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PRECONCEPTUAL DESIGN AND COST ESTIMATE FOR A 55 MWe POWER PLANT AT THE MEAGER CREEK GEOTHERMAL AREA

Prepared for

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

under contract with

NEVIN/SADLIER-BROWN/GOODBRAND LTD.

BECHTEL

BECHTEL CANADA LTD.
Toronto, Ontario

RESEARCH & ENGINEERING OPERATION
San Francisco, California

Bechtel Job No. 14604
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ABSTRACT

The objective of this study is to prepare a preconceptual design and rough order-of-magnitude capital cost estimate of a geothermal power plant project for the Meager Creek geothermal area. The Meager Creek area is a promising geothermal prospect, but additional exploration must be completed and resource conditions evaluated before a single conceptual design can be developed. Therefore, three sets of resource characteristics are assumed as follows:

- Vapor dominated - as at The Geysers
- Very-hot liquid dominated - downhole liquid temperature of 345°C (653°F)
- Hot liquid dominated - downhole liquid temperature of 280°C (536°F)

Descriptions and cost estimates are given for 55 MWe (gross) power plants and gathering systems for the three assumed resource conditions. A direct steam expansion process is chosen for the vapor dominated resource, and a two stage flash steam process is selected for each of the two liquid dominated resources. In each case, direct contact condensers and a mechanical draft wet (evaporative) cooling tower are used.

A schedule is presented for design and construction of a typical geothermal power plant and gathering system at Meager Creek for any of the three assumed resource conditions defined above.

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ILLUSTRATIONS

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Section 1

SUMMARY

The Meager Creek area of northern British Columbia is a promising geothermal prospect based on exploration done to date by Nevin/Sadlier-Brown/Goodbrand Ltd. under contract to the British Columbia Hydro and Power Authority. A temperature of 202°C (396°F) at 367 m (1204 ft) has been recorded for one hole with higher temperature likely at greater depth.

A capital cost estimate and construction schedule for a geothermal power plant project would be useful data for planning the development of this prospect. However, much more exploration must be completed before data are available to define the resource sufficiently for a single conceptual design. Therefore, this preconceptual study was performed to furnish rough order-of-magnitude capital cost data and a construction schedule for representative geothermal power plant projects.

In this study, three sets of resource characteristics are assumed as representing possible resource conditions for the Meager Creek area. A geothermal power plant project design is defined, and a capital cost estimate is developed for each. The three assumed resource conditions, based on geothermal temperatures measured to date, are as follows:

- Vapor dominated - as at The Geysers
- Very-hot liquid dominated - downhole liquid temperature of 345°C (653°F)
- Hot liquid dominated - downhole liquid temperature of 280°C (536°F).

In each of the three cases, hydrogen sulfide (H_2S) and dissolved solids in the geothermal fluid are assumed to be negligible.

The following power generation processes were selected for each of the three assumed resource conditions:

- Vapor dominated - direct steam expansion through a turbine
- Very-hot liquid dominated - two-stage flash steam process with steam admission to a turbine at two different pressures
- Hot liquid dominated - two-stage flash steam process with lower steam admission pressures than for the very-hot liquid dominated resource.

In each of the three cases, the plant capacity is 55MWe (gross), the main and auxiliary condensers are the direct contact type, and a mechanical draft wet (evaporative) cooling tower is used.

The performance and cost data for a geothermal power plant with each assumed resource are summarized in Table 1-1.

Estimated additional costs for two features that may be eventually needed, but are not included in Table 1-1, are as follows:

- Hydrogen sulfide abatement system for conditions similar to The Geysers — $5 090 000
- Liquid disposal by reinjection
  - Vapor — $660 000
  - Very-hot liquid — $740 000
  - Hot liquid — $840 000

A construction schedule for a geothermal power plant and gathering system at Meager Creek is presented showing 20 months of continuous construction activity to commercial operation. This assumes that the continuous construction activity starts in April and is preceded by site preparation the previous summer.

Table 1-1

PERFORMANCE AND COST SUMMARY

PERFORMANCE		Vapor	Very-Hot Liquid	Hot Liquid
Gross output	MWe	55	55	55
Auxiliary loads	MWe	2.3	1.8	2.2
Net output	MWe	52.7	53.2	52.8
Number of initial geothermal production wells		8	6	9
CAPITAL COST				
Power plant		$37 200 000	$35 000 000	$37 700 000
Fluid gathering system		14 200 000	4 200 000	8 800 000
Fluid disposal system		300 000	600 000	1 200 000
Geothermal wells		13 600 000	10 200 000	15 300 000
Construction camp		5 200 000	5 200 000	5 200 000
Total Project Capital Cost First Quarter 1981 Canadian Dollars		$70 500 000	$55 200 000	$68 200 000

Section 2

INTRODUCTION AND ASSUMPTIONS

2.1 INTRODUCTION

The objective of this study is to prepare a preconceptual design of a geothermal power plant and attendant systems for the Meager Creek geothermal area. This design includes a rough order-of-magnitude estimate of the capital cost and a construction schedule for use in further project planning.

Exploratory drilling indicates that a very-hot resource may exist at the Meager Creek geothermal area. A temperature of 202°C (396°F) at 367 m (1,204 ft) depth has been recorded for one hole (Ref. 2-1). Prospects appear good for higher temperatures at greater depth. However, making an accurate estimate of the geothermal resource characteristics needed for a single power plant conceptual design must await the results of further exploration.

Until exploration proceeds sufficiently to evaluate the geothermal resource characteristics, the best approach to defining an appropriate geothermal power plant and estimating project costs is to assume a set of characteristics that may approximate the actual resource. A power plant can then be defined for the assumed geothermal resource characteristics, and this plant definition can be used for developing a project cost estimate.

To cover a range of resource characteristics considered possible for the Meager Creek geothermal area, three sets (rather than a single set) of resource characteristics are assumed for this study. For each resource assumed, a baseline 55 MWe (gross) geothermal power plant is defined, and a project cost estimate is developed. A power plant rating of 55 MWe (gross) is selected because that is a common size for current geothermal power plant units.

Section 2.2 of this report presents the resource assumptions for the three baseline cases treated in this study. Section 3.1 describes the geothermal power plant defined for each of the three assumed resources, and Section 3.2 discusses the alternatives considered in defining these power plants. Section 4 presents cost estimates for the three baseline plants and for some alternatives that may be included in plant designs if certain resource conditions differ greatly from those assumed. Section 5 contains a typical geothermal power plant and gathering system engineering, procurement and construction schedule tailored for conditions at the Meager Creek location.

2.2 ASSUMPTIONS

For this study, the following three sets of resource characteristics, considered as possible for the Meager Creek geothermal area, are assumed:

- Vapor dominated - For this type of resource, steam is produced from geothermal wells. Steam conditions for this study are assumed to be the same as for The Geysers resource in California where present generating capacity is 908 MWe.
- Very-hot liquid dominated - For a liquid dominated resource, a self-flowing well produces a mixture of steam and hot water. For the very-hot liquid dominated resource, liquid enthalpy (energy content) equal to that at the Tongonan resource in the Philippines is assumed. This is one of the hottest geothermal resources discovered to date.
- Hot liquid dominated - For this resource condition, liquid enthalpy equal to that at the Salton Sea resource in California is assumed. Other resources, such as Baca in New Mexico and Tiwi in the Philippines, have comparable energy content.

Table 2-1 summarizes the specific thermodynamic conditions for each assumed geothermal resource type.

Table 2-1

ASSUMED GEOTHERMAL RESOURCES

RESOURCE TYPE	RESOURCE CONDITION
VAPOR DOMINATED	Reservoir conditions: temperature 236°C (456°F) enthalpy - 2 770 kJ/kg (1,190 Btu/lb) pressure - 3 100 kPa (450 psia)
VERY-HOT LIQUID DOMINATED	Reservoir conditions: temperature - 345°C (653°F) enthalpy - 1 630 kJ/kg (701 Btu/lb) pressure - above saturation pressure
HOT LIQUID DOMINATED	Reservoir conditions: temperature - 280°C (536°F) enthalpy - 1 240 kJ/kg (532 BTU/lb) pressure - above saturation pressure

Since knowledge of the chemical composition of the geothermal fluid is also needed for power plant design, the following assumptions are made:

- Noncondensable gas flow rate to the power plant is assumed to be equal to that for a plant of equal capacity at The Geysers. This amounts to 1% by weight of the steam flow for the vapor dominated resource. For the very-hot and hot liquid dominated resources this is equivalent to 0.5% and 0.3% respectively of the geothermal fluid as noncondensable gas.
- Hydrogen sulfide is assumed to have such low concentration that no abatement system is required.
- Total dissolved solids in the geothermal fluid is assumed to be low. Further, the geothermal fluid is assumed to contain no significant amounts of noxious materials so that residual geothermal liquid and excess condensate can be released into Meager Creek.

These assumptions about chemical composition probably do not reflect the actual conditions, but they do establish a baseline case for each of the three resource conditions. Handling more noncondensable gas than the assumed amount is likely to add only a relatively small amount to the project cost; therefore, the assumption concerning noncondensable gas is adequate for this study.

A reinjection facility or H_2S abatement system to dispose of excess geothermal liquids could add significantly to the project cost. Therefore, typical reinjection and H_2S abatement systems are described in Sections 3.4.4 and 3.4.5 with cost estimates for these alternative systems given in Sections 4.2.1 and 4.2.2.

Site climatic data most important to geothermal power plant conceptual design are the summer wet bulb temperature for cooling tower design and the direction of the prevailing summer winds for proper orientation of the cooling tower. Since collection of climatic data was started only recently and several years' data are needed, wet bulb temperature and wind direction are assumed for this study as follows:

- The summertime wet bulb temperature is assumed to be 18°C(65°F) under severe conditions. This value is used for design at The Geysers which is at about the same elevation as the Meager Creek geothermal area.
- The direction of the prevailing summer winds is assumed to be westerly in accordance with the general summertime air movement in the Coast Range.

Climatic, soil and seismic conditions affecting design of foundations and structures are assumed to be equivalent to those at the Baca Ranch geothermal power plant site in New Mexico.

Section 3

SYSTEM DESCRIPTIONS

This section contains a description of a power plant and a geothermal gathering system, including alternatives considered, for each of the three resources assumed in Section 2. In each case, the power plant output is 55 MWe gross. The geothermal fluids for the three cases are steam (as at The Geysers), very-hot liquid (as discovered in the Philippines) and hot liquid (as at the Baca Ranch plant or the Salton Sea resource). These assumed fluids reflect a range of characteristics which might occur at the Meager Creek resource, and they are representative of conditions for which conceptual or detailed system designs have been prepared in the past.

