GEOTHERMAL TECHNOLOGY

Circular C-108

State of Hawaii
DEPARTMENT OF LAND AND NATURAL RESOURCES
Division of Water and Land Development

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PREFACE

Act 296, Session Laws of Hawaii 1983, as amended by Act 151, SLH 1984, requires that the Board of Land and Natural Resources examine various factors when designating subzone areas for the exploration, development, and production of geothermal resources. These factors include potential for production, prospects for utilization, geologic hazards, social and environmental impacts, land use compatibility, and economic benefits. The Department of Land and Natural Resources has prepared a series of reports which address each of the subzone designation factors. A brief description of geothermal technology emphasizing those aspects with possible environmental effects is provided in this publication.

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CONTENTS

FIGURES

SUMMARY

In Hawaii, geothermal reservoirs are expected to occur 4,000-8,000 feet below sea level. Rotary drilling rigs likely to be used in Hawaii are rated for drilling to a maximum depth of about 16,000 feet. Holes may be drilled perpendicular to the ground surface or directional to almost any desired angle from ground surface. The local subsurface geology and the availability of well control techniques and blow-out prevention equipment minimizes the risk of well blow-outs. Approximately ten acres of cleared land may be needed to site the wells necessary for a 25 megawatt power plant. Drilling mud and cuttings may be disposed of at the drill site sump or can be removed if required. While in the production zone, return air is likely to contain hydrogen sulfide which can be abated by a caustic soda abatement system. After well completion, up to eight hours of unabated venting may be necessary to clear rock debris. Well casing intergrity is essential if usable water aquifers are to be protected. Steam piping from well-head to power plant may be placed about five feet above ground on saddles or may be buried for safety and aesthetics.

Before a power plant becomes operational the State Department of Health must issue permits regarding the quality of the air and fluids discharged from the plant. The proposed DOH regulations require a 98% H_2S removal and a maximum concentration of about 25 parts per billion H_2S at the property line. Abatement systems are available which can meet these standards, eg. the Stretford abatement system. Contingency abatement systems are likely to be designed into the power plant. The plume exiting the cooling tower should consist entirely of water vapor. The use drift eliminators in the cooling tower should prevent water droplets from exiting with the vapor. Liquid effluent should be piped into deep injection wells. If the silica content of the effluent is high, a silica dropout system may be utilized to prevent injection well plugging. The surface area for a 25 megawatt power plant may be about seven acres.

Roads and electric transmission lines may be constructed or upgraded to accomodate geothermal exploration, development, and production activities.

The County of Hawaii geothermal noise guidelines limit noise to 55 decibels by day and 45 decibils at night at nearby residences. Abatement technology exists to abate noise to acceptable levels.

GEOTHERMAL TECHNOLOGY

GEOTHERMAL WELLS

Drilling Depth

In Hawaii, geothermal reservoirs are expected to occur 4,000-8,000 feet below sea level. The rotary drilling rigs likely to be used in Hawaii are rated for drilling to a maximum depth of about 16,000 feet. Some mainland oil-rigs can drill to 22,000 feet but are not considered economical when applied to geothermal development here. The basic elements of a rotary drilling rig are shown in figure 1.

Directional Drilling

A geothermal rig can drill a hole perpendicular to the ground surface or directional holes to almost any desired angle from ground surface. A moderate curve in the drill route can also be achieved. Directional drilling can reduce both environmental and economic costs by allowing multiple holes to be drilled from one drill site. However the most economic and shortest route for a drill hole is usually straight and perpendicular to the surface.

Drill Hole Casing

Figure 2 depicts a typical well profile. The drilled hole has a 26-inch diameter for the first 250 feet, tapering to an eight inch diameter bottom hole in the production zone. The usual casing program includes a conductor pipe (surface to 250 feet), surface casing (surface to 2500 feet), intermediate casing hung from the end of the surface casing (2500 to 4000-6000 feet), and possibly a production liner hung from the end of the intermediate casing to bottom hole. All joints should be cemented and joined to ensure casing integrity into the production zone. Available well control techniques and blow-out prevention equipment can substantially reduce the risk of well blow-outs.

Drill Site Surface Area

A 2/1 ratio of good to bad wells is expected in a proven resource area. Once a successful well is drilled, six closely spaced wells (four expected successful) may be drilled within a radius of 2000 feet of the drill site. Two acres of land would be cleared for an exploratory hole. Approximately five acres of land would be cleared on a proven drill site. Four successful wells (three and spare) may be needed for a 12.5 megawatt (MW) plant. Generation capacity can vary from three to ten MW per well depending on the output rate and type (water or vapor dominated) of geothermal resource. The HGP-A test well is producing about three MW; however commercial wells are expected to have a larger capacity. Unsuccessful or expended wells would be abandoned unless used for injection of geothermal effluent.

Drilling Emissions and Effluents

Depending on geologic structure and capability of drilling equipment, either "drilling mud" or air will be used to remove cuttings and lubricate the drill bit. Drilling activities may use 2000 barrels of water per day per well. The mud and cuttings are disposed of at a drill site sump but can be removed to an approved disposal site if required. In the production zones, air drilling (instead of mud) may be used to avoid reduction of permeability in the production zone. While in the production zone, the return-air will contain cuttings and geothermal gases (most significant being H_2S). A caustic soda (NaOH) injection system and cyclone muffler can be used to abate hydrogen sulfide (H_2S), particulates, and noise during drilling (see figure 3). After completing the well, four to eight hours of unabated venting may be required to clear the hole of rock debris. Completed wells will be subjected to flow testing to determine reservoir characteristics. Emissions must meet Department of Health (DOH) standards. If the well is water dominated, a flash separator may be used at the well site to return brine to either a nearby percolation pond or reinjection well.

Injection Wells

One injection well may be needed for the three active wells which may be required to fuel a 12.5 MW plant. The number of injection wells will vary depending on the permeability of the injection well and the quantity of brine flowing from the production wells. The initial injection wells (specifically drilled for injection) are likely to be close to the plant to limit brine piping distance. Nonproducing or expended production holes may also be used for injection. Geothermal effluents will be injected into a geothermal aquifer having similar characteristics. Drill casing intergrity through overlying fresh water aquifers is essential if usable water supplies are to be protected. Injection wells are subject to standards and regulations of the State Department of Land and Natural Resources and Department of Health.

STEAM PIPING

The steam piping from well-head to plant is likely to be 16 to 22 inch diameter carbon-steel pipes. Piping may be placed four to six feet above ground-level on "saddles" which may be fortified to accomodate pahoehoe lava flows. Alternatively, piping may be buried for safety and aesthetics. The piping will have expansion joints which will allow for thermal expansion and some ground movement. Surface area needed for a pipeline corridor is discussed in "roads" section below.

GEOTHERMAL POWER PLANTS

Operation

Figure 4 depicts a simplified geothermal power generation system, emphasizing emissions and effluents. Before a plant becomes operational the Department of Health must issue permits regarding the quality of the air and fluids discharged from the plant. Components of this system are described below.

The characteristics of the geothermal fluid may vary from site to site. It may be liquid or vapor dominated. A vapor dominated system provides more steam for power generation per hole while reducing the hamount of brine which must be injected back into the ground. HGP-A is a water dominated system. Kapoho wells #1 and #2 have been reported to be vapor dominated.

As the geothermal fluid enters the power plant the steam and brine components are separated in the "separator". The compostion of the HGP-A brine is given in figure 5. Various heavy metal concentration such as arsenic, lead, and mercury are very low and should remain in the brine that is eventually reinjected. The steam phase leaving the separator consists of primarily water vapor and non-condensable gases. These gases as found at HGP-A are listed in figure 6. The two most significant noncondensable gases are H_2S and Radon 222. As described below, the level of H_2S can be almost completely abated. Outdoor concentration levels of emitted radon, if properly abated by dilution in the cooling tower, are lower than most indoor levels; since cement emits some radon in most buildings. Again, the composition of fluids and gases are likely to vary a bit with each reservoir.

The steam phase from the separator enters the turbine, turns the rotors, and exhausts into the condenser. Electricity is produced as the turbine spins the generator. The steam flow and resultant turbine-rotor turning is enhanced by the vacuum created in the condenser as the steam is condensed into liquid. This liquid (condensate) returns with the warm condenser cooling water to the cooling tower where it is cooled by evaporation. The size of the steam plume will vary with the size and efficiency of the plant, the coding tower design, and the ambient weather characteristics.

Emission Abatement

The gas phase which exits the condenser consists primarily of the same noncondensable components which left the separator, most notably H_2S. An abatement system is utilized at this point to reduce the H_2S content to an acceptable level (see figure 4). A report recently prepared for the U.S. Environmental Protection Agency, Evaluation of BACT for and Air Quality Impact of Potential Geothermal Development in Hawaii, analyzes most available H_2S abatement systems. These include the iron catalyst primary system; the iron catalyst secondary system; the hydrogen peroxide, caustic, iron catalyst (HPCC) primary system; burner-scrubber system; and the Stretford system. The report recommends the Stretford system as the primary on-line abatement system. This system can remove over 99% of the H_2S contained in the noncondensable gases. By-products of the Stretford system include marketable elemental sulfur and sludge which requires disposal.

