquids can be injected into the reservoir.



ITEM	DEPTH BELOW GRADE
WATER TABLE	~ 600'
TOP OF CAP ROCK	~2500'
TOP OF GEOTHERMAL RESERVOIR	~4000'

Figure 1 CONCEPTUAL MODEL OF THE PUNA GEOTHERMAL RESERVOIR

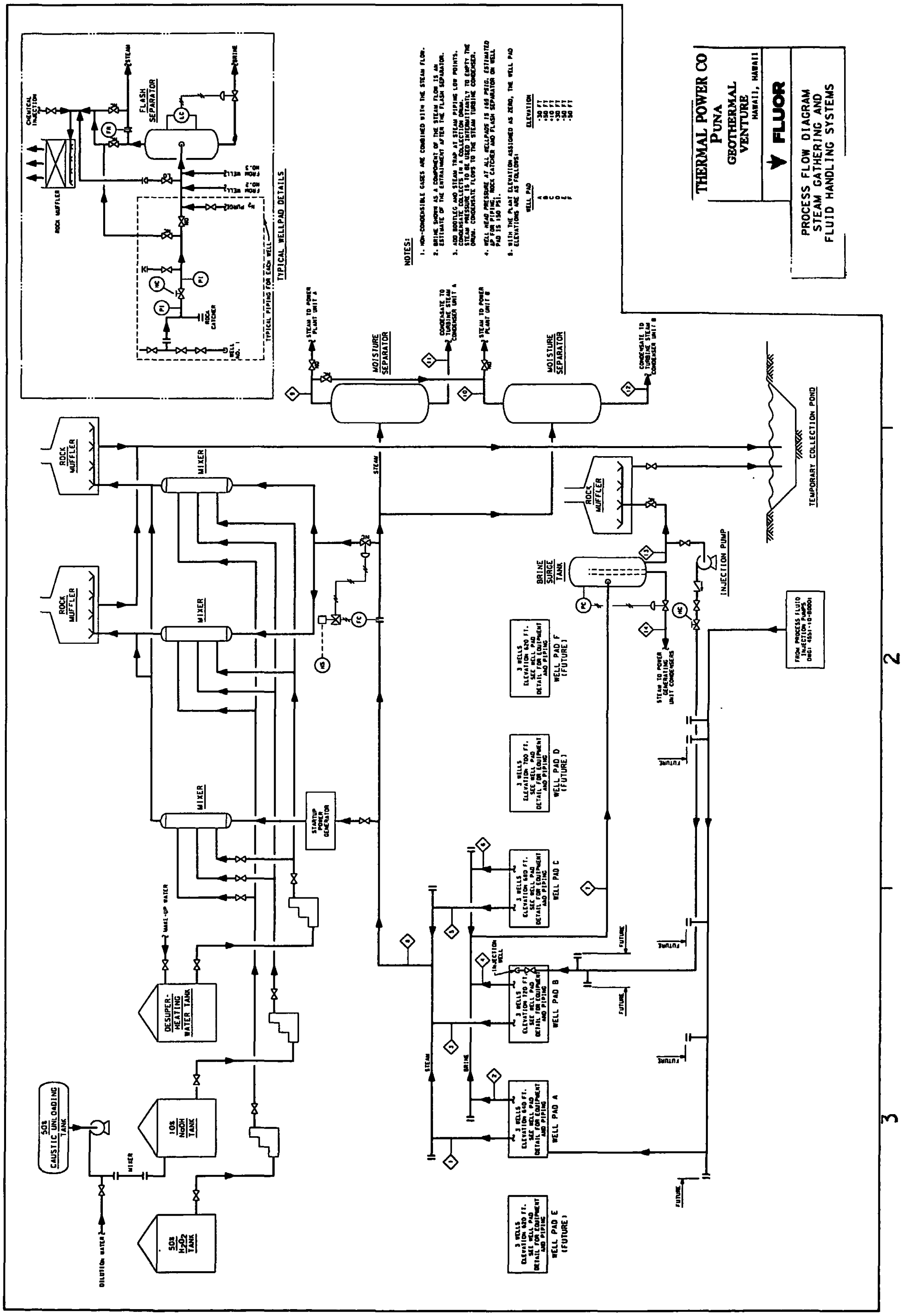

THERMAL POWER CO
PUNA
GEOTHERMAL
VENTURE
HAWAII, HAWAII
FLUOR
PROCESS FLOW DIAGRAM
STEAM GATHERING AND
FLUID HANDLING SYSTEMS
TYPICAL WELLPAD DETAILS
FLASH SEPARATOR
ROCK MUFFLER
MIXER
MOISTURE SEPARATOR
BRINE SURGE TANK
INJECTION PUMP
TEMPORARY COLLECTION POND
STARTUP POWER GENERATOR
DESUPER-HEATING WATER TANK
50% CAUSTIC UNLOADING TANK
10% NaOH TANK
WELL PAD A
WELL PAD B
WELL PAD C
WELL PAD D (FUTURE)
WELL PAD E (FUTURE)
WELL PAD F (FUTURE)
NOTES:

Figure 2

Table 1

GEOTHERMAL FLUID CHEMICAL COMPOSITION
COMPOSITE DATA[a]

Element	Brine[b] (ppm)(w))	Steam Condensate[b] (ppm(w))
Na	600 - 10,000	0.17
K	123 - 2,700	0.1
Ca	40 - 920	0.1
Mg	1 - 2	<0.1
Fe	<1 - 8.4	0.05
Mn	<1 - 8.5	--
B	4 - 11	<0.5
Br	40 - 80	--
I	<20	--
F	0.2 - 0.9	--
Li	1 - 9	<0.01
Cl	925 - 21,000	<2
NH_3	<0.01 - 0.1	0.12
SO_4 (c)	9.2 - 24	13
Hg	<0.001 - <0.05	--
As	0.09 - 0.4	<0.01
S= (d)	5 - 100	--
Total Alkalinity	≤10	<10
HCO_3	0 - 18	0
CO_3	0	0
SiO_2	420 - 1,500	0.7
TSS	70	--
TDS(e)	2,500 - 35,000	15
pH	≤5 - 5.5	3.5
Conductivity (mho/cm)	3,100 - 67,000	120
Density	1.03	--

(a) Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.
(b) Wellhead pressure (WHP)-155 psig; Wellhead Temperature (WHT) = 368°F
(c) Concentration high due to oxidation of S= to SO_4.
(d) Concentration low due to oxidation of S= to SO_4.
(e) TDS = Total Dissolved Solids

NONCONDENSABLE GAS COMPOSITION
COMPOSITE DATA[a]

Element	Observed Content in Steam[b] ppm(w)	Design Composition ppm(w)
CO_2	250 - 1,042	956
H_2S	800 - 1,300	1950
NH_3	(c)	-