3.1 VAPOR DOMINATED RESOURCE BASELINE SYSTEM

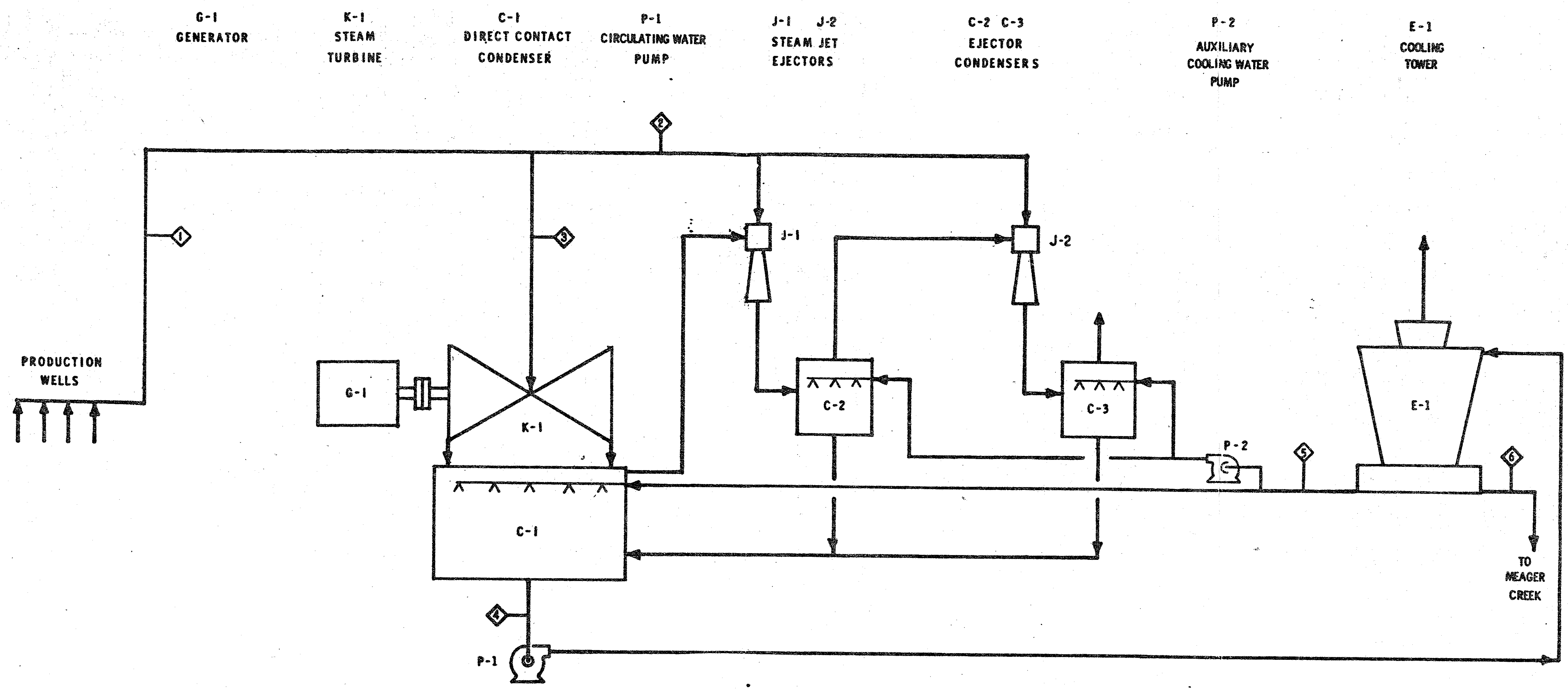
The power plant for a vapor dominated resource includes all the systems required to accept clean steam from the gathering system and to deliver power to an external electric transmission system. The steam gathering system is comprised of well pad steam piping, separators, and steam collection piping needed to gather steam from geothermal wells, remove solids and liquids, and transport steam to the power plant. A description of the power plant and the steam gathering system follows.

3.1.1 Power Plant

Power Generation Process. The flow diagram for the power generation process is shown in Figure 3-1. Steam from geothermal wells is supplied through the gathering system to the turbine-generator where thermal energy is converted to electric power. The turbine exhausts to a direct contact condenser where the steam is condensed and the noncondensable gases from the geothermal steam are removed by the ejector-operated noncondensable gas removal system. The noncondensable gas is vented to the atmosphere. Circulating water for the main condenser is supplied from the cooling tower basin, using the differential pressure that exists due to the vacuum in the main condenser. The cooling water for the noncondensable gas removal system condensers and other plant auxiliaries is supplied from the cooling tower basin, using auxiliary cooling water pumps. Heat acquired by the circulating and cooling water is dissipated to the environment through evaporative cooling in a mechanical draft cooling tower. Steam condensate mixes with the circulating water in the direct contact condenser and serves as make-up for the water evaporated in the cooling tower. Excess condensate equal to about 15% of the steam flow rate is released into Meager Creek.

Process Parameters. In accordance with the power plant design conditions used at The Geysers, the steam pressure is assumed to be 793 kPa (115 psia) at the turbine inlet with enthalpy equal to 2 770 kJ/kg (1,190 Btu/lb). The steam is assumed to have negligible H_2S.

The turbine exhaust pressure is taken as 10 kPa (3 in Hg) in accordance with current designs for plants at The Geysers.



STREAM NUMBER		1	2	3	4	5	6
STREAM DESCRIPTION		DOWNHOLE STEAM	STEAM TO EJECTORS	PRIMARY FLOW TO TURBINE	CIRCULATING WATER	COOLING WATER	BLOWDOWN
ABSOLUTE PRESSURE	kPa	NOTE 1	793	793	10	93	93
TEMPERATURE	°C	NOTE 1	176	176	44	27	27
WATER FLOW	kg/h	0	0	0	12 410 000	11 998 000	62 000
STEAM FLOW	kg/h	412 000	25 000	387 000	0	0	0
TOTAL FLOW	kg/h	412 000	25 000	387 000	12 410 000	11 998 000	62 000
ABSOLUTE PRESSURE	PSIA	NOTE 1	115	115	3.0 In Hg	13.5	13.5
TEMPERATURE	°F	NOTE 1	348	348	111	80	80
WATER FLOW	LB/HR	0	0	0	27,360,000	26,450,000	136,000
STEAM FLOW	LB/HR	907,000	54,000	853,000	0	0	0
TOTAL FLOW	LB/HR	907,000	54,000	853,000	27,360,000	26,450,000	136,000

NOTES:

1. DOWNHOLE TEMPERATURE IS ASSUMED TO BE 236 °C (456 °F) AT A PRESSURE OF 3 100 kPa (450 PSIA) AND ENTHALPY OF 2 770 kJ/kg (1190 BTU/LB)

TURBINE INLET CONDITION IS 793 kPa (115 PSIA) WITH STEAM ENTHALPY OF 2 770 kJ/kg (1190 BTU/hr)

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MEAGER CREEK GEOTHERMAL PRE-CONCEPTUAL ASSESSMENT

POWER PLANT FLOW DIAGRAM
VAPOR DOMINATED RESOURCE

JOB No. 14604
DRAWING No. FIGURE 3-1
REV.

Pressures, temperatures and flow rates at major points in the process are shown in Figure 3-1.

Steam Flow Requirements. The geothermal steam flow required for a given power output is a function of the steam turbine design. Thus, it is dependent upon the specific design of the turbine-generator eventually selected. For this preconceptual design the turbine-generator is assumed to have performance characteristics similar to turbines currently being supplied for installation at The Geysers. Based on the above, the geothermal steam flow requirement is 387 000 kg/h (853,000 lb/hr) for 55 MWe gross power output.

Steam and Condensate System. Steam from the geothermal gathering system flows to each of two turbine inlets. Each inlet consists of a strainer, stop valve, and a control valve in series. The 55 MWe (gross) turbine is a single casing, double flow machine with two inlet ports. Turbine vendors have determined that this type of machine provides optimum balance between cost and efficiency.

The turbine exhausts the steam to a single-shell direct contact condenser located directly below it. The condensed steam mixes with the circulating water and is collected in the condenser hotwell. The circulating water pumps take suction from the hotwell and are located nearby. Two 50 percent capacity pumps, instead of one 100 percent pump, are provided for increased generating unit reliability.

The steam from the geothermal wells is relatively noncorrosive; therefore, the main steam lines leading to the turbine are made of carbon steel. However, the condensate is more corrosive because of dissolved impurities (such as carbon dioxide) carried over from the geothermal steam. Therefore, the condenser and the circulating water pump wetted surfaces are made of type 304L stainless steel.

Noncondensable Gas Removal System. Noncondensable gases entering the condenser along with the steam are removed by ejectors, which use steam from the geothermal wells as motive steam. The noncondensable gas removal system is a two-stage type with direct contact inter- and after-condensers which are cooled by parallel streams of auxiliary cooling water. The condensate/cooling water mixture is drained to the main condenser. The noncondensables collect in the after-condenser and are vented to the atmosphere.

The noncondensable gas piping, the condensate lines, and the internal surfaces of the inter- and after-condensers are made of type 304L stainless steel for corrosion protection.

Circulating Water System. The cooling requirements of the main condenser are met by the circulating water system which includes the cooling tower, circulating water pumps, and the related piping and valves. The circulating water pumps take suction from the condenser hotwell and pump water to the top of the cooling tower. The cooling tower dissipates heat to the environment by evaporating some of the water sprayed into the air stream which is circulated through the tower by means of fans mounted on top of the tower. The cooled water is collected in the tower basin and recirculated to the main condenser by the vacuum maintained in the main condenser. The circulating water lines between the turbine building and the cooling tower are made of fiberglass reinforced plastic for low cost and corrosion resistance.

The amount of water evaporated in the cooling towers is dependent upon the ambient air conditions, evaporation being greater in summer and less in winter. Under all conditions the evaporation is less than the amount of condensate from the geothermal steam. This excess condensate serves as cooling tower blowdown and is discharged into Meager Creek.

Instrumentation and Control. The power plant includes instrument and control devices to permit safe and efficient operation of all systems during all operating modes (startup, power generation, and shutdown). Emergency actions necessary to minimize personnel hazard or major equipment damage and actions necessary to bring standby equipment on line to maintain continuity of service are performed automatically.

A control room, located on the turbine deck, houses necessary instrumentation and controls to monitor and control remote operation of the plant.

Electrical. The main components of the electrical system are a circuit breaker, the main step-up transformer, the main line breaker, and the two auxiliary transformers.

Power is distributed within the plant through a two-voltage level system:

- 4160V for motors 250 to 3000 hp
- 480V for motors 0-200 hp, and miscellaneous loads.