A geothermal plant is expected to be on-line 90-95% of the time. Contingency abatement systems can be utilized in the event the plant is "down" for maintenance or emergency. If maintenance is required on either the turbine or generator, the geothermal steam can be routed directly into the condenser utilizing the primary abatement systems. Since the turbine does not dissipate any heat or energy in the bypass mode, the cooling system must be over-designed to accomodate the extra heat during "turbine bypass". If the primary abatement system is not operational, a secondary abatement system such as NaOH (caustic soda) scubbing can be used in combination with a rock muffler to achieve 92-95% H_2S removal (see figure 4). In emergencies, well throtting may be accomplished by manual valve turndown or automatic valve control. Throtting must be slow (at least 15 minutes) and can reduce flow to a fraction of the well's maximum flow rate. The degree of throtting possible will depend upon the characteristics of each well. However, there is a danger that the additional stress with increased pressure could damage the well-bore, casing, or well-head equipment. If a geothermal development has more than one power plant, the wells could be moderately throtted and diverted to an operating plant. If all the above contingency abatement options are not available, a geothermal well may have to be free vented through a silencer without H_2S abatement until the required maintenance is completed or such time as the well can be shut-in completely.

The abated gases, condensate, and warm water are circulated through the cooling tower. Cooled water from the cooling tower is recirculated through the condenser; any excess water (blowdown) is piped into an injection well. It is expected that a wet, mechanical draft, cooling tower will be applied to geothermal development. Warm water enters the tower near the top, while a fan forces air through slats designed to maximize the surface area of the falling warm water. Use of drift eliminators significantly reduces the chance that any water droplets will exit with the steam plume. This falling water also scrubs any particulates from the gas exiting the abatement system. At "The Geysers" geothermal development in California, small amounts of boron from the condensate has been emitted with cooling tower drift (small water droplets entrained in the the steam plume) having some adverse effects on nearby vegetation. Based on the characteristics of the HGP-A reservoir fluids and the emission abatement which will be required by the DOH, cooling tower emissions from Hawaii's geothermal resources should not be toxic to flora and fauna in the vicinity of the geothermal power plant. Data available from the HGP-A indicates that the plume from the cooling tower should consist entirely of water vapor. The proposed DOH regulations require 98% H_2S abatement and a concentration of no greater than 25 parts per billion H_2S at the property line of a development.

In addition to cooling tower blowdown, brine leaving the separator will be piped into the injection well. If the rate of silica deposition in the brine is high, a silica-dropout system will be utilized between the steam-brine separator and the injection well. Otherwise, silica deposition within the injection well might cause it to become plugged. The silica deposits will be removed periodically and disposed of in an acceptable manner.

Plant Site Surface Area

The surface area required for a power plant varies with its megawatt output. Figures 8 through 13 depict the dimensions of the 12.5 and 55 MW capacity power plants. By using these units in tandem a 25 MW or 110 MW facility can be constructed without increasing the land area of the plant site significantly. Generally, a 12.5 or 25 MW plant will have structure dimensions of 90 feet x 40 feet x 54 feet high (per 12.5 MW unit) sited on a surface area of about 7 acres. A 55 or 110 MW plant will have structure dimensions of 350 feet x 80 feet x 75 feet high (per 55 MW unit) sited on a surface area of about 15 acres.

ROADS

Roads must be constructed to accomodate geothermal exploration, development, and production activities. Their placement should avoid volcanic hazards as much as possible. The extent of road building activities at a particular location will be influenced by the existing road infrastructure. Figure 14 depicts the design of access, well field, and power line roads. Road designs must be submitted to the counties for construction permit approval. Approximate road dimensions are given below.

	Width	Height	Description
Initial access	20'	-	One lane with shoulders.
Main access with transmission lines	78'	76'*	Two lanes, shoulders, & transmission lines on both sides.
Well field road	30'	4-6'**	One lane, shoulders, dual pipeline corridor on one side.

ELECTRIC TRANSMISSION LINES

Construction of a new transmission line corridor is required to connect the geothermal power plant to the existing power grid. By referring to figure 15, which depicts the existing power grid on the island of Hawaii, it appears that the need for new power line corridors will be minimal. However, existing lines may need to be upgraded. Figure 16 shows the clearance needed for 69 kilovolt (68' wide-67' high) and 138 kilovolt (78' wide-76' high) power line corridors. Dual lines will be used to assure reliability.

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*electric transmission line poles

**steam piping height

NOISE LEVELS AND ABATEMENT

During the initial phases of field development, persons in the immediate vicinty of a geothermal site may be exposed to noise levels varying from 40 to 125 decibels, depending upon the distance from the well site. High noise levels are produced during well drilling, production testing, and bleeding before connection to the generator. Drill rig noise varies from 60 to 98 decibels with muffler. Initial venting noise varies from 90 to 125 decibels which may be mitigated using a stack pipe insulator or cyclone muffler. Periodic operational venting noise is about 50 decibels using a pumice filled muffler. While most operations can be effectively muffled by acoustical baffling and rock mufflers, some emit unavoidable noise. Above noise levels apply to the immediate vicinity within 100 feet of the source.

The County of Hawaii geothermal noise level guidelines state that a general noise level of 55 decibels during the daytime and 45 decibels at night may not be exceeded at existing residential receptors which might be impacted.

The design standard for the HGP-A Wellhead Generator Project specifies that the noise level one-half mile from the well site must be no greater than 65 decibels. Construction of a rock muffler at the facility has reduced noise levels to about 44 decibels at the fence line of the project. A chart is provided in figure 17 which describes the noise levels from geothermal operations at "The Geysers" in California. Noise will vary with weather conditions and topography. Technology exists which should abate noise to acceptable levels.

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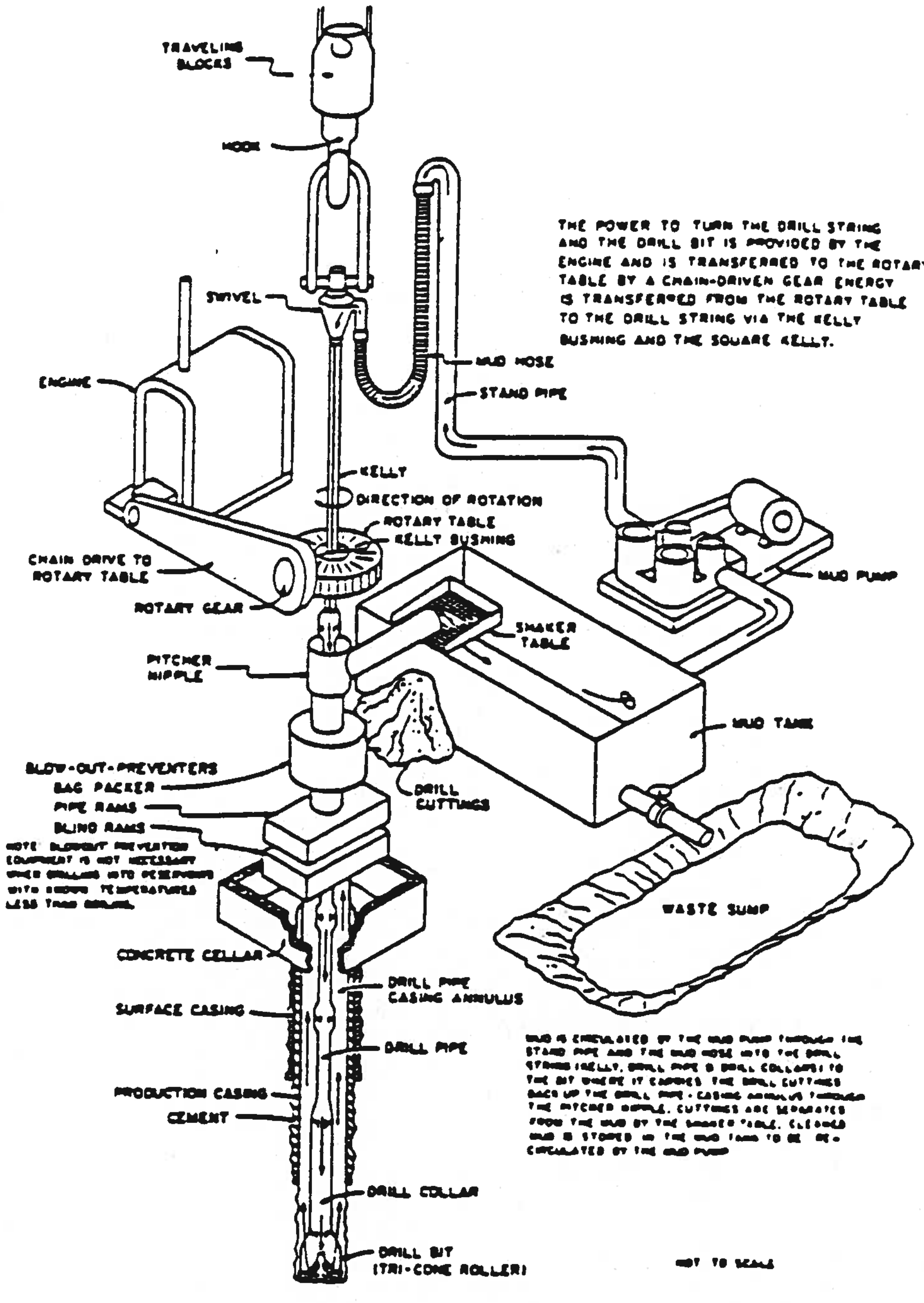


Figure 1. Basic Elements of a Rotary Drilling Rig.
(Source: Geothermal Power Development in Hawaii, 1982)