Ar	6 - 13	-
N_2	10 - 700	582
CH_4	(d)	-
He	<0.009	-
H_2	11 - 140	12
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Total NCG	1,500 - 2,200	3500

(a) Composite data from three wells on the PGV site (KS-1, KS-1A, and KS-2) and the HGP-A well.
(b) WHP = 155 psig; WHT - 368°F
(c) Below Detection Limit (<1.5 ppm NH_3 in KS-1A)
(d) Below Detection Limit (<0.2 ppm CH_4 in KS-1A)

b. Brine Injection

Silica-laden brine recovered at each well pad separator will be quickly transported at high temperature to a brine injection well for injection into the reservoir.

Marginal geothermal production wells will be used as reinjection wells modified by hangdown strings of special or coated solid steel liners used to protect the premium 9-5/8" casing of the well during its use.

Power Production

The PGV power plant will be designed to provide 30 MW gross, 25 MW (net) of electricity to the HELCO energy grid system. The excess capacity will be utilized by the power plant for internal energy requirements and transmission line losses. The power plant will consist of two units, each capable of functioning independently and supplying 12.5 MW. A flow diagram of one of the power plant units is shown in figure 3.

The plant design calls for a condensing turbine generator design utilizing steam at a pressure of 155 psia, and 370° temperature. A 100% turbine bypass system will be used to bypass the steam around the turbine during an upset condition. An air-cooled, direct coupled electric generator will produce the electricity. Protective devices will guard against overspeed, over voltage, loss of field and fluctuation in frequency. The generator's main power transformer will adjust the generator voltage level to the required 69 kv transmission levels.