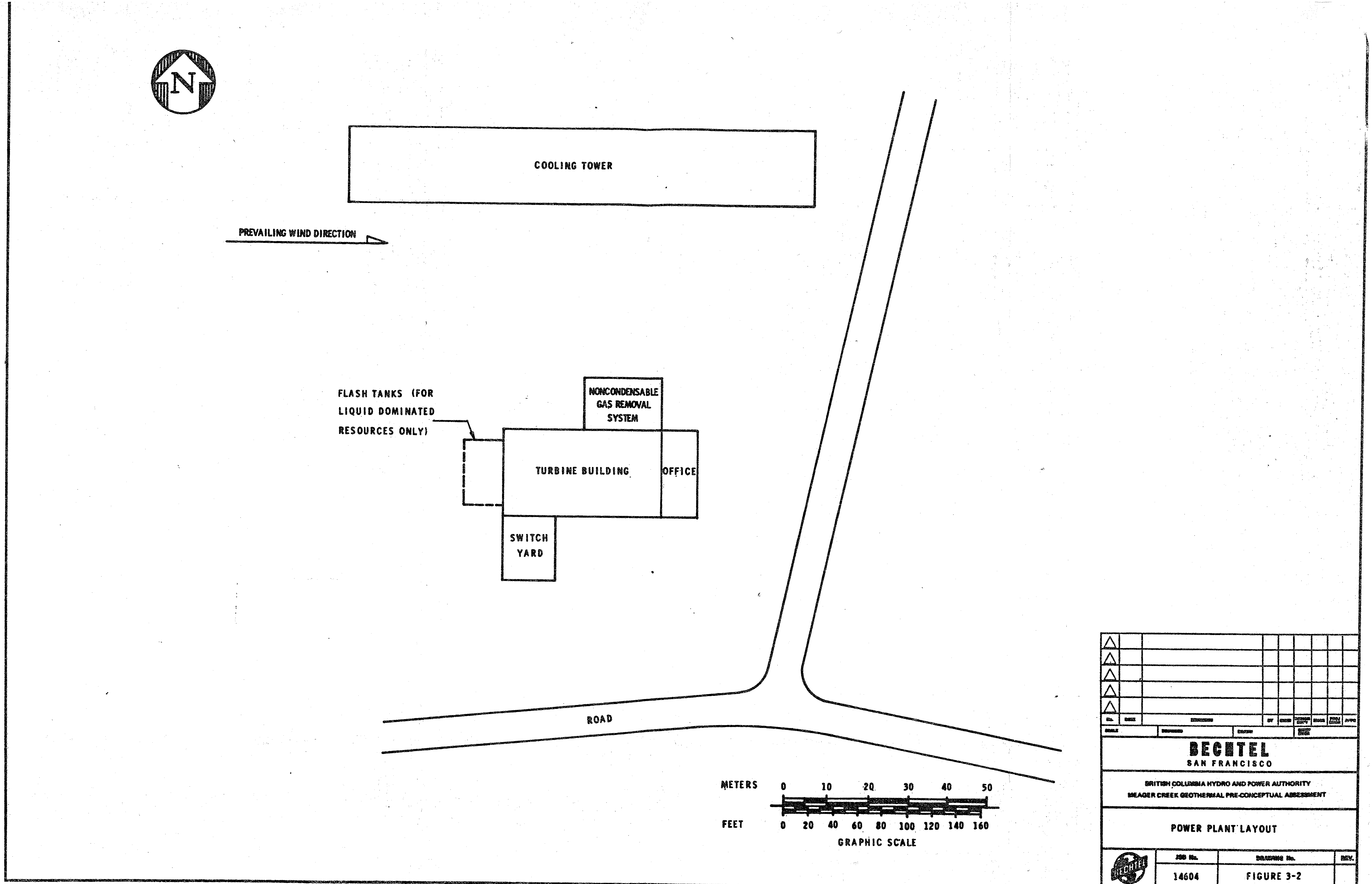
The switchyard containing the main transformer, circuit breaker and transmission terminations is located adjacent to the turbine building.

Civil/Structural. The civil/structural features of the power plant at Meager Creek are typical of those for The Geysers and the Baca Ranch areas. The turbine building is enclosed and framed in structural steel with insulated metal siding and a galvanized metal roof. The turbine pedestal is a massive reinforced concrete rigid frame structure supporting the turbine-generator, condenser and associated equipment. A reinforced concrete slab operating deck, supported on steel framing, surrounds the turbine pedestal at the operating floor level. The deck is designed for turbine parts laydown during maintenance. The turbine building is equipped with a bridge crane capable of serving the turbine-generator and auxiliary equipment. Offices for the power plant administrative personnel are located on the mezzanine of the turbine building located between the ground floor and operating deck.

The cooling tower basin is reinforced concrete. The circulating water lines are buried underground between the cooling tower and the turbine building.

Earthwork required for the site is extensive because of the rugged terrain of the Meager Creek area.

Power Plant Layout. A preferred arrangement of major components and structures for the power plant is shown in Figure 3-2. For efficiency of operation, the long dimension of the cooling tower is parallel to the direction of the prevailing winds. The switchyard and the turbine building are located crosswind from


N
COOLING TOWER
PREVAILING WIND DIRECTION
FLASH TANKS (FOR LIQUID DOMINATED RESOURCES ONLY)
NONCONDENSABLE GAS REMOVAL SYSTEM
TURBINE BUILDING
OFFICE
SWITCH YARD
ROAD
METERS 0 10 20 30 40 50
FEET 0 20 40 60 80 100 120 140 160
GRAPHIC SCALE
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POWER PLANT LAYOUT
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FIGURE 3-2
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the cooling tower to minimize damage from cooling tower drift. The noncondensable gas removal system is located on a concrete pad close to the turbine building to minimize the length of large diameter gas piping from the condenser. The plant covers approximately 1.2 ha (3.0 acres).

Net Power Output. The power plant is designed for 55 MWe (gross) and has the following plant auxiliary loads at nominal flow conditions:

• Circulating water pumps	0.96 MWe
• Cooling tower fans	0.65 MWe
• Miscellaneous loads	0.67 MWe

After subtracting the auxiliary loads from the gross power output, the net power output is 52.7 MWe for a power plant using the assumed vapor dominated resource.

Plant Personnel Requirement. The full-time personnel needed to staff a 55 MWe geothermal power plant after start of commercial operation varies considerably depending on which utility company is the operator. Staffing plans by the Northern California Power Agency (NCPA) and the Sacramento Municipal Utility District (SMUD) serve to illustrate this point. NCPA plans to man its two 55 MWe units (located in one building) with a full-time staff of twelve. On the other hand, SMUD plans to employ twenty full-time staff members for its one 55 MWe unit. Thus, the operating philosophy of the utility company has considerable effect on staff size.

The estimated staffing given below in Table 3-1 uses a minimal level of twelve (equal to NCPA's plan). This provides for two operators during the day shift and one operator during each of the other two shifts.

Even though this staffing level is minimal with respect to types of personnel and continuous operator coverage, the same staff should be adequate to man both the power plant and the wellfield. Furthermore, this staff could probably man additional units as the Meager Creek geothermal area is developed to its potential output. Pacific Gas and Electric Company is currently manning 15 units at The Geysers with a single crew of operators at a central control room. This sort of operating economy can be achieved with appropriate plant design where the units are located reasonably close together.

Table 3-1

FULL-TIME STAFF

Function	No. Req'd
Superintendent	1
Chief Operator	1
Plant Operators	4
Maintenance Electrician	1
Maintenance Mechanic	1
Instrument Repairman	1
Laborer	2
Steno Clerk	1
TOTAL	12

Major Equipment List. Table 3-2 is a list of the major equipment required for the power plant described above.

3.1.2 Steam Gathering System

The steam gathering system includes well pad piping, steam collection piping and centrifugal separators to remove particulates. Figure 3-3 shows the preconceptual layout of the gathering system for well pad and power plant locations presently considered as likely. The farthest well pad is approximately 1.3 km (4,300 ft) from the power plant.

The geothermal wells are slant drilled from multiple well pads with up to four wells from each well pad. This is expected to reduce the drilling cost and also reduce the costs of surface piping and roads compared to drilling a single well from each well pad.

To estimate the number of steam production wells required for a 55 MWe (gross) power plant, an average flow rate per well of 68 000 kg/h (150,000 lb/hr) is assumed based on average flow rates for wells at The Geysers (Refs. 3-1 and 3-2). With this average steam flow rate, six production wells are required to operate the power plant, and two spare wells are included to provide an operating margin consistent with current geothermal wellfield practice. Thus, the initial complement of production wells includes eight wells. It is anticipated that approximately eight replacement wells will be required over the power plant life to maintain the needed steam flow and to replace wells that become inoperable. Therefore, three well pads are specified