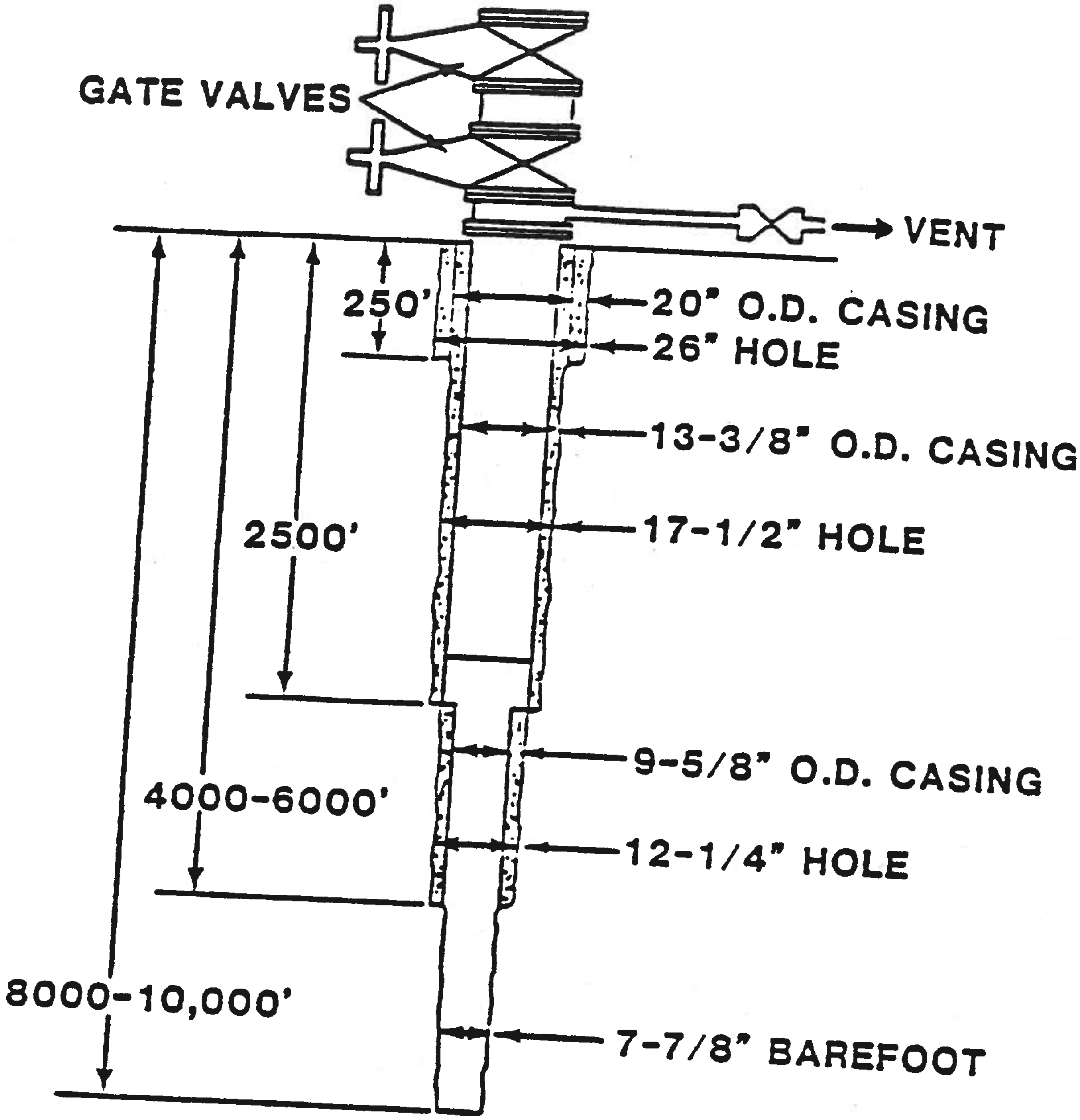


Figure 2. Typical Well Profile.
(Source: Kahaualea EIS, 1982)

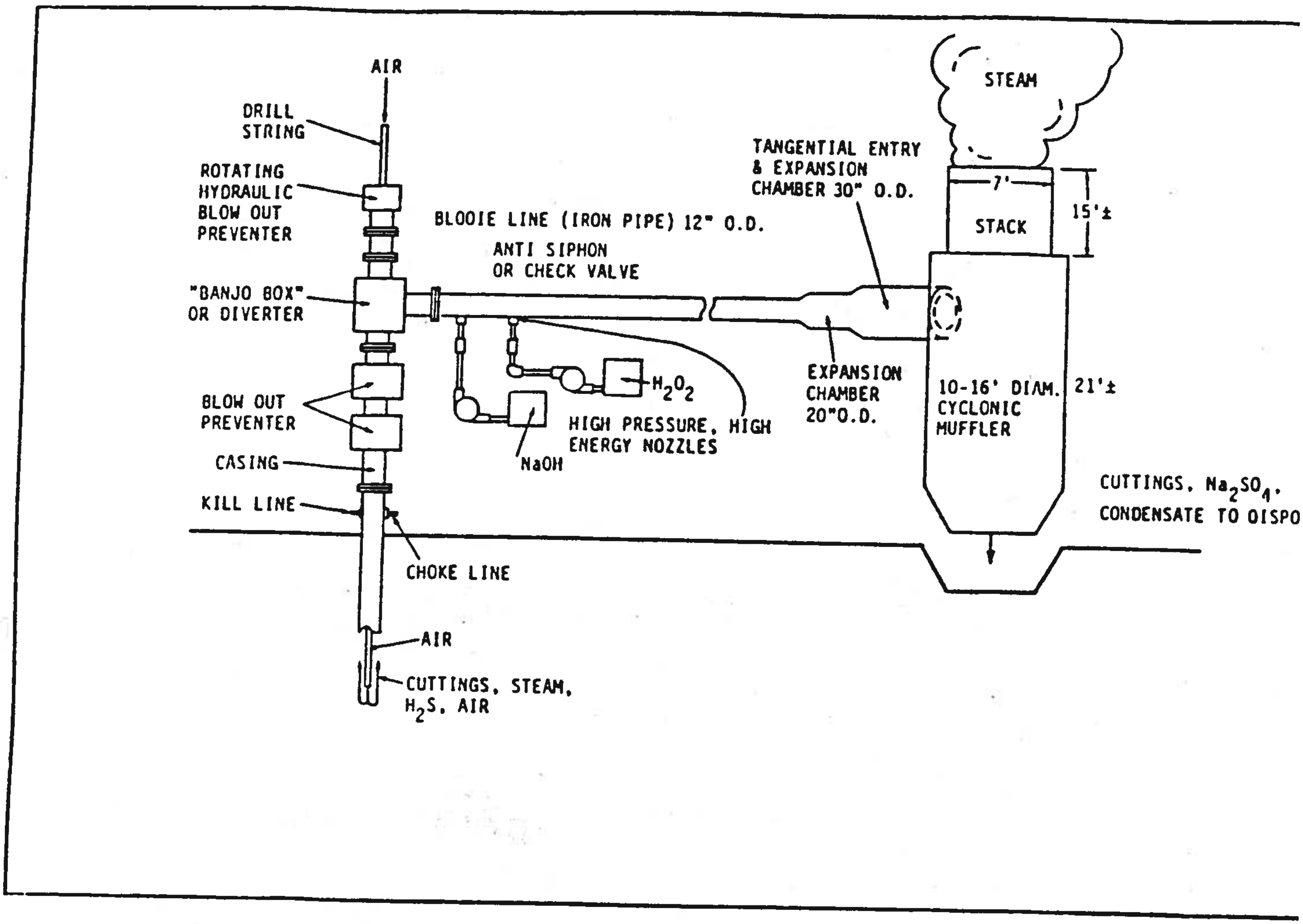


Figure 3. H_2S Removal During Well Drilling.
(Source: Dames & Moore, 1984)