Due to the isolation of the plant location, a start-up steam turbine generator unit that produces power for essential electrical services during plant start-up is proposed. Start-up units will be capable of powering 1 cooling tower fan, 1 cooling water circulation pump, the brine and process fluids injection pumps, heating, ventilating and air conditioning and emergency lighting. Steam discharging from the start-up turbine will be chemically treated in one of the power plant rock mufflers. A shell and tube condenser is proposed for the operation and will operate at a pressure of about 4" of mercury absolute at full throttle with cooling water at a designed temperature of 85°F. The cooling tower will consist of two cooling tower units, each consisting of two cells. Each cooling tower unit will cool approximately 15,000 gpm of circulating water required for each turbine unit. The cooling tower will be of standard geothermal power plant design and will include condensate additions to the cooling water system to balance the amount of blowdown removed. The cooling tower blowdown will be piped into an absorber and subsequently delivered to the process fluids injection well.

The steam release facility consisting of an automatically controlled system diverting steam to a rock muffler located near the power plant, will be designed to dissipate the steam's acoustic energy. Each muffler will be designed to handle 100% of the total plant flow and will be treated with caustic and hydrogen peroxide to remove the majority of the H_2S.

Abatement System

The primary abatement system will remove the noncondensible gas stream from the condenser, compress it (99% of the H_2S included) to approximately 200 psig and send it to an absorber where the noncondensible gases will mix with blowdown water from the cooling tower. The H_2S and CO_2 will dissolve in the water while the other noncondensible gas components will not.

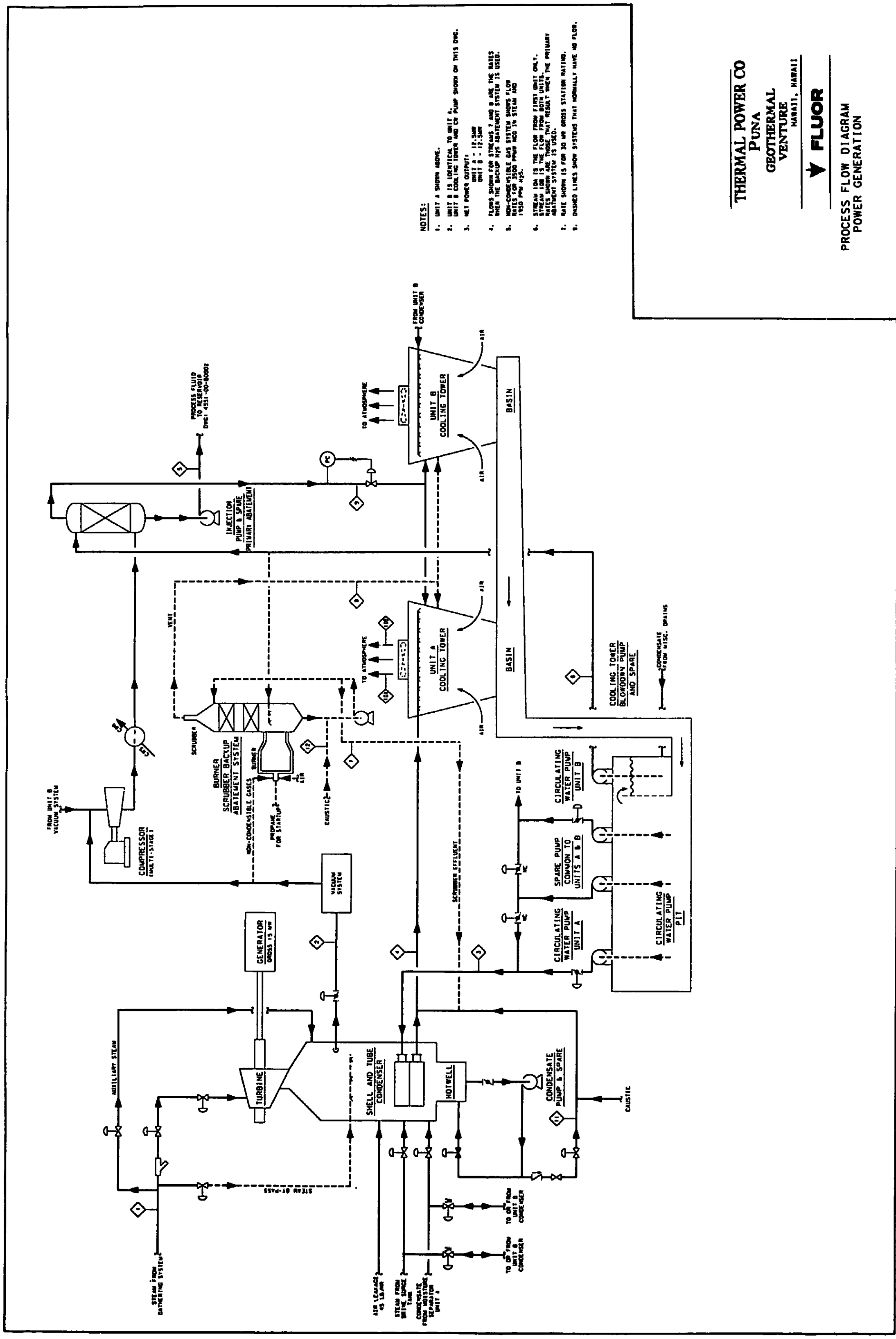
THERMAL POWER CO
PUNA
GEOTHERMAL
VENTURE
HAWAII, HAWAII
FLUOR
PROCESS FLOW DIAGRAM
POWER GENERATION
UNIT B
COOLING TOWER
UNIT A
COOLING TOWER
BASIN
TURBINE
GENERATOR
SHELL AND TUBE
CONDENSER
HOTWELL
CONDENSATE
PUMP & SPARE
COMPRESSOR
VACUUM SYSTEM
BURNER
SCRUBBER BACKUP
ABATEMENT SYSTEM
INJECTION
PUMP & SPARE
PRIMARY ABATEMENT
CIRCULATING
WATER PUMP
UNIT A
SPARE PUMP
COMMON TO
UNITS A & B
CIRCULATING
WATER PUMP
UNIT B
CIRCULATING
WATER PUMP
PIT
COOLING TOWER
BLOWDOWN PUMP
AND SPARE
NOTES:
2
3