Table 3-2

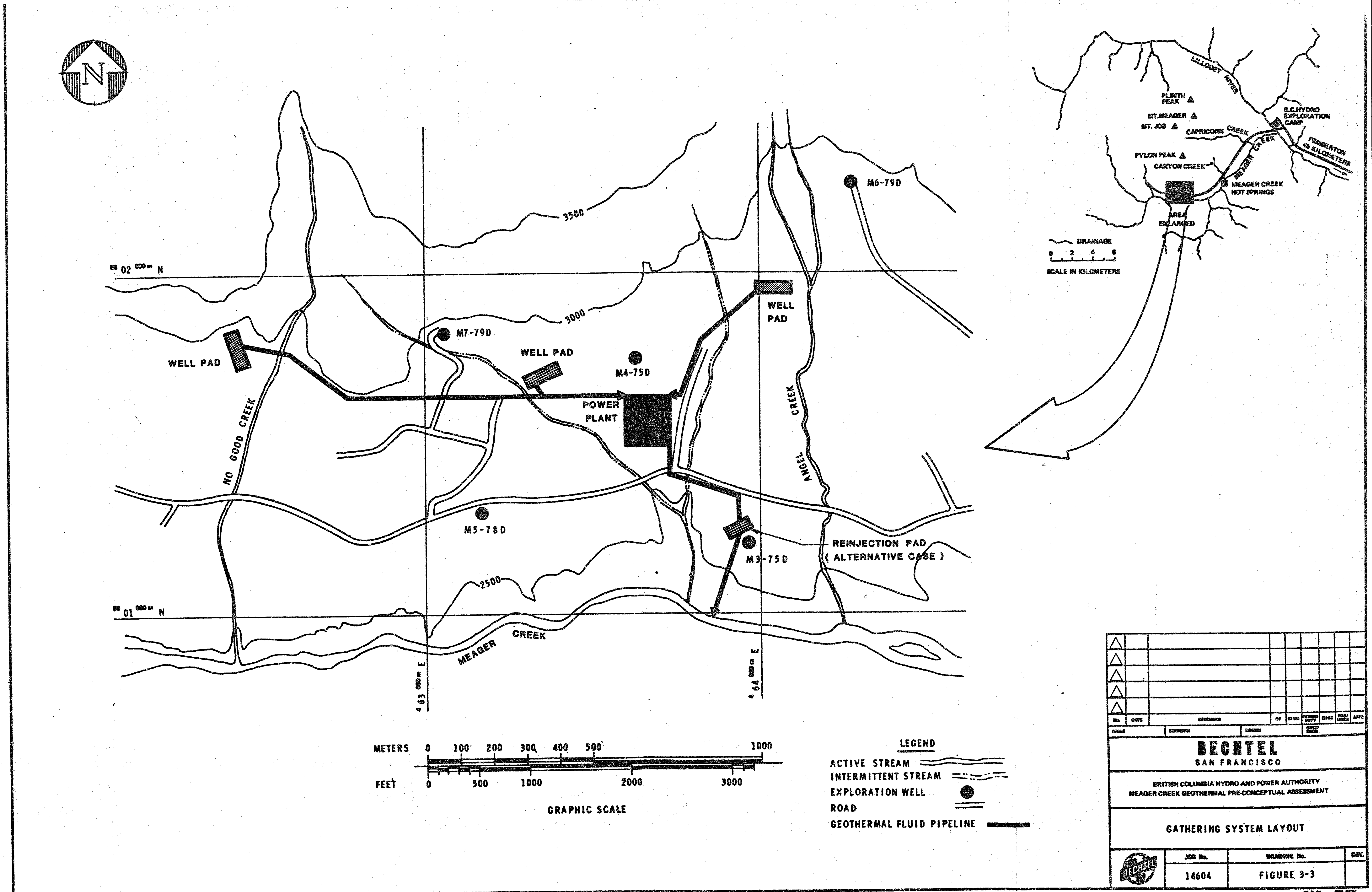
MAJOR EQUIPMENT LIST

VAPOR DOMINATED RESOURCE

Equipment	Description	
Steam Turbine K-1	Quantity:	One
	Type:	Double axial flow
	Rating:	55 000 kWe/3 600 rpm
	Inlet:	Steam at 793 kPa (115 psia) dry saturated
	Exhaust:	10 kPa (3 in Hg)
	General:	Inclusive of inlet stop and control valves, gland seal system, control system, lube oil system, hydrogen system, and panel
Generator G-1	Quantity:	One
	Type:	Hydrogen cooled, three phase, direct coupled to turbine
	Rating:	61 100 kVA, PF 0.90
	General:	13.8 kV, 60 Hz, Class B, static excitation
Condenser C-1	Quantity:	One
	Type:	Direct contact
	Rating:	10 kPa (3 in Hg), 802 x 10^6 kJ/hr (760 x 10^6 Btu/hr)
	General:	2.2°C (4°F)terminal temperature difference, 17.2°C (31°F) cooling water temperature range, 27°C (80°F) inlet, 304L stainless steel shell
Cooling Tower E-1	Quantity:	One, multicell
	Type:	Mechanical draft crossflow
	General:	18°C (65°F) wetbulb, 8.3°C (15°F) approach, 17.2°C (31°F) range, cooling water flow 3 330 L/s (52,900 gpm US)
Circulating Water Pumps P-1	Quantity:	Two 50% capacity
	Type:	Vertical mixed flow
	General:	1 730 L/s (27,400 gpm US) @ 24.4 m (80 ft) TDH, 316 stainless steel with carbon steel stand and sole plate, 700 hp motor

Table 3-2, Continued

Equipment	Description
Auxiliary Cooling Water Pumps P-2	Quantity: Three 50% capacity Type: Vertical, can-type General: 123 L/s (1,950 gpm US) @ 24.4 m (80 ft) TDH 316 stainless steel. 60 hp motor
Noncondensable Gas Removal System J-1, J-2, C-2 and C-3	Quantity: One Type: Two stage, w/direct contact inter- and after-condensers Size: 3 850 kg/h (8,500 lb/hr) gases General: Stainless steel construction


N
LILLOOET RIVER
PLINTH PEAK
MT. MEAGER
MT. JOB
B.C.HYDRO EXPLORATION CAMP
CAPRICORN CREEK
MEAGER CREEK
PEMBERTON 48 KILOMETERS
PYLON PEAK
CANYON CREEK
MEAGER CREEK HOT SPRINGS
AREA ENLARGED
DRAINAGE
0 2 4 6
SCALE IN KILOMETERS
3500
3000
2500
M6-79D
M7-79D
M4-75D
M5-78D
M3-75D
WELL PAD
WELL PAD
WELL PAD
POWER PLANT
REINJECTION PAD (ALTERNATIVE CASE)
NO GOOD CREEK
ANGEL CREEK
MEAGER CREEK
56 02 000 m N
56 01 000 m N
4 63 000 m E
4 64 000 m E
METERS 0 100 200 300 400 500 1000
FEET 0 500 1000 2000 3000
GRAPHIC SCALE
LEGEND
ACTIVE STREAM
INTERMITTENT STREAM
EXPLORATION WELL
ROAD
GEOTHERMAL FLUID PIPELINE
BECHTEL
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GATHERING SYSTEM LAYOUT
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DRAWING No.
FIGURE 3-3
REV.

initially for the vapor dominated resource case, and at least one more well pad may be required over the life of the project.

Well Pad Piping Arrangement. The wells of each well pad are manifolded into a single 36 inch diameter header for collecting steam. At each well pad, a single connection is made into the collection piping. Valves are provided for isolating each well from the header. A wellhead centrifugal separator, to remove solid debris and water, and instrumentation for monitoring the production capability of each well are provided.

Steam Collection Piping. The steam from each well pad is transported to the power plant in large 36 inch diameter pipes to minimize pressure drop. The collection piping consists of three main pipelines (as shown in Figure 3-3) sized to carry steam from four wells at each well pad. Each pipeline has expansion loops to accommodate thermal expansion between hot and cold conditions. The pipelines are low carbon steel insulated from the wellhead to the power plant to conserve heat.

3.2 VERY-HOT LIQUID DOMINATED RESOURCE BASELINE SYSTEM

The baseline system for a very hot liquid dominated resource is described in this section. The power plant and gathering system are similar to that for a vapor dominated resource with three important exceptions:

- The geothermal fluid gathering system is designed for a two-phase fluid rather than a vapor.
- Flash vessels are required to provide geothermal steam to the turbine.
- A turbine with steam admitted at two different pressures is used to efficiently extract energy from the geothermal fluid. The reasons for this process selection are discussed in Section 3.4.1

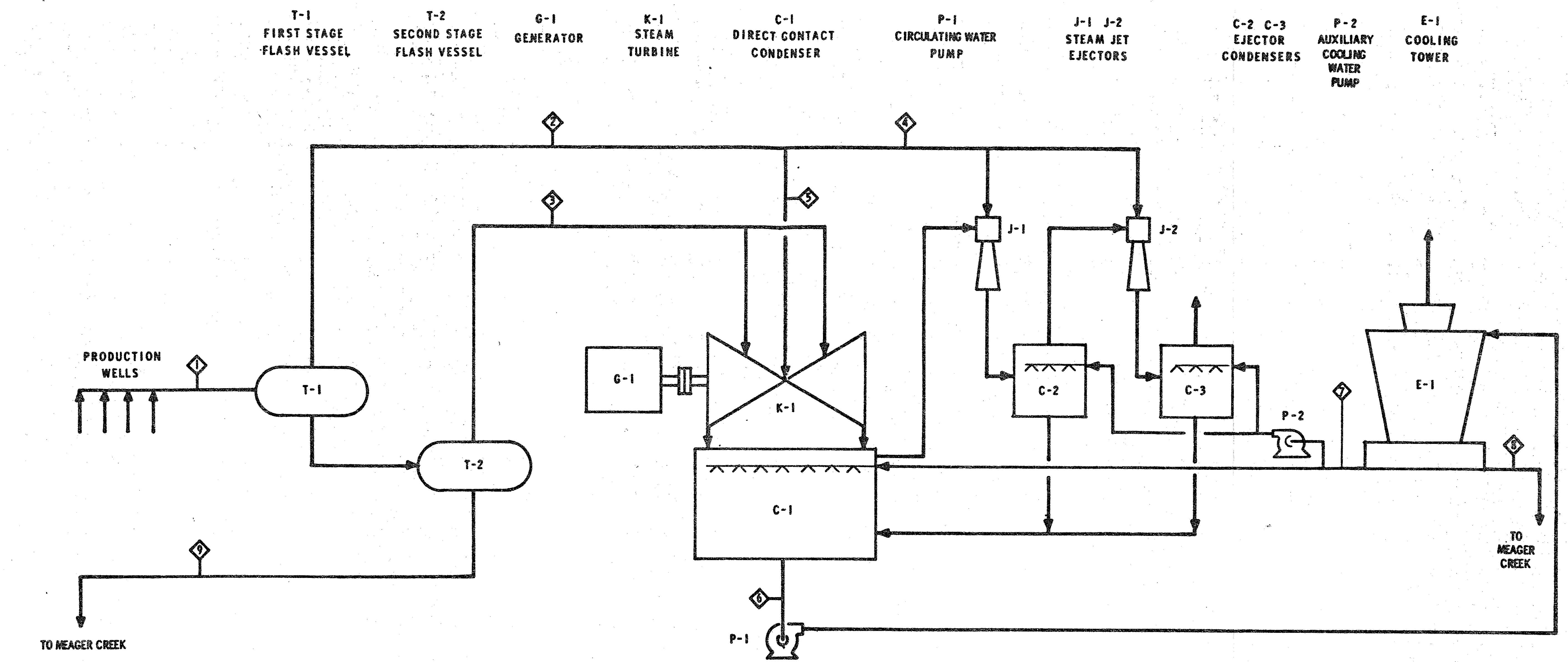
3.2.1 Power Plant

Power Generation Process. The flow diagram for the power generation process is shown in Figure 3-4. Geothermal fluid from the wells is supplied through the gathering system to two stages of flash vessels in series. High- and low-pressure steam from the flash vessels flow through the turbine-generator to convert thermal energy to electric power. The geothermal liquid from the low-pressure flash vessel is piped with excess condensate from the cooling tower to Meager Creek for disposal. The rest of the power generation process is the same as that for the power plant for utilizing a vapor dominated resource.

Process Parameters. As stated in Section 2.2, the downhole liquid temperature is assumed to be 345°C (653°F). The geothermal fluid is assumed to have low dissolved solids and negligible hydrogen sulfide.

The turbine exhaust pressure is specified as 10 kPa (3 in Hg) as for the power plant using a vapor dominated resource.