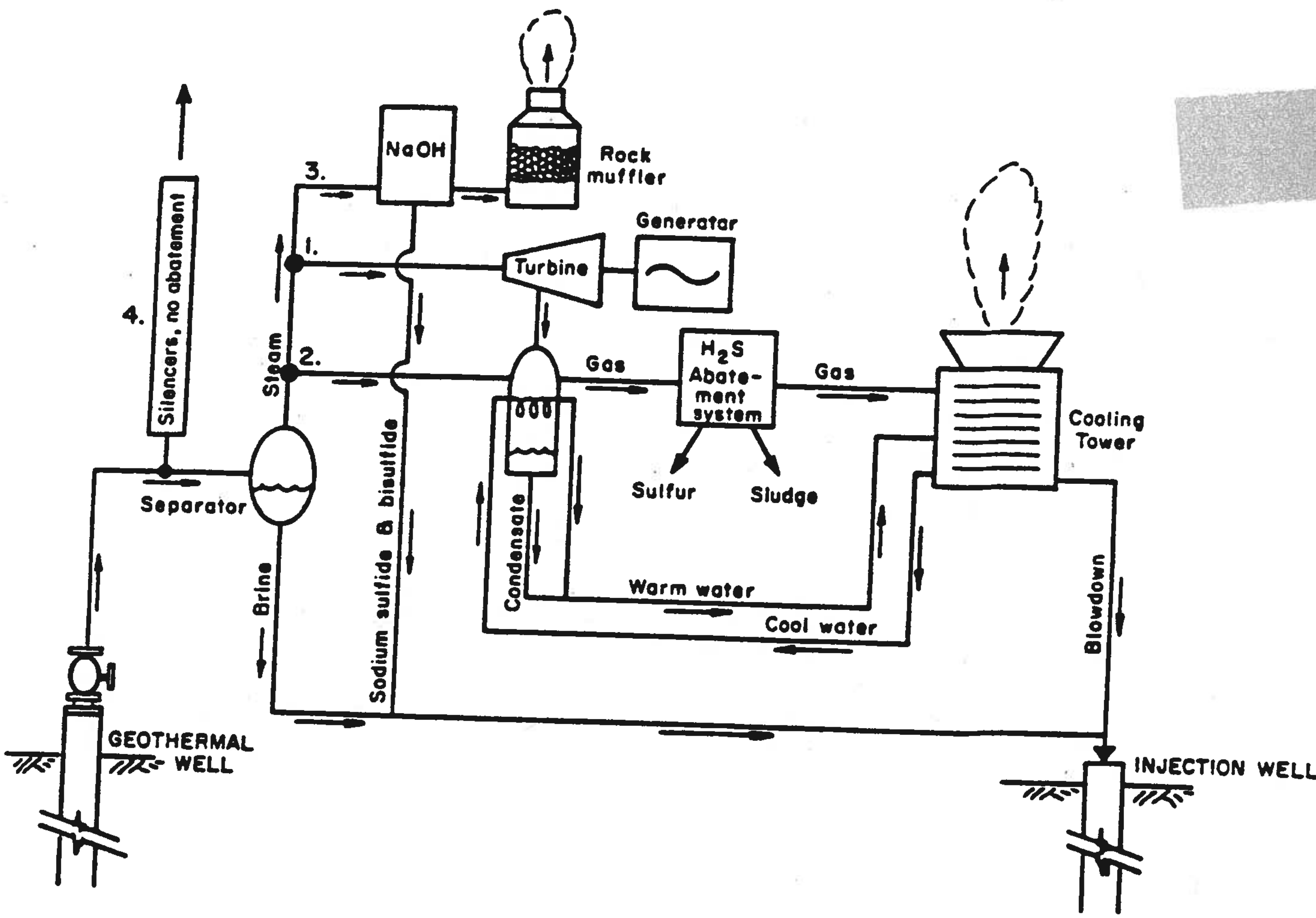


Figure 4. Hydrogen Sulfide Abatement During Power Plant Operation.

1) using primary abatement system (sulfur and sludge are byproducts of the Stretford abatement system);
2) using "turbine bypass" gas still abated through primary abatement system;
3) using contingency caustic (NaOH) abatement system;
4) unabated flow in emergency situations.

Element	Concentration, ppmw
Arsenic	0.01 - 0.001[b]
Barium	2
Boron	2
Calcium	218
Cadmium	<1.0[c]
Carbonate	75
Chloride	7200
Cobalt	0.014
Copper	<0.004
Gold	<0.00004
Iron	0.02
Lead	<1[c]
Lithium	0.034
Magnesium	0.131
Manganese	0.034
Mercury	<0.001
Molybdenum	0.067
Nickel	<0.02
Niobium	<0.4
pH	7.4[d]
Phosphorous	0.2
Platinum	<0.006
Potassium	600
Silica	800
Silver	<0.02
Sodium	3700
Strontium	2.0
Sulfate	50
Sulfide	17
Tantalum	<0.001
Thallium	<1[c]
Tin	<0.2
Titanium	0.006
Uranium	0.16
Vanadium	0.016
Zinc	0.012

[a] Liquid samples taken from cyclone separator (Thomas, 1983a).
[b] Rough estimate based on preliminary analysis, Thomas, 1983b.
[c] Thomas, 1982b. 'Less than' signs indicate detection limit of analyzer.
[d] Before atmospheric flashing, Thomas, 1982a.

Figure 5. Particulate Composition of HGP-A Brine. (Source: Dames & Moore, 1984)

Gas		Concentration (ppmw in steam) Geysers[a] (dry steam)	ENEL-A[b] (separated steam)
CO_2		3260	1200
H_2S		222	900
NH_3		194	0
CH_4, C_2H_6		202	NR[c]
N_2		52	125
H_2		56	56
He		NR	0.5
	Total (ppmw)	3985	2237
	Total (wt%)	0.40	0.22
Rd^{222}	nCi/lb steam	6.1	1.5

[a] Source: NCPA, 1981; Squire and Robinson, 1981.
[b] Source: Thomas, 1983a.
[c] NR - not reported.

Figure 6. Geothermal Noncondensable Contents. (Source: Dames & Moore, 1984)

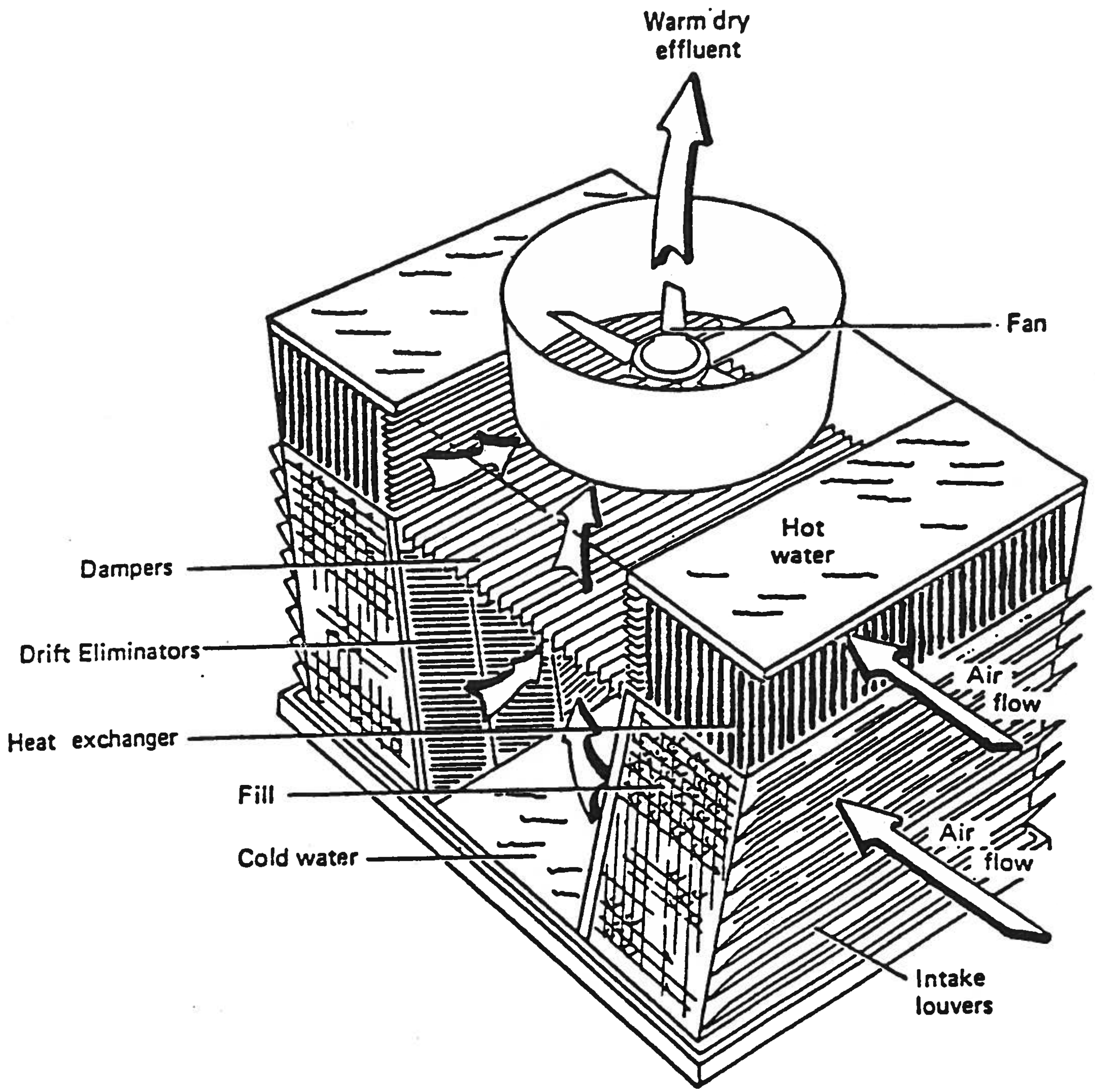


Figure 7. Cross-flow Mechanical Draft Cooling Tower.
(Source: Molenkamp, 1979)