Figure 3

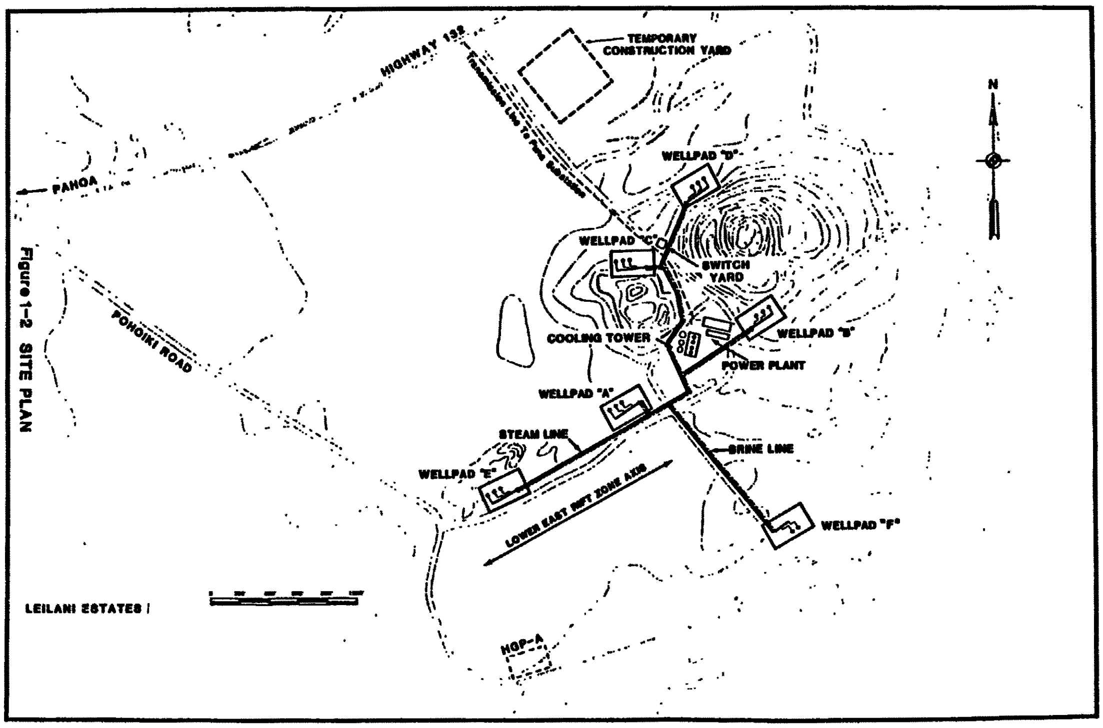

Figure 4

The gaseous components that do not dissolve in the water will pass through the absorber and will be sent to the cooling tower where they will be vented to the atmosphere with the cooling tower air. The fluids from the absorber will be injected into the injection well. Process fluids consists principally of the cooling tower blowdown with lesser amounts of H_2S, CO_2, condensate from the gathering system and moisture separator fluids. The collected fluids will be pumped into the process fluids injection well. Disposal by injection will remove any need to discharge the process water to the surface. The average fluid injection flow rate during normal plant operations will be about 280 gpm. In the unlikely event that the primary abatement system will becomes upset or is shut down, a back-up H_2S abatement system will be provided consisting of an incinerator/scrubber system that will incinerate the H_2S into SO_2 and then will scrub the noncondensible gases with sodium hydroxide, converting the SO_2 to non-toxic sulfides and bi-sulfide compounds. If the backup system does not function properly the power plant will shut down and the steam will be diverted to the steam release facility and be chemically abated. The less than 1% of H_2S concentration to the cooling tower will be mostly oxidized to sulfites under normal operating conditions, thereby resulting in non-detectable air emissions of H_2S. In all normal operating cases, H_2S emissions will be less than 4 lb/hr. The primary and backup abatement systems will not generate any solid waste including solid sulfur. Silica contained in the brine will be reinjected with the brine.

Geologic Hazards

Two types of potential geologic hazards exist in the area - volcanic and seismic. Both will be significantly mitigated by appropriate procedures from the facility's siting, design nd operation. The potential volcanic hazard consists of lava eruptions, lava flows, ash falls, splatter falls, and their associated disruptions. The risks will be greatly reduced by locating the plant site and new well pads on high ground to avoid lava flows in the low areas. Berms will be utilized to protect the lower well pads and key elements of pipeline from lava flow. Each well pad in low ground will be protected from lava flow by timely closure of the wellhead valves and by burying the cellar and wellhead with insulating cinder piles.