A two-stage flash process is selected to minimize the flow rate of geothermal fluid required to operate the power plant. The two flash conditions are selected to give maximum energy recovery from the geothermal fluid. This optimum condition occurs when the flash temperatures are taken at equal temperature intervals between the downhole liquid temperatures and the condensing temperature. For downhole liquid temperature of 345°C (653°F) and condensing temperature of 46° C (115°F), the optimum flash temperatures are 245°C (474°F) and 146°C (294°F). These flash temperatures produce steam at turbine inlet pressures of 3 680 kPa (534 psia) and 422 kPa (61 psia).



STREAM NUMBER		1	2	3	4	5	6	7	8	9
STREAM DESCRIPTION		DOWNHOLE GEOTHERMAL FLUID	1st STAGE FLASH STEAM	2nd STAGE FLASH STEAM	STEAM TO EJECTORS	PRIMARY FLOW TO TURBINE	CIRCULATING WATER	COOLING WATER	BLOWDOWN	LIQUID INJECTION
ABSOLUTE PRESSURE	kPa	Note 1	3 682	422	3 682	3 682	10	93	93	422
TEMPERATURE	°C	345	245	146	245	245	44	27	27	146
WATER FLOW	kg/h	Note 1	0	0	0	0	9 497 000	9 165 000	50 000	375 000
STEAM FLOW	kg/h	Note 1	231 000	101 000	7 000	224 000	0	0	0	0
TOTAL FLOW	kg/h	707 000	231 000	101 000	7 000	224 000	9 497 000	9 165 000	50 000	357 000
ABSOLUTE PRESSURE	PSIA	Note 1	534	61.2	534	534	3.0 in Hg	13.5	13.5	61.2
TEMPERATURE	°F	653	474	294	474	474	111	80	80	294
WATER FLOW	LB/HR	Note 1	0	0	0	0	20,935,000	20,204,000	110,000	827,000
STEAM FLOW	LB/HR	Note 1	509,000	222,000	15,000	494,000	0	0	0	0
TOTAL FLOW	LB/HR	1,558,000	509,000	222,000	15,000	494,000	20,935,000	20,204,000	110,000	827,000

NOTES:
1. DOWNHOLE TEMPERATURE IS ASSUMED TO BE 345°C (653°F) WITH GREATER THAN SATURATION PRESSURE AND ENTHALPY OF SATURATED LIQUID.

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POWER PLANT FLOW DIAGRAM
VERY - HOT LIQUID DOMINATED RESOURCE

14604 | FIGURE 3-4

Pressures, temperatures and flow rates at major points in the process are shown in Figure 3-4.

Geothermal Fluid Flow Requirement. The flow rate of geothermal fluid required to produce a given power output depends on the resource conditions, the flash pressures selected, and the steam flow required by the particular steam turbine used. For typical steam turbine efficiency, the assumed resource conditions and the optimum flash pressures selected, the geothermal fluid flow requirement is 707 000 kg/h (1,558,000 lb/hr) for a 55 MWe (gross) power plant. Of that quantity, 33% is flashed to high pressure steam, 14% to low pressure steam and 53% is residual liquid at 146°C (294°F) for disposal.

Flash Vessels. Two-phase fluid from the geothermal fluid gathering system flows to the first stage flash vessel. The flashed steam from this vessel flows to the turbine high pressure inlets and the noncondensable gas removal system steam jet ejectors.

The remaining geothermal liquid from the first stage flash vessel flows to the second stage flash vessel where it is flashed at lower pressure. The resulting steam from the second-stage vessel flows to the turbine low pressure inlets.

The flash train piping and flash vessels are made of carbon steel.

Steam and Condensate System. Steam from the flash vessels flows to each turbine inlet which consists of a strainer, stop valve, and a control valve in series. The 55 MWe (gross) turbine is a single casing, dual admission double axial flow machine with two inlet ports for each admission pressure.

The turbine exhausts the steam to a single-shell direct contact condenser located directly below it. Thus, the condensate system for the liquid dominated resource is similar to that described in Section 3.1.1 for the power plant for a vapor dominated resource.

Other Power Plant Systems. The noncondensable gas removal, circulating water, instrumentation and control, electrical, and civil/structural systems are designed to the same criteria as those for the vapor dominated power plant. Thus, the descriptions of these systems in Section 3.1.1 apply here also.

Power Plant Layout. The arrangement for the power plant is similar to that for the plant using the vapor dominated resource, shown in Figure 3-2, except that a concrete pad is required near the turbine-generator building for the flash vessels. Other design considerations stated in Section 3.1.1 are the same.

Net Power Output. The power plant is designed for 55 MWe (gross) and has the following plant auxiliary loads at nominal flow conditions:

- Circulating water pumps 0.74 MWe
- Cooling tower fans 0.50 MWe
- Miscellaneous loads 0.60 MWe

The circulating water pump and cooling tower fan power requirements are lower for this case than for the vapor dominated case because of the lower condenser heat load. Miscellaneous loads are also reduced because transformer losses and auxiliary cooling water pumping power requirements are less.

After subtracting the auxiliary loads from the gross power output, the net power output is 53.2 MWe for a power plant designed for using the assumed very-hot liquid dominated resource.

Plant Personnel Requirement. The full-time personnel required for staffing a power plant using a very-hot liquid resource is the same as for a plant using a vapor dominated resource as discussed in Section 3.1.1.

Major Equipment List. Table 3-3 is a list of the major equipment required for the power plant described above for the assumed very-hot liquid dominated resource.

3.2.2 Geothermal Fluid Gathering System

The geothermal fluid gathering system for the very-hot liquid dominated resource has the same routing as for the vapor dominated resource as shown in Figure 3-3. Piping sizes differ because the geothermal fluid in this case is a two-phase mixture of steam and hot liquid. Centrifugal separators are not required at the wellhead since the two-phase geothermal fluid is flashed at the power plant.

To estimate the number of production wells needed to operate a 55 MWe (gross) power plant, an average flow rate of steam and liquid mixture equal to 180 000 kg/h (400,000 lb/hr) per well is assumed. This flow rate is the midpoint in the published range of average flow rates from 90 000 kg/h (200,000 lb/hr) (Ref. 3-3) and 270 000 kg/h (600,000 lb/hr) (Ref. 3-4) for wellfields at liquid dominated resources. For the assumed average flow rate per well, four production wells are required to operate

Table 3-3

MAJOR EQUIPMENT LIST

VERY-HOT LIQUID DOMINATED RESOURCE

Equipment	Description
Steam Turbine K-1	Quantity: One Type: Dual admission, double axial flow Rating: 55 000 kWe/3 600 rpm Inlet: Steam at 3 680 kPa (534 psia) and 422 kPa (61 psia), both dry saturated Exhaust: 10 kPa (3 in Hg) General: Inclusive of inlet stop and control valves, gland seal system, control system, lube oil system, hydrogen system, and panel
Generator G-1	Quantity: One Type: Hydrogen cooled, three phase, direct coupled to turbine Rating: 61 100 kVA, PF 0.90 General: 13.8 kV, 60 Hz, Class B, static excitation
Condenser C-1	Quantity: One Type: Direct contact Rating: 10 kPa (3 in Hg), 644 x 10^6 kJ/h (610 x 10^6 Btu/hr) General: 2.2°C (4°F) terminal temperature difference, 17.2°C (31°F) cooling water temperature range, 27°C(80°F) inlet, 304L stainless steel shell
Cooling Tower E-1	Quantity: One, multicell Type: Mechanical draft crossflow General: 18°C (65°F) wetbulb, 8.3°C (15°F) approach, 17.2°C (31°F) range, cooling water flow 2 550 L/s (40,400 gpm US)
Circulating Water Pumps P-1	Quantity: Two 50% capacity Type: Vertical mixed flow General: 1 320 L/s (21,000 gpm US) @ (80 ft) TDH, 316 stainless steel with carbon steel stand and sole plate, 500 hp motor

Table 3-3, Continued

Equipment	Description	
Auxiliary Cooling Water Pumps P-2	Quantity: Type: General:	Three 50% capacity Vertical, can-type 33 L/s (520 gpm US) @ 24.4 m (80 ft) TDH 316 stainless steel 15 hp motor
Noncondensable Gas Removal System J-1, J-2, C-2 and C-3	Quantity: Type: Size: General:	One Two stage, w/direct contact inter- and after-condensers 3 850 kg/h (8,500 lb/hr) gases Stainless steel construction
First-Stage Flash Vessel T-1	Quantity: Type: Size: Design: General:	One Horizontal with elliptical heads 2.4 m (8 ft) dia x 3.0 m (10 ft) long 3 960 kPa gage/252°C (575 psig/485°F) Carbon steel, stainless steel mist eliminators, external insulation
Second-Stage Flash Vessel T-2	Quantity: Type: Size: Design: General:	One Horizontal with elliptical heads 2.4 m (8 ft) dia x 3.0 m (10 ft) long 520 kPa gage/154°C (75 psig/310°F) Carbon steel, stainless steel mist eliminators, external insulation

the power plant, and two spare wells are included to provide an operating margin. Thus, six wells are required initially, and approximately six replacement wells are anticipated over the power plant life. Therefore, three well pads are specified initially for the very-hot liquid dominated resource, and no additional well pads are expected to be required over the life of the project.

Well Pad Piping Arrangement. The well pad piping arrangement is similar to that described previously for the vapor dominated resource. The two-phase geothermal fluid from each production well is transported in an 8 inch diameter pipe to a single 12 inch diameter header which connects to the collection piping system.

Collection Piping. The fluid from each well pad is transported to the power plant in large diameter pipes to minimize the pressure drop. The diameter of the piping from the farthest wellfield point to the power plant is 12 inches. Each pipeline has expansion loops to accommodate thermal expansion between hot and cold conditions. The pipelines are low carbon steel insulated from well head to the power plant to conserve heat.

3.3 HOT LIQUID DOMINATED RESOURCE BASELINE SYSTEM

The baseline system for a hot liquid dominated resource is similar to that for a very-hot liquid dominated resource as described in Section 3.2. However, differences in geothermal fluid conditions do affect equipment size and performance requirements, since greater amounts of lower temperature geothermal fluid must be handled. The result is that the gathering system, flash vessels, steam turbine, condenser and cooling tower must be larger to achieve the same electric power output.