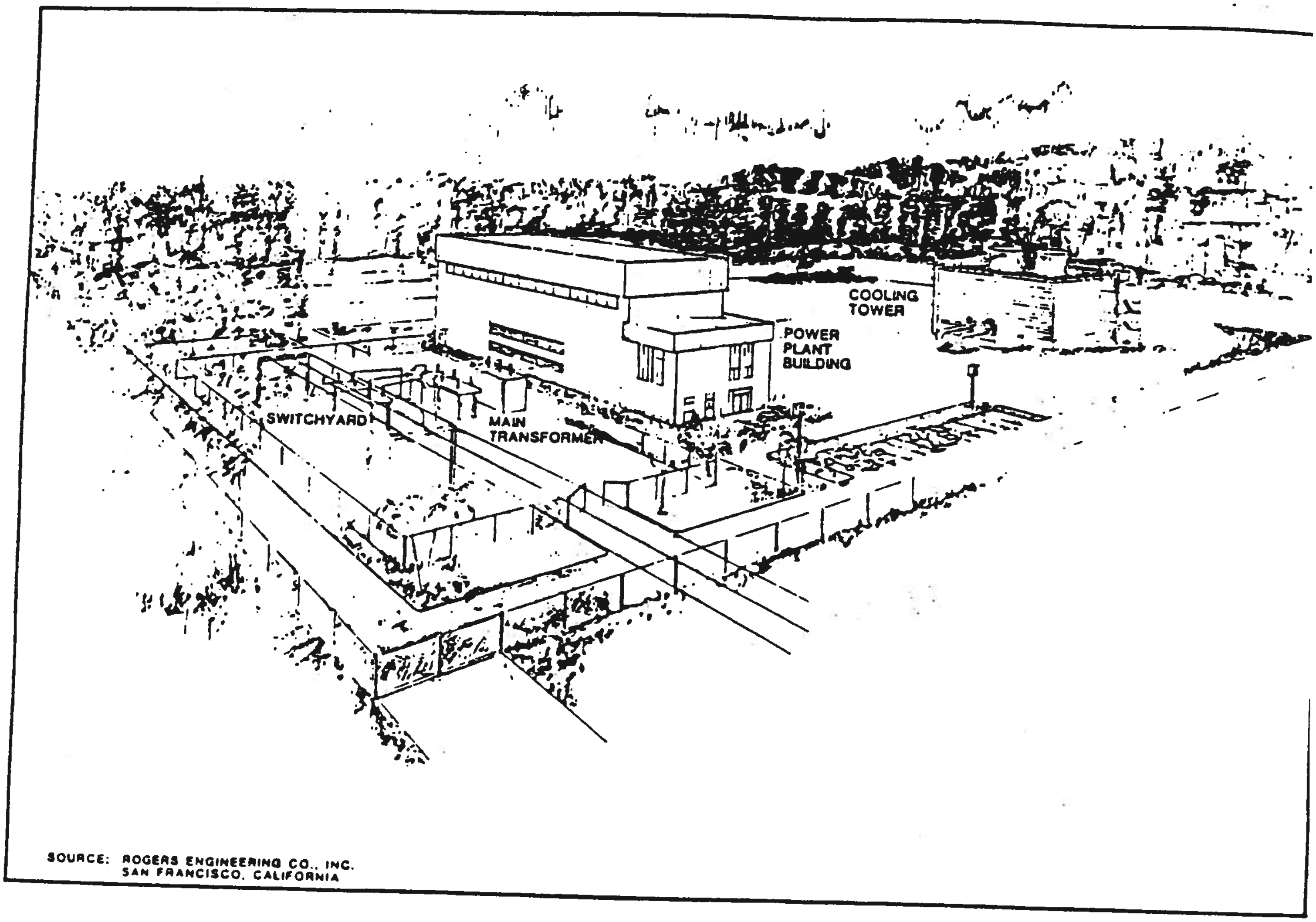
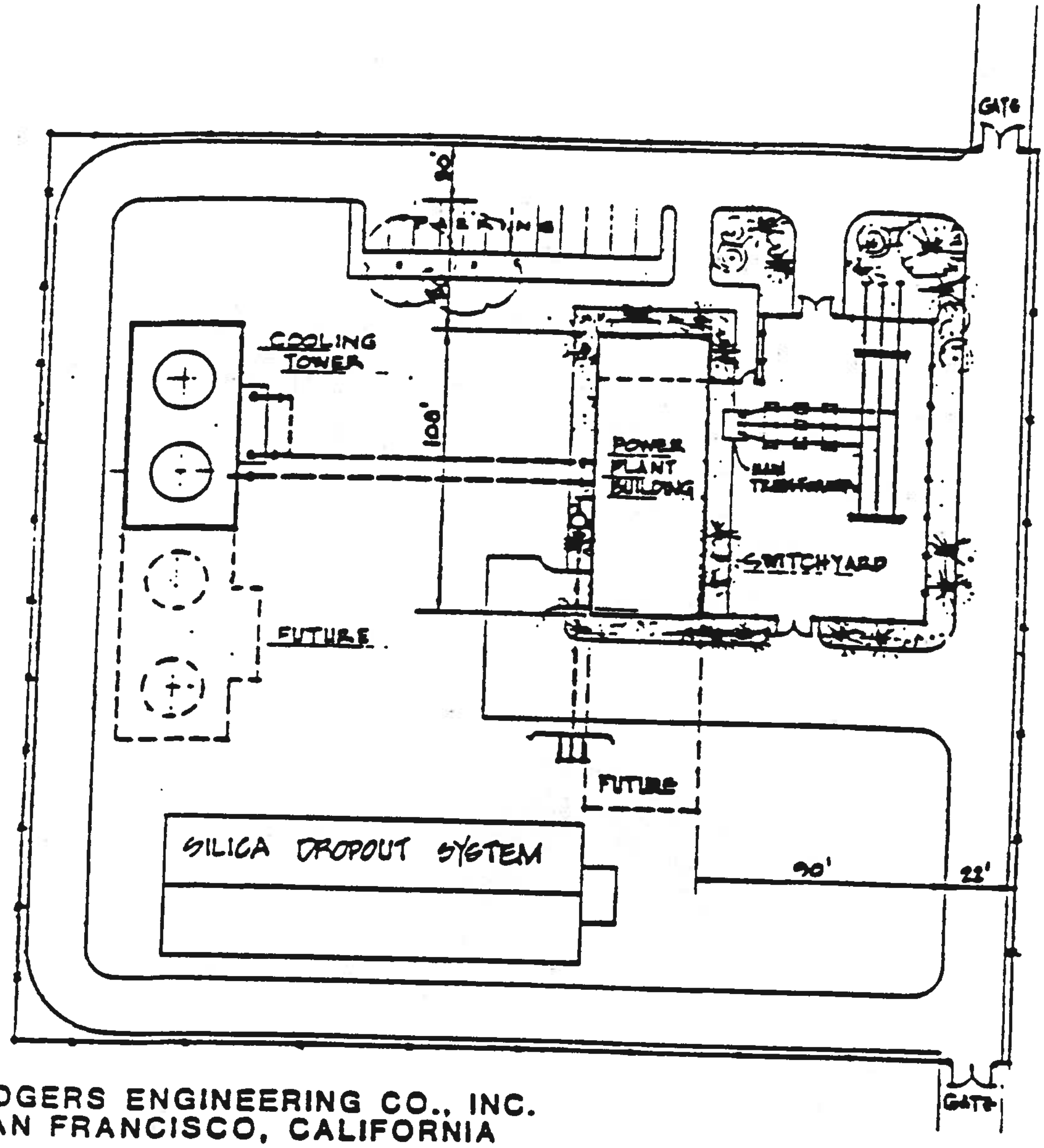


Figure 8. Perspective - Initial 12.5 MWe Power Plant.



SOURCE: ROGERS ENGINEERING CO., INC.
SAN FRANCISCO, CALIFORNIA

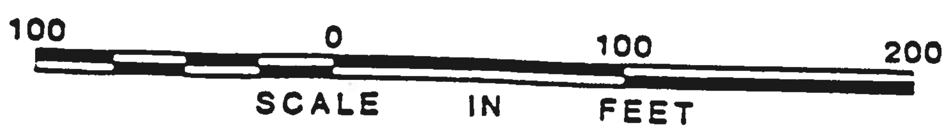


Figure 9. Site Plan - Initial 12.5 MWe Power Plant. (With Expansion to 25 MWe)