Potential seismic hazards generated by earthquakes will be mitigated by appropriate design of the critical components at the most stringent seismic zone 4 for seismic building requirements, even though the project area is officially in a seismic zone 3. The pipeline will be designed to allow for flexibility in movement. Close coordination is planned with the Hawaii Volcano Observatory, Institute of Geophysics and County officials to further reduce risk and insure timely warnings of impending geologic hazards.

Buildings and Structures

The power plant will be designed and built using modular construction methods in order to minimize the field construction effort and emphasize factory fabrication. The exact locations and dimensions of the structures will be determined during detailed and engineering design. The preliminary design includes two main structures - the main turbine generator building and two adjacent cooling towers. Several small structures and buildings including an administration building, control building, machine shop, warehouse facilities, transformers, chemical tanks are also included in this design. The proposed turbine building design calls for a close coupled turbine generator with a parallel condensor located outside the main building. Therefore, no turbine pedastal will be constructed. Support buildings will be adjacent to the turbine generator building and will contain the control room, electrical equipment, maintenance room, battery rooms, administration offices and lavatories. The two-celled mechanically induced draft cooling towers will be positioned to maximize access to wind flow and allow proper ventilation of the stack flow.

Operations and Maintenance

The power plant and wellfield will be operated in a manner which protects human health and the environment. The staff will operate equipment, oversee production and respond to emergencies and regularly monitor and maintain both the power plant and the wellfield. Approximately 19 employees will be required for operation and maintenance. Most, if not all of the employees will be from the local area. The power plant and wellfield will operate continuously seven days per week. Plant and wellfield monitoring is proposed to be through a computer controlled distribution system. The power plant will be controlled from the centralized control room and the wellfield will be monitored only. Wellfield operations will be handled at the equipment site location.