3.3.1 Power Plant

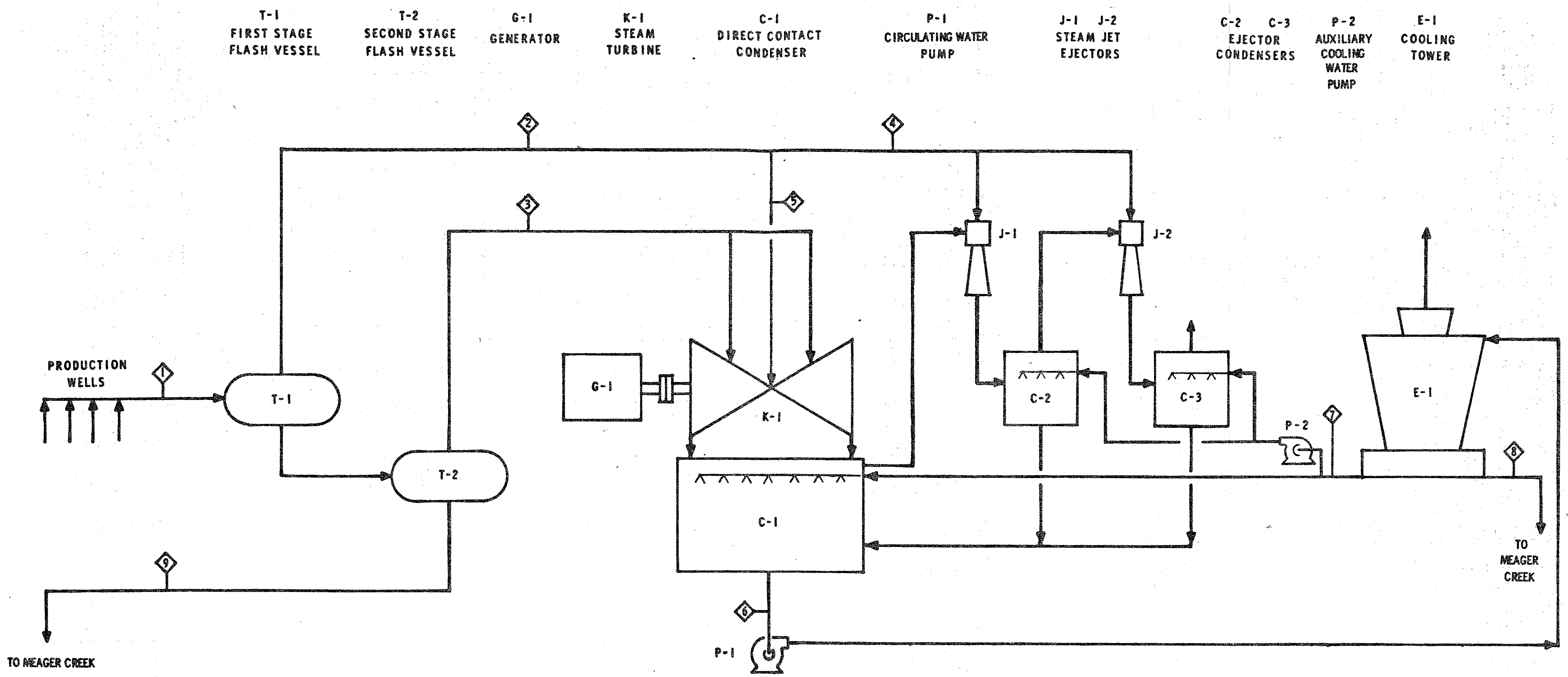
Power Generation Process. The flow diagram for the power generation process is shown in Figure 3-5. This power generation process is fundamentally the same as that described in Section 3.2 for a very-hot liquid dominated resource. Only the flash conditions and flow rates are different for this lower temperature resource.

Process Parameters. As indicated in Section 2.2, the downhole liquid temperature is assumed to be 280°C (536°F) for the hot liquid dominated resource. The geothermal fluid is assumed to have low dissolved solids and negligible H_2S.

The turbine exhaust pressure is taken as 10 kPa (3 in Hg) as for the power plants using vapor dominated and very-hot liquid dominated resources. Optimum flash temperatures for these downhole and turbine exhaust conditions are 202°C (396°F) for the high pressure steam and 124°C (255°F) for the low pressure steam. These flash temperatures produce steam at turbine inlet pressures of 1 682 kPa (244 psia) and 224 kPa (32.5 psia).

Pressures, temperatures, and flow rates at major points in the process are shown in Figure 3-5.

Geothermal Fluid Flow Requirement. For the assumed resource conditions, the optimum flash pressure selected and typical turbine steam requirements, the geothermal fluid flow requirement is 1 280 000 kg/h (2,821,000 lb/hr) for a 55 MWe (gross) power plant. Of that quantity, 19% is flashed to high pressure steam, 13% to low pressure steam and 68% is residual liquid at 124°C (255°F) for disposal.



STREAM NUMBER		1	2	3	4	5	6	7	8	9
STREAM DESCRIPTION		DOWNHOLE GEOTHERMAL FLUID	1st STAGE FLASH STEAM	2nd STAGE FLASH STEAM	STEAM TO EJECTORS	PRIMARY FLOW TO TURBINE	CIRCULATING WATER	COOLING WATER	BLOWDOWN	LIQUID INJECTION
ABSOLUTE PRESSURE	kPa	NOTE 1	1682	224	1682	1682	10	93	93	224
TEMPERATURE	°C	280	202	124	202	202	44	27	27	124
WATER FLOW	kg/h	NOTE 1	0	0	0	0	12 239 000	11 829 000	61 000	870 000
STEAM FLOW	kg/h	NOTE 1	224 000	166 000	15 000	229 000	0	0	0	0
TOTAL FLOW	kg/h	1 280 000	244 000	166 000	15 000	229 000	12 239 000	11 829 000	61 000	870 000
ABSOLUTE PRESSURE	PSIA	Note 1	244	32.5	244	244	3.0 in Hg	13.5	13.5	32.5
TEMPERATURE	°F	536	396	255	396	396	111	80	80	255
WATER FLOW	LB/HR	Note 1	0	0	0	0	26,981,000	26,079,000	135,000	1,919,000
STEAM FLOW	LB/HR	Note 1	537,000	365,000	32,000	505,000	0	0	0	0
TOTAL FLOW	LB/HR	2,821,000	537,000	365,000	32,000	505,000	26,981,000	26,079,000	135,000	1,919,000

NOTES:

1. DOWNHOLE TEMPERATURE IS ASSUMED TO BE 280°C (536°F) WITH GREATER THAN SATURATION PRESSURE AND ENTHALPY OF SATURATED LIQUID.

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POWER PLANT FLOW DIAGRAM
HOT LIQUID DOMINATED RESOURCE

JOB No.	DRAWING No.	REV.
14604	FIGURE 3-5	

Power Plant Systems and Plant Layout. All the power plant systems for a hot liquid dominated resource are similar to those described in Section 3.2.2 for a very-hot liquid dominated resource except that the flash conditions and flow rates are different. These differences cause the equipment sizes to be larger for the hot resource but do not change the general plant configuration or layout. Except for these quantitative differences, the power plant description in Section 3.2.2 applies.

Net Power Output. The power plant is designed for 55 MWe (gross) and has the following plant auxiliary loads at nominal flow conditions:

- Circulating water pumps 0.95 MWe
- Cooling tower fans 0.64 MWe
- Miscellaneous loads 0.64 MWe

Auxiliary power requirements are virtually the same for both the hot liquid dominated and vapor dominated designs.

After subtracting the auxiliary loads from the gross output, the net power output is 52.8 MWe for a power plant using the assumed hot liquid dominated resource.

Plant Personnel Requirement. The full-time personnel required for staffing a power plant using a hot liquid resource is the same as for a plant using a vapor dominated resource as discussed in Section 3.1.1.

Major Equipment List. Table 3-4 is a list of the major equipment required for the power plant for the assumed hot liquid dominated resource.

Table 3-4

MAJOR EQUIPMENT LIST

HOT LIQUID DOMINATED RESOURCE

Equipment	Description	
Steam Turbine K-1	Quantity:	One
	Type:	Dual admission, double axial flow
	Rating:	55 000 kWe/3 600 rpm
	Inlet:	Steam at 1 680 kPa (244 psia) and 224 kPa (32 psia), both dry saturated
	Exhaust:	10 kPa (3 in Hg)
	General:	Inclusive of inlet stop and control valves, gland seal system, control system, lube oil system, hydrogen system, and panel
Generator G-1	Quantity:	One
	Type:	Hydrogen cooled, three phase, direct coupled to turbine
	Rating:	61 100 kVA, PF 0.90
	General:	13.8 kV, 60 Hz, Class B, static excitation
Condenser C-1	Quantity:	One
	Type:	Direct Contact
	Rating:	10 kPa (3 in Hg), 817 x 10^6 kJ/h (774 x 10^6 Btu/hr),
	General:	2.2°C (4°F) terminal temperature difference, 17.2°C (31°F) cooling water temperature range, 27°C (80°F) inlet, 304L stainless steel
Cooling Tower E-1	Quantity:	One, multicell
	Type:	Mechanical draft crossflow
	General:	18°C (65°F) wetbulb, 8.3°C (15°F) approach, 17.2°C (31°F) range, cooling water flow 3 290 L/s (52,200 gpm US)
Circulating Water Pumps P-1	Quantity:	Two 50% capacity
	Type:	Vertical mixed flow
	General:	1 700 L/s (27,000 gpm US) @ 24.4 m (80 ft) TDH, 316 stainless steel with carbon steel stand and sole plate, 700 hp motor

Table 3-4, Continued

Equipment	Description
Auxiliary Cooling Water Pumps P-2	Quantity: Three 50% capacity Type: Vertical, can-type General: 72 L/s (1,150 gpm US) @ 24.4 m (80 ft) TDH, 316 stainless steel, 40 hp motor
Noncondensable Gas Removal System J-1, J-2, C-2 and C-3	Quantity: One Type: Two stage, w/direct contact inter- and after-condensers Size: 3 850 kg/h (8,500 lb/hr) gases General: Stainless steel construction
First-Stage Flash Vessel T-1	Quantity: One Type: Horizontal with elliptical heads Size: 2.4 m (8 ft) dia x 3.7 m (12 ft) long Design: 1 900 kPa gage/210°C (275 psig/410°F) General: Carbon steel, stainless steel mist eliminators, external insulation
Second-Stage Flash Vessel T-2	Quantity: One Type: Horizontal with elliptical heads Size: 3.0 m (10 ft) dia x 4.6 m (15 ft) long Design: 345 kPa gage/140°C (50 psig/285°F) General: Carbon steel, stainless steel mist eliminators, external insulation

3.3.2 Geothermal Fluid Gathering System

With the exception of the number of wells and sizes of piping and equipment, the gathering system for the hot liquid dominated resource is identical to that described in Section 3.2.2 for a very-hot resource.