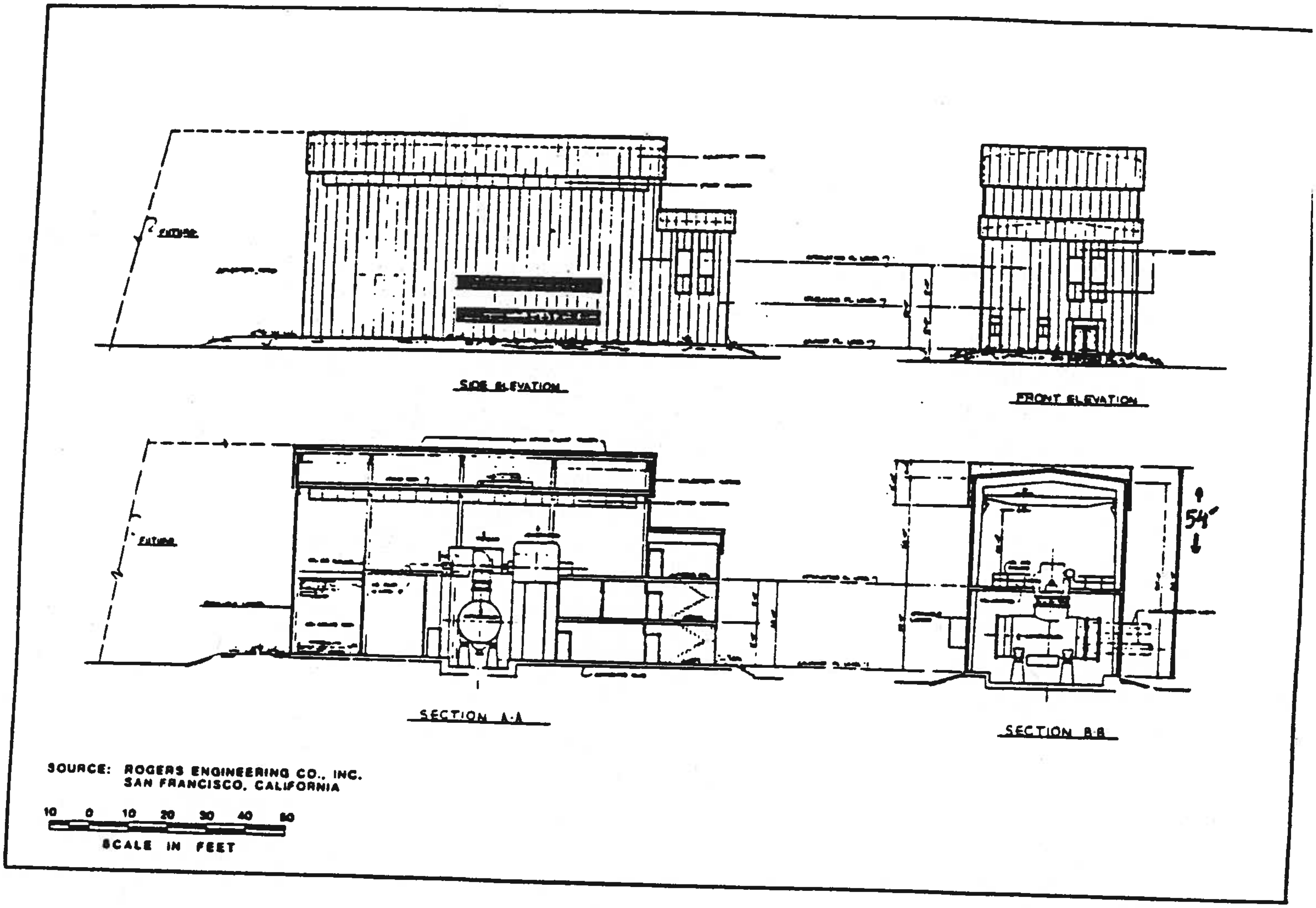


Figure 10. Elevations and Sections - Initial 12.5 MWe Power Plant.

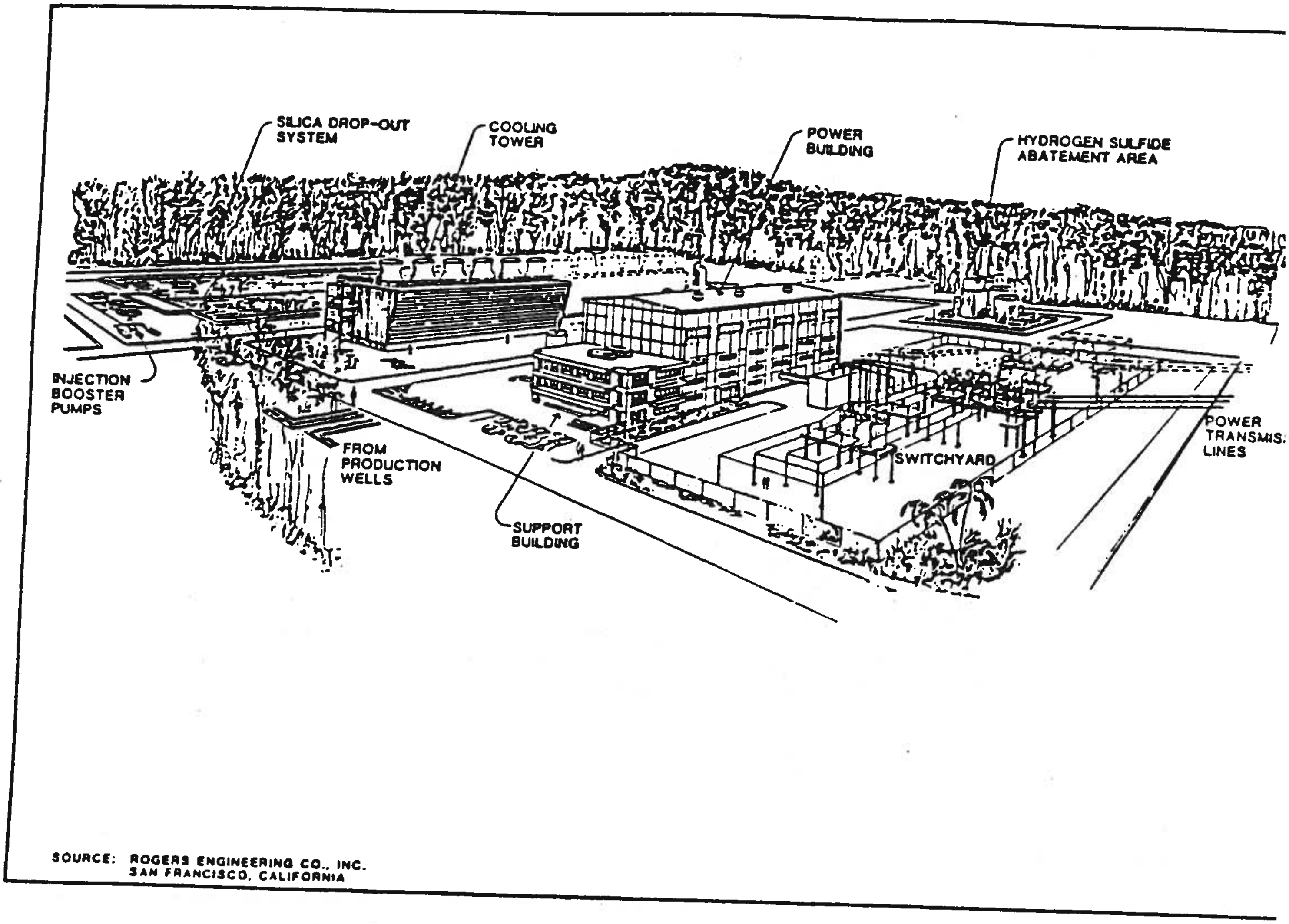


Figure 11. Perspective - 55 MWe Power Plant. (With Expansion to 110 MWe)

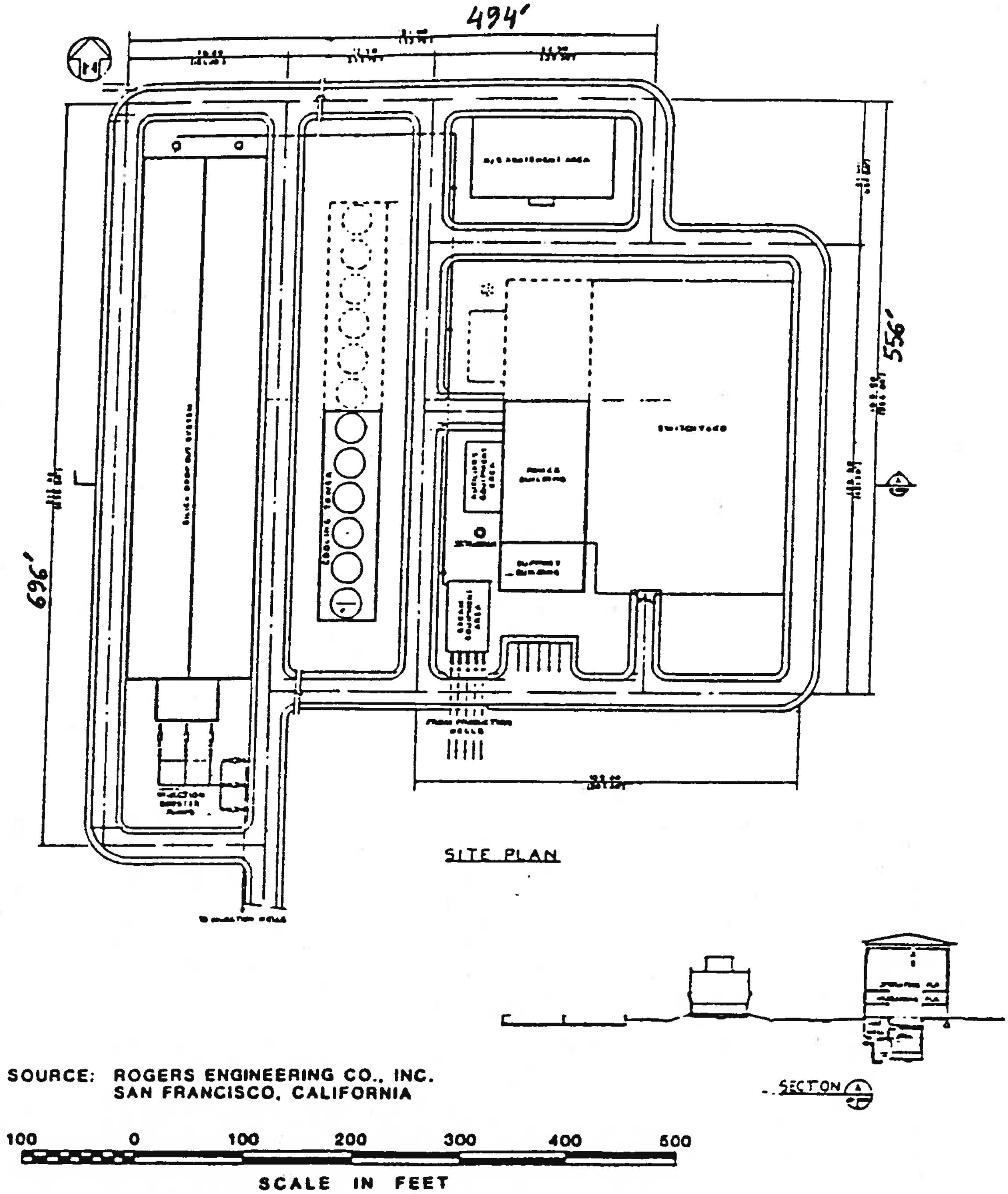


Figure 12. Site Plan and Section, 55 MWe Power Plant. (With Expansion to 110 MWe)