Project Milestone

The following describes some of the key milestones that must be accomplished by PGV prior to the construction and start-up of the power plant facilities.

a. Power Sales Contract.

In March 1986, Thermal Power Company (TPC) entered into a power purchase agreement with HELCO, the public utility serving the Big Island. This agreement is based upon Hawaii's implementation of the PURPA Act of 1978 and similar state laws and was approved by the Hawaii PUC. It provides for purchase by HELCO of up to 25 MW of energy from TPC's planned geothermal power plant. The terms of the agreement are that a power plant will be built in two increments of 12.5 MW each to be on-line by 1990 and 1992 respectively. The term of the agreement is 35 years. Currently, there are no sanctions in the contract for non-performance. The price is set at the higher of the applicable floor price under Hawaii PURPA rules or HELCO's avoided energy cost at the time of delivery. In the second half of 1986, the parties began negotiations to amend the agreements to provide for the purchase of firm energy and capacity pursuant to transactions and performance standards in return for capacity payments and other pricing and operational terms. In connection with the 1986 agreement, the parties entered into a letter agreement in July 1986 providing for certain environmental permitting and preliminary engineering work to prepare for the construction of one or more 69 kv transmission lines to interconnect the power plant with the HELCO system. The work done under the letter agreement is funded by TPC. A routing study has been completed and an EIS is being prepared. Although there has been considerable community interest in and some opposition to the 69 kv lines, TPC believes that the required line can be built within existing transmission corridors with minimal community disruption.

b. EIS and Application for Construction.

The EIS process for the power plant and wellfield has been completed and approval has been received. Application has been made for air quality permits and the authority to construct - the approval process is underway.

c. Engineering Design.

In connection with the EIS and permit application process, in late 1987 Fluor Technology Inc. completed a conceptual engineering design and a cost estimate for the proposed single flash power plant. Fluor also began plans for procurement of equipment for the power plant and steam gathering system, management of plant construction and testing and start-up services.

d. Plant Construction and Wellfield Drilling.

Actual plant construction has been estimated to take 14 months from the firm ordering of the turbine generator to the on-line date. The time period would allow for completion of the production wellfield at approximately 60 days per well and for the necessary plant site preparations. Thus, a project schedule of 18 months which would include a time allowance for the completion of permitting actions has been estimated. The required 69 kv transmission line could be built within this project time period as long as environmental and permitting work in this phase of the overall project is achieved successfully.

PROPOSED TEST OPERATION

KS-1A Steam to HGP-A Power Plant

Thermal Power Company has executed an agreement, to supply steam from its KS-1A well to the HGP-A demonstration power plant for a long term flow test. The test is a side issue in relation to the overall 25 MW conceptual development and its purpose is to gain long-term production data and operational experience. At this date TPC has designed and purchased materials for a transmission pipeline from its KS-1A well to the plant, about 3000' distance.

The specific objectives of the program include:

a. a long term flow test of the KS-1A well;
b. the continuing study of the pressures, temperatures and chemistry of the Kapoho geothermal reservoir and evaluation of changes to these parameters over time;
c. an evaluation of direct use of geothermal brines and steam for commercial purposes other than electricity production (ongoing);
d. continued testing and evaluation of geothermal abatement methods;
e. research into geothermal fluids injection methodologies;

The primary testing will consist of regular periodic measurements of the flowing parameters of the well and operating conditions of the power plant and its auxiliaries. Additional tests may be conducted at the adjacent Puna Research Center and plant. The value of the long-term flow test with the plant is very high. Trends will be more evident and a greater number of reservoir variables will be examined. In addition, the reliability and suitability of materials, consumable supplies and equipment in the plant will be measured over a long-term test period.

REFERENCES

Fluor Technology, Inc.· Puna Geothermal Venture Project Conceptual Design, Project 4551, 1987.

Fluor Technology, Inc./Thermal Power Co. Puna Geothermal Venture Project Environmental Impact Statement, August 1987.