To estimate the number of production wells required for a 55 MWe (gross) power plant, an average flow rate of steam and liquid mixture equal to 180 000 kg/h (400,000 lb/hr) per well is assumed as discussed in Section 3.2.2. For this average flow rate, seven production wells are required to operate the power plant, and two spare wells are included to provide an operating margin. Thus, nine wells are required initially, and approximately nine replacement wells are anticipated over the power plant life. Therefore, three well pads are required for the initial wells for the hot liquid dominated resource, and as many as two additional well pads may be needed over the life of the project.

Well Pad Piping Arrangement. The geothermal fluid is transported from each production well in an 8 inch diameter pipe to a single 16 inch diameter header which connects to the collection piping system.

Collection Piping.

The diameter of the piping from the farthest wellfield point to the power plant is 16 inches. Insulation, expansion loops, and auxiliary equipment associated with the pipeline are as described in Section 3.2.2.

3.4 ALTERNATIVES CONSIDERED

The configurations of the three baseline power plant designs are based on the assumptions listed in Section 2, results from previous geothermal power plant studies and considerations of conditions specific to the

Meager Creek area. This section discusses alternatives that were considered and dismissed as inappropriate for these baseline designs, such as other energy conversion processes, once through cooling and installation of a spare cooling water pump. The geothermal resource may later be shown to contain noxious chemicals requiring reinjection of the excess geothermal fluid or concentrations of H_2S requiring an abatement system. These two alternatives are also discussed.

3.4.1 Alternative Energy Conversion Processes

The binary, single-stage flash steam, and multi-stage flash steam processes have all received extensive consideration by the industry for use with liquid dominated geothermal resources.

Binary Cycle. A binary cycle is a closed Rankine cycle using a working fluid heated by hot geothermal liquid. The working fluid is a halocarbon, a light halocarbon, or a mixture of light hydrocarbons. The main advantages of a binary cycle compared to a flashed steam process are that more energy can be recovered per unit mass of geothermal liquid, lower temperature resources can be used, and no H_2S abatement system is needed since the H_2S never separates from the geothermal resource. The binary cycle is in development (Refs. 3-5 and 3-6) with a commercial size demonstration plant scheduled to begin operation at Heber, California in the mid-1980s. Since the binary cycle is not yet a commercially proven process, only the flash steam processes were given detailed consideration in this study.

Other Flash Steam Processes. In a flash steam power plant, energy output per unit mass of geothermal fluid increases with the number of flash stages. On the other hand, the cost and complexity of the steam turbine and piping increase with the number of flash stages. Therefore, an optimization considering these two opposing trends is necessary to define the proper number of flash stages.

A two-stage flash process uses 20 to 30 percent less geothermal fluid than a single-stage flash process, depending on the resource conditions, for the same electric energy generation. A single-stage flash plant would result in a slightly lower steam turbine cost but require a larger number of wells for the same electric power output. By contrast, a three-stage flash process uses only slightly less geothermal fluid - 5 to 10% - than a two-stage flash process. Furthermore, turbine manufacturers have indicated that turbines for a three-stage flash process are not available because of the complexity.
As a result of these considerations, the base case design for both sets of assumed liquid dominated resource conditions is a two-stage flash process.

3.4.2 Once Through Cooling

The cooling system in the three base case designs uses an evaporative cooling tower to dissipate the reject heat to the atmosphere.

Where feasible, once through cooling is usually less costly than evaporative cooling. Therefore, the possibility of using water from Meager Creek for once through cooling was considered.

An analysis was done to estimate the capacity of Meager Creek for once through cooling. Since long term flow records for Meager Creek are not available, an approximation was made. The catchment area of Meager Creek at the prospective plant site was ratioed to the catchment area of the Lillooet River (of which Meager Creek is a tributary) at Pemberton. This ratio was then multiplied by flowrates of the Lillooet River taken over the past 65 years at Pemberton. These results show that an average flow of 30 m^3/s (360 ft^3/s) is likely in Meager Creek. The cooling water requirement of a 55 MWe (gross) geothermal power plant is approximately 20 m^3/s (255 ft^3/s). Therefore, although once through cooling may be possible for one 55 MWe unit in the Meager Creek geothermal area, it is not incorporated into the three base case designs because that would make the designs atypical of additional units that would be built to further develop this geothermal resource.

3.4.3 Installed Spare Circulating Water Pump

Installed spares are often specified for rotating machinery in power plant systems critical to maintaining full load operation. However, the desirability of a redundant circulating water pump must be determined by comparison of the capital cost of a spare pump (and all required interconnecting piping and valves) and the value of the incremental increase in plant reliability.

Two 50% capacity circulating water pumps are specified in the three base case designs in this study. The qualitative basis for this preliminary selection is:

- Circulating water pumps and motors have relatively high reliability as demonstrated by actual geothermal service at The Geysers.
- A loss of one 50% capacity circulating water pump results in a plant output reduction of only 20 to 40 percent depending upon pump, turbine and cooling tower performance characteristics.

- Circulating water pumps and motors are large and expensive. The increased reliability gained by installing a spare pump does not justify the additional cost.

- Most existing geothermal power plants do not have installed spare circulating water pump capacity as a result of the factors listed above.

3.4.4 Reinjection of Excess Geothermal Fluid

The three base case designs are prepared assuming that the cooling tower blowdown and all liquid exiting the low-pressure flash tank is discharged directly into Meager Creek.

This might not be feasible for one or a combination of the following three reasons:

- Further exploration may show that the geothermal fluid contains excessive amounts of noxious materials such as arsenic, boron or copper.

- Possible excess thermal loading to the creek water may occur at certain times of the year when using a liquid dominated resource. The effluent temperatures from the low pressure flash tanks are 146°C (294°F) and 124°C (255°F) for the very-hot and hot resource applications respectively. This might heat the creek water excessively during periods of low creek flow.

- Reinjection of some geothermal fluid may be needed to prevent excessive subsidence.

Reinjecting the excess geothermal fluid is the most likely way to cope with any of these potential problems.

To accomplish reinjection of the geothermal fluid, injection wells are required, and pumps with appropriate piping, valves and controls may be needed depending on subsurface reservoir structure. A likely location for a reinjection well pad is shown in Figure 3-4.

Reinjection requirements, different for each of the three assumed resources, are discussed below on the basis of experience to date.

Vapor Dominated Resource. The excess geothermal fluid in this case is the steam condensate not needed for evaporative cooling. This amounts to about 15% of the steam flow, or 20 L/s (270 gpm US), under nominal flow conditions. Experience at The Geysers shows that this excess condensate, as blowdown from the cooling tower, can be reinjected without pumping. One injection well is required based on well flow information developed by Well Production Testing (Ref 3-7).

Very-Hot Liquid Dominated Resource. Both the effluent from the low pressure flash tank and the excess condensate, totalling 120 L/s (1,900 gpm US), may require pumping to accomplish reinjection although gravity flow is a possibility. One injection well is required. A 700 hp motor is provided to drive the pump under the conservative assumption that it is needed.

The required pumping power at nominal flow conditions subtracts 0.5 MWe from the plant net output leaving a net power output of 52.7 MWe if pumped reinjection is needed.

Hot Liquid Dominated Resource. As in the very-hot liquid case, both the effluent from the low pressure flash tank and the excess condensate, totalling 260 L/s (4,100 gpm US), are assumed to be pumped into a reinjection well. A 3,000 hp motor is required to drive the pump. The pumping power could be reduced by using more injection wells, but a detailed cost tradeoff is needed to arrive at an optimum design. This type of detailed study is beyond the scope of this preconceptual design effort.

The pumping power at nominal flow conditions subtracts 2.2 MWe from the plant net output leaving a net power output of 50.6 MWe if reinjection is needed.

Incremental capital costs for reinjection systems for the three assumed resource conditions are discussed in Section 4.2.1.

3.4.5 H_2S Abatement System

Hydrogen sulfide is one of the gases commonly found in geothermal reservoirs throughout the world. If relatively large quantities exist in the geothermal fluid in the Meager Creek area, it is likely that an H_2S abatement system will be required to minimize discharge of H_2S to the atmosphere. Presently, the commercial technique to minimize H_2S emissions is to use a Stretford unit to convert the H_2S in the noncondensable gas stream to sulfur and discharge the remaining gas to the atmosphere.

Application of a Stretford unit involves using a surface condenser, instead of a direct contact condenser, to improve partitioning (the fraction of H_2S removed by the noncondensable gas removal system).

In a direct contact condenser, the condensate is at a temperature less than the boiling point, and the total quantity of water in contact with gases is about 30 times the quantity of condensate in a surface condenser. Hence, a significant amount of gases could be dissolved in the condensate and carried out of the condenser into the cooling tower. This allows a high fraction of the H_2S from the geothermal steam to escape to the atmosphere.

In a surface condenser the quantity of H_2S dissolved in the condensate is smaller, the actual amount depending on the temperature, pressure, degree of approach to equilibrium, and the condensate pH. This ensures that most of the H_2S will be treated in the Stretford unit and a minimal amount will escape through the cooling tower.

Typical costs for an H_2S abatement system are presented in Section 4.2.2.

Section 4

COST ESTIMATES

This section contains rough order-of-magnitude capital cost estimates based on the preconceptual designs described in Section 3. Cost estimates for a baseline design for each of three resource characteristics - vapor, very-hot liquid and hot liquid dominated - are given in Section 4.1. Section 4.2 gives cost estimates of possible additions to the baseline designs for reinjecting excess geothermal fluids and for H_2S abatement.

4.1 BASELINE SYSTEMS

4.1.1 Bases and Exclusions

Bases. The following items are the bases for the cost estimates:

- Power plant and wellfield cost estimates summarized in Section 4 are for the preconceptual designs described in Section 3.
- All cost estimates are in first quarter 1981 Canadian dollars.
- The estimated project costs include geothermal wells, gathering system, power plant and switchyard.
- The cost estimates are for project design and construction and do not include owner costs such as interest during construction or exploration.
- The project location is the Meager Creek geothermal area. Likely adverse weather and the remote location are taken into account.
- Temporary construction electrical power is provided by a portable diesel generator.

- Workers are housed in a construction camp, and each on-site worker works 40 hours per week straight time plus 20 hours per week overtime.

- Cost estimates for the geothermal wells are furnished by Nevin/Sadlier-Brown/Goodbrand Ltd. (Ref. 4-1).

Exclusions. The following items are excluded from the project cost estimates:

- Transmission lines
- Cost escalation beyond first quarter 1981
- Roadwork and snow removal
- Telephone lines
- Provincial or local sales and gross receipts tax
- Transportation for workers
- Temporary water supply during construction
- Exploration (except for work camp facilities for 50 workers)
- Replacement wells
- Spare parts
- Owner costs
  - General and administrative
  - Engineering and management
  - Interest during construction
  - Permits and licenses
  - Consultants
  - Land or land use
  - Guard service
  - Special insurance

4.1.2 Methodology

The reference cost estimate used for each of the baseline project cost estimates is the definitive cost estimate for the Baca Ranch geothermal power plant based on the detail design for that plant, for which all major procurements and subcontracts have been placed. The cost estimates for Baca are also a logical starting point for Meager Creek because of similarities in resource conditions, terrain, climate, and power generation level.