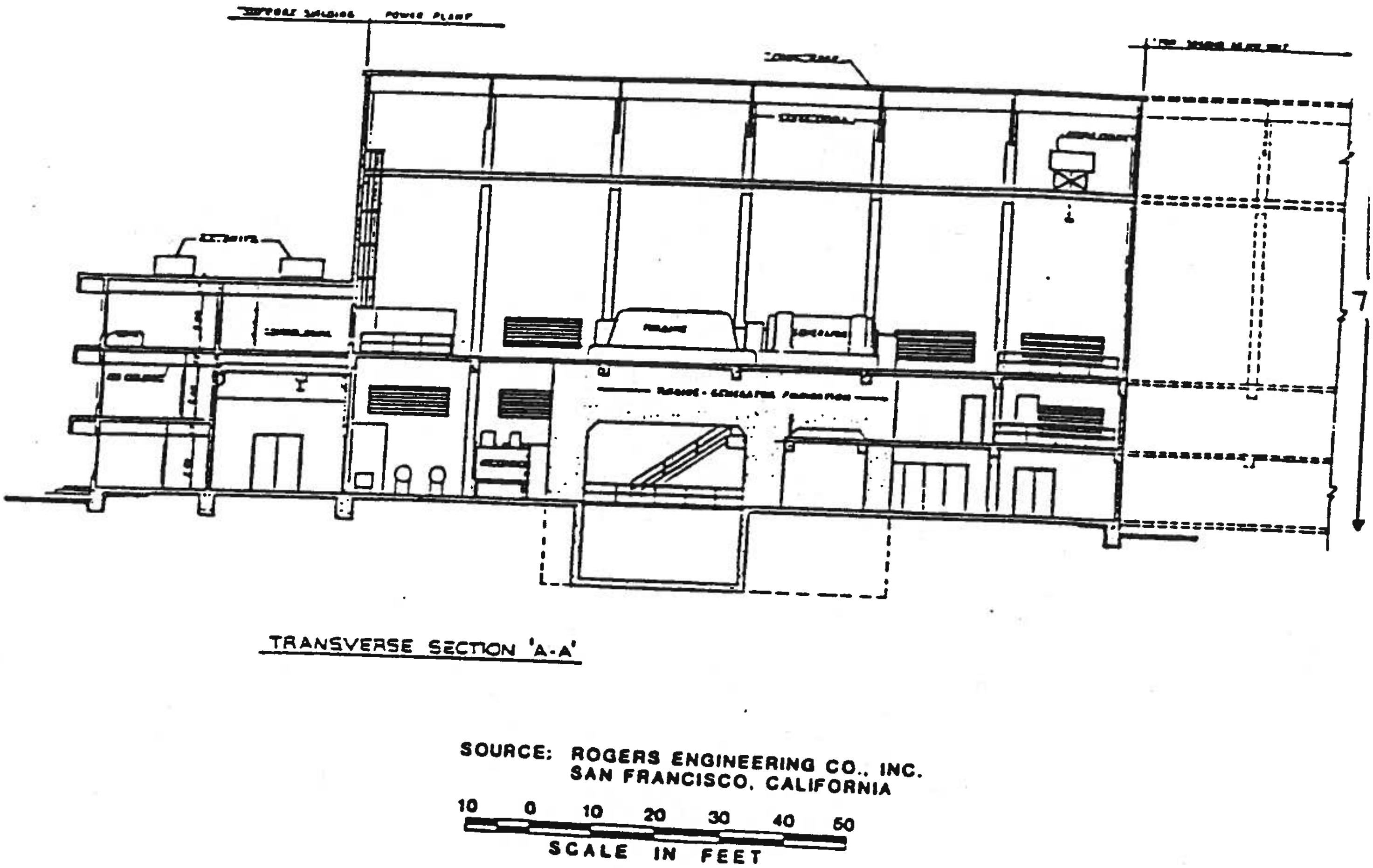


Figure 13. Transverse Section, 55 MWe Power Plant.
(With Expansion to 110 MWe)

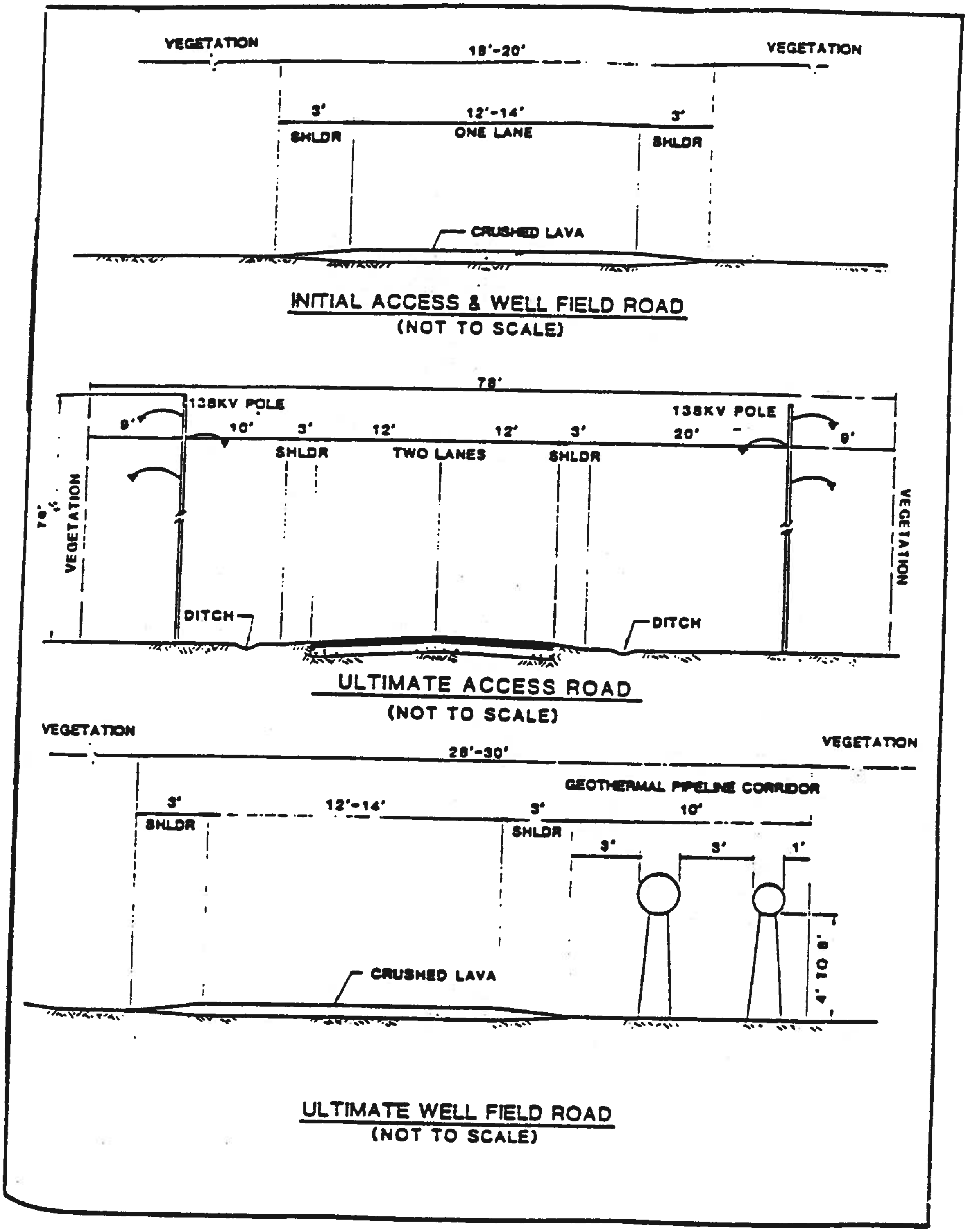


Figure 14. Road Design.
(Source: Kahaualea EIS, 1982)