For each of the baseline power plants for Meager Creek, the following adjustments are made to the cost estimate for the Baca Ranch plant:

- First quarter 1981 Canadian dollars are used for the estimates.
- The cost of the H_2S abatement system is subtracted.
- Adjustments are made which account for 55 MWe (gross) output for Meager Creek instead of 50 MWe (gross) for Baca Ranch.
- Adjustments are made for major equipment differences - turbine, condenser, and cooling tower.
- Overtime construction work and labor productivity adjustments are included.
- Adjustments are made for equipment, material and labor costs in British Columbia.
- Cost estimates are added for the geothermal wells, gathering system, fluid disposal system, and construction camp. The construction camp is assumed to have a capacity of 250 total workers (150 maximum for power plant and gathering system construction, 50 for well drilling, and 50 for exploration) and an average occupancy of 200 workers.

4.1.3 Estimates

Rough order-of-magnitude cost estimates based on the preconceptual designs described in Section 3 are given in Table 4-1. These estimates probably approximate actual costs within about ± 25%. In particular, fairly large differences may occur in turbine-generator costs where actual bid prices with a 2:1 spread between high and low bid have been observed within the past two years. For the cost estimates for the Meager Creek power plant and wellfield, typical prices are used.

Table 4-1

PROJECT CAPITAL COST ESTIMATES

Item	Vapor Cost $1 000s	Very-Hot Liquid Cost $1 000s	Hot Liquid Cost $1 000s
Power Plant			
Mechanical Equipment			
Turbine/Generator	5 500	5 170	5 610
Cooling Tower	2 240	1 910	2 220
Other Mechanical Equipment	2 510	2 210	2 620
Piping and Instrumentation	1 720	1 600	1 740
Electrical Equipment	2 040	1 930	2 070
Civil/Structural	4 420	4 180	4 490
Yardwork and Miscellaneous	640	600	650
Switchyard	110	110	110
Direct Field Cost	19 180	17 710	19 510
Indirect Cost	4 230	4 200	4 270
Labor Productivity Adjustment	3 140	3 120	3 170
Total Field Cost	26 550	25 030	26 950
Engineering Services	3 190	2 990	3 230
Total Field Cost Plus Engineering	29 740	28 020	30 180
Contingency @ 25%	7 460	6 980	7 520
Total Power Plant Capital Cost	37 200	35 000	37 700
Fluid Gathering System	14 200	4 200	8 880
Fluid Disposal System	300	600	1 200
Geothermal Wells (1)	13 600 (2)	10 200 (3)	15 300 (4)
Construction Camp Mobilization	2 400	2 400	2 400
Construction Camp Operation 25 Months @ $111 000	2 800	2 800	2 800
Total Project Capital Cost (First Quarter 1981 Canadian Dollars)	70 500	55 200	68 200

Notes:
1. Well cost estimates are from Nevin/Sadlier-Brown/Goodbrand Ltd. (Ref. 4-1)
2. Eight production wells @ $1 700 000
3. Six production wells @ $1 700 000
4. Nine production wells @ $1 700 000

4.1.4 Operating and Maintenance Costs Estimate

The annual operating and maintenance (O&M) costs for a geothermal power project are expected to be approximately two percent of the capital costs. Thus, for the geothermal baseline plant designs covered in this study, the O&M costs are estimated as being in the range from $1 100 000 to $1 500 000 each year. This rough estimate is based on utility company experience at The Geysers (Ref. 4-2) and a study of published annual O&M costs for 29 fossil-fueled steam electric power plants (Ref. 4-3). Although the data in the two cited references apply to power plants and not to wellfields, extension to wellfields at the same percentage appears justified at this early stage of project development.

4.2 COST ESTIMATES FOR SOME ALTERNATIVES CONSIDERED

4.2.1 Reinjection of Excess Geothermal Fluid

The baseline designs described in Section 3 include disposal of excess geothermal fluid by release into Meager Creek.

There are some circumstances as discussed in Section 3.4.4, that would require reinjection. Estimates of the additional capital cost for reinjection of excess geothermal fluid are given in Table 4-2.

Table 4-2

ADDITIONAL COST FOR REINJECTION

Item	Vapor Cost $1 000s	Very-Hot Liquid Cost $1 000s	Hot Liquid Cost $1 000s
Reinjection well (1)	790	790	790
Pump and motor	not required	260	620
Less piping adjustment	- 130	- 310	- 570
Total additional cost	660	740	840

Note: 1. Well cost estimate is from Well Production Testing (Ref. 3-7).

4.2.2 H_2S Abatement System

The capital cost of H_2S abatement for the vapor dominated resource with 200 ppm_w H_2S in the steam, as for typical wells at The Geysers, is $5 090 000. This cost includes:

- Addition of a Stretford unit
- Replacement of the direct contact main condenser and gas removal system inter- and after-condensers with surface condensers
- Replacement of condensate-circulating water pumps with circulating water pumps
- Addition of condensate pumps

Section 5

SCHEDULE

A schedule is given in Figure 5-1 for engineering, procurement and construction of a 55 MWe (gross) geothermal power plant and gathering system. This schedule is typical for any of the three baseline systems described in Section 3. It includes conceptual, preliminary and detail design; civil/structural, mechanical and electrical construction; and startup for the power plant. It also includes design, procurement and construction of the gathering system.

This schedule is based on the following assumptions:

- Heavy snow in the Meager Creek area precludes outdoor construction from November 1 to March 31.
- Indoor construction can be done during the November 1 to March 31 period of heavy snow.
- Site preparation, consisting of grading and stabilizing a pad for the power plant, is done in the summer preceding the start of year-round construction the following April.
- On-site construction personnel work 40 hours per week straight time plus 14 hours per week overtime.

An alternative schedule was considered in which site preparation starts in April and the turbine building is fully enclosed by the following November to permit indoor construction work during the period of expected heavy

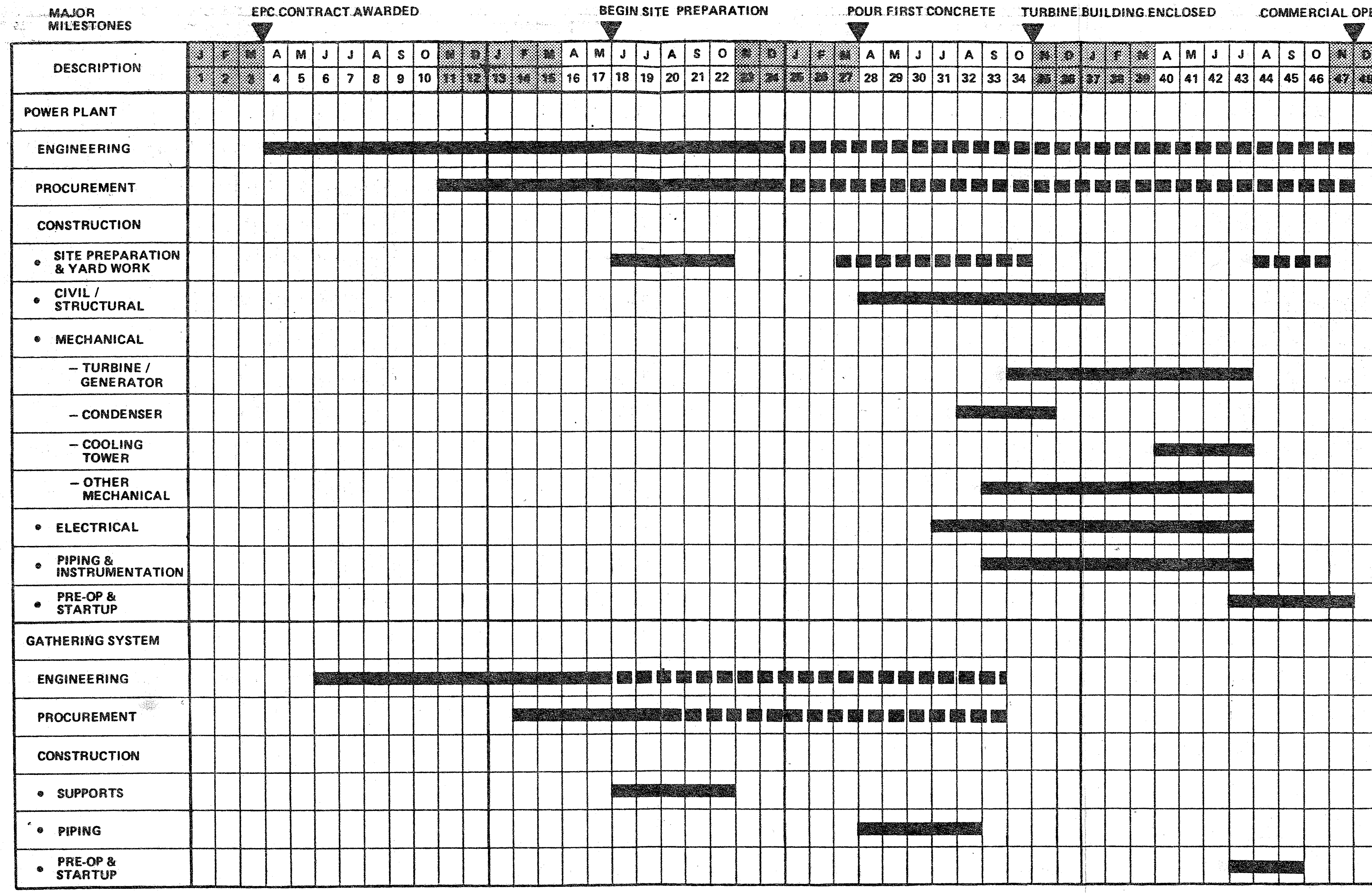

Figure 5 – 1 Schedule for Power Plant and Gathering System Design and Construction.

INCLEMENT WEATHER

MAJOR WORK

LOW LEVEL EFFORT

snow. This alternative schedule was rejected because the schedule is so tight during the first summer that any delay would prevent completion of the turbine building enclosure before November.

The schedule in Figure 5-1 has site preparation starting the summer before major construction begins. To make the early start, drawings for the power plant pad and major excavations, based on approximate horizontal dimensions for the power plant structures, must be completed before starting site preparation. This schedule has the advantage of allowing some flexibility during site preparation, concrete work and turbine building erection without requiring major project rescheduling.

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