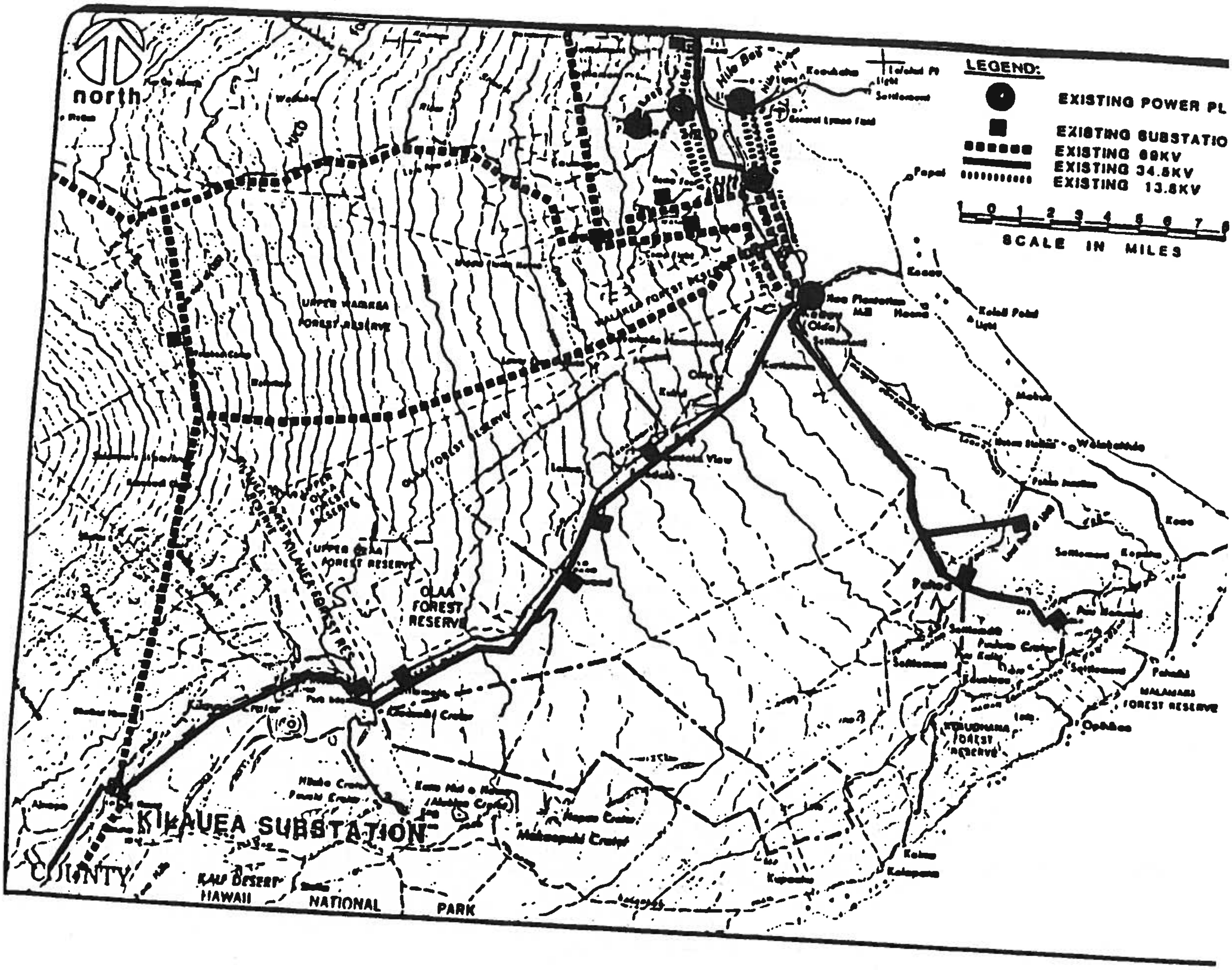
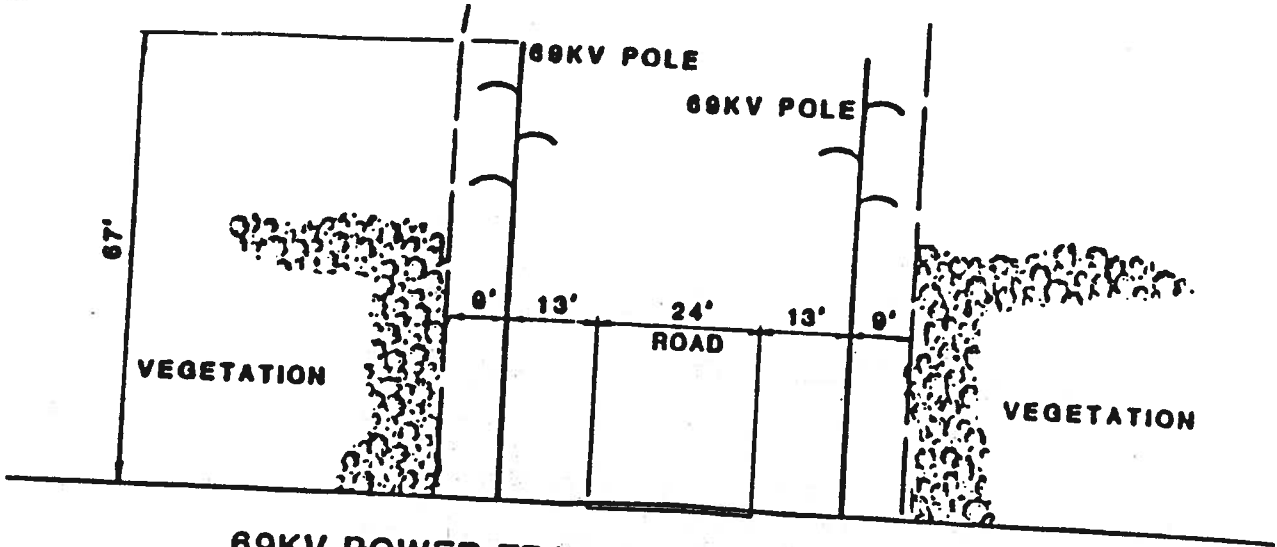
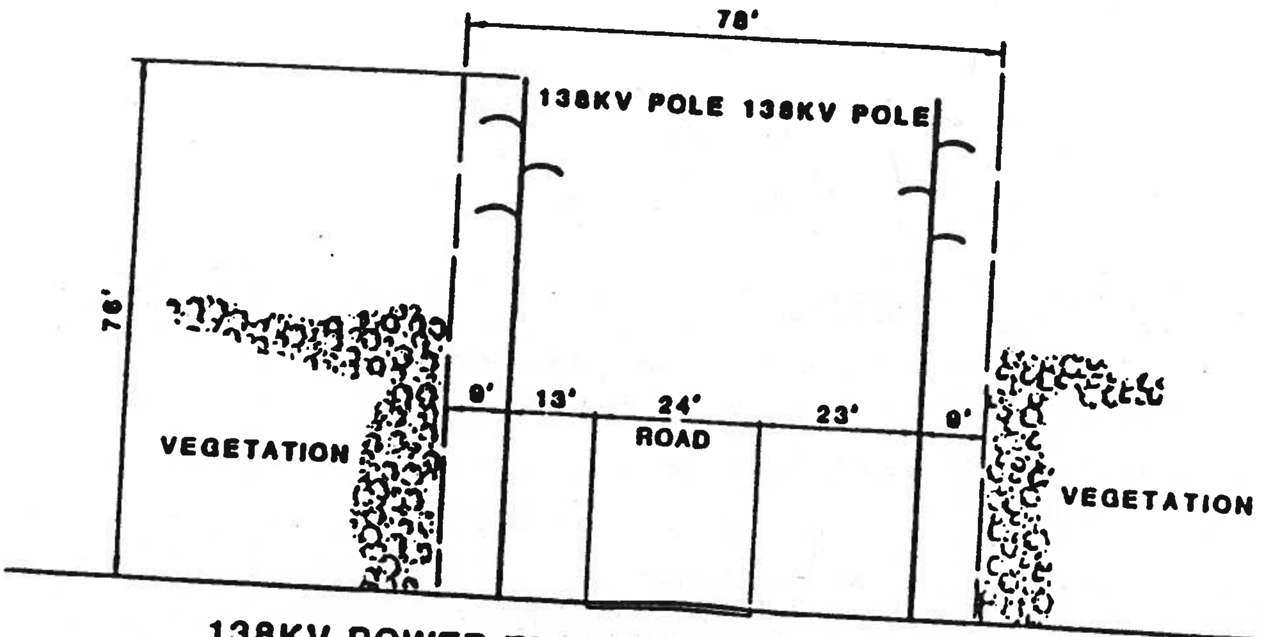


Figure 15. HELCO Power Transmission System.



69KV POWER TRANSMISSION LINE CORRIDOR
(DETAIL "A")



138KV POWER TRANSMISSION LINE CORRIDOR
(DETAIL "B")

SCALE: 1" : 30'

Figure 16. Power Transmission Line Corridors.
(Source: HECO)

Operation	Duration	dBA at 100'
WELL DRILLING		
Mud Drilling	60 days/well	69-74
Air Drilling, Including	30 days/well	
blow line		108
blow line w/air sampler		83
blow line w/air sampler & water injection		73
Well Cleaning; Open Well	3-6 days	112
Well Testing; Open Wells	14 days	112
Rock Muffler		77
Well Bleeding Before Connection to Generator	Variable	
open hole		60
rock-filled ditch		39
blowouts	Variable (infrequent)	112
CONSTRUCTION		
Operation of Construc. Machinery (Trucks, Bulldozers, etc.)	1-2 yrs.	64-84
PLANT OPERATION	20-30 Years	
Steam Line Vent (Muffled)	Intermittent	90
Jet Gas Ejector	Continuous	
unattenuated (old design)		97
with acoustical insulation		64
Steam Line Separator	Continuous	68
Steam Line Breaks	Brief, Infrequent	94
Cooling Tower	Continuous	60-70
Turbine-Generator Bldg.	Continuous	

Figure 17. Noise Levels of Geothermal Operations at The Geysers. (Source: Kahaualea EIS, 1982)