GEOTHERMAL WELL STIMULATION

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The stimulation of geothermal wells presents some new and challenging problems. Formation temperatures in the 300-600°F range can be expected. The behavior of stimulation fluids, frac proppants, and equipment at these temperatures in a hostile brine environment must be carefully evaluated before performance expectations can be determined. In order to avoid possible damage to the producing horizon of the formation, high temperature chemical compatibility between the in situ materials and the stimulation materials must be verified. Perhaps most significant of all, in geothermal wells the required techniques must be capable of bringing about the production of very large amounts of fluid. This necessity for high flow rates represents a significant departure from conventional petroleum well stimulation and demands the creation of very high near-wellbore permeability and/or fractures with very high flow conductivity.

Stimulation treatments may be conducted in formations which produce either hot water or steam from both matrix permeability and from natural fracture systems. The following targets of opportunity are of common interest in geothermal fields today:

- Wells that did not intersect nearby major fracture systems;
- Wells that can benefit from the establishment of high conductivity linear flow channels to improve flow capacity from surrounding localized regions of low permeability formation;
- Wells that suffered man-made damage during drilling, completion, or workover operations, including mud or cement invasion; and

DISCLAIMER

- Wells that require periodic remedial treatment as a result of fluid production related damage.

If stimulation can reduce or eliminate the need for new wells or redrills in these situations, then the potential for improving geothermal development economics and extending the resource base is substantial.

Recognition of the potential benefits of developing a successful geothermal well stimulation capability led the Department of Energy/Division of Geothermal Energy to sponsor the Geothermal Reservoir Well Stimulation Program (GRWSP) beginning in 1979. The principal purpose of this discussion is to review the accomplishments to date and the current status of the program.

The GRWSP is organized into two phases. Phase I consists of literature and theoretical studies, laboratory investigations, and numerical work. The main purpose of this work is to establish the technological bases for geothermal well stimulation design. Phase II includes the planning, execution, and evaluation of six actual well stimulation treatments in the field which utilize the technology developed in Phase I.

A significant portion of the Phase I laboratory investigation effort has been directed at finding suitable proppants for hydraulic fracture stimulation use. Although sand is generally used as a proppant today in the oil and gas industry, it has not proven to be strong enough to withstand the conditions in most geothermal wells. Sand permeabilities were shown to decline to unacceptably low levels when tested in hot water or brine under stress. The strongest proppant tested to date is resin-coated bauxite. It shows no temperature sensitivity or permeability decrease under load. Resin-coated sand is also not temperature or load sensitive, but does have a slightly lower permeability at any closure stress due to variability in particle size. Such resin-coated materials are cohesive; therefore, once emplaced in the fracture, flowback is reduced during production. Although slightly crushable, plain sintered bauxite is also much stronger than sand and effectively inert in hot brines.

Many fluids and fluid systems have been tested under Phase I for geothermal applications. Water soluble polymers are the main viscosifiers available for hydraulic fracturing. Above 250°F almost all polymer systems show a decline in viscosity. The rapid decline in viscosity of some polymers at temperature could result in poor proppant placement in a high temperature geothermal stimlulation treatment. The type and amount of polymer determines the speed and extent of degradation. A series of static aging, flow, and HPLC tests have been performed to try to understand the degradation of frac polymers and its relationship to viscosity, plugging, and exposure time. These tests are useful not only for a fundamental understanding of frac fluid behavior, but help to select or reject fluids for specific applications.

Two stimulation experiments were performed at the Raft River, Idaho, known geothermal resource area (KGRA) in late 1979. This is a naturally fractured, hard rock reservoir with a relatively low geothermal resource temperature (300°F±). A conventional planar hydraulic fracture job was performed in Well RRGP-5 and a "Kiel" dendritic, or reverse flow, technique was utilized in Well RRGP-4.

In mid-1980, two stimulation experiments were performed at the East Mesa, California, KGRA. The stimulation of Well 58-30 provided the first geothermal well fracturing experience in a moderate temperature (350°F±), reservoir with matrix-type rock properties. The two treatments consisted of a conventional hydraulic fracture of a deep, low-permeability zone and a mini-frac "Kiel" treatment of a shallow, high permeability zone in the same well.

Most recently, Well Ottoboni 22 in The Geysers, California dry steam field, was acid fractured. The stimulation technique was an acid etching treatment (Halliburton Services' MY-T-ACID) utilizing 20,000 gal of 10% HF - 5% HCL solution behind a pre-pad of very viscous polymer. The 1,000-foot isolated treatment interval was non-productive prior to stimulation. A post-stimulation production test has not been performed to date. This experiment was cost-shared with Union Oil Company.

The stimulation experiment results to date were evaluated using short-term production tests, conventional pressure transient analysis, interference pressure data, chemical and radioactive tracers, borehole acoustic televiewer surveys and numerical models. This combination of evaluation techniques yielded an interpretation of fracture geometry and productivity enhancement. In all the field experiments, artificial fractures were created, and well productivity was increased in at least three of the five experiments.

Table 1

Major Tasks Phase I

Technology Review

- Technology Transfer
- Equipment Review - Surface
- Equipment Review - Downhole

Stimulation Materials Evaluation

- Fracture Fluid Evaluation
- Fracture Proppant Evaluation
- Recent Stimulation Technology Development Analysis
- Chemical Stimulation Analysis

Numerical Simulation

- Numerical Model Development
- Numerical Analysis

Table 2

Major Tasks - Phase II

Planning Field Experiments

- Reservoir Identification, Evaluation and Qualification
- Well Identification, Evaluation and Qualification
- Prepare Specific Well Experiment
- Environmental and Permitting
- Field Experiment Administration Planning
- Specifications and Subcontracting

Field Experiment and Analysis

- Design and Provide Surface Production Facilities
- Field Experiment and Production Testing
- Monitoring and Data Collection
- Data Analysis and Interpretation
- Radioactive Tracers

Project Reporting and Management

Geothermal Well Stimulation Symposium

Table 3

RRGP-4
4-Stage Kiel Frac 8/20/79

Frac Fluid:	7900 bbl 10 lb H.P. Guar/1000 gal 2 lb XC Polymer/1000 gal
Sand:	50,400 lb 100 mesh 58,000 lb 20/40 mesh proppant
Rate:	50 bpm
Interval:	4705'-4900' (195')
Frac Height:	195'

Table 4

RRGP-5
Conventional (Planar) Frac 11/12/79

Frac Fluid:	7600 bbl 30 lb H.P. Guar/1000 gal
Sand:	84,000 lb 100 mesh 347,000 lb 20/40 mesh proppant
Rate:	50 bpm
Interval:	4587'-4803' (216')
Frac Height:	135'

Table 5

East Mesa 58-30 (Deep Zone)
Conventional (Planar) Frac 7/3/79

Frac Fluid:	2800 bbl Crosslinked polymer gel 20 lb calcium carbonate/1000 gal (fluid loss additive in prepad and pad)
Sand:	44,500 lb 100 mesh 59,200 lb 20/40 mesh 60,000 lb 20/40 mesh "Supersand"
Rate:	40 bpm
Interval:	6587'-6834' (247')
Formation:	350°F-15 md

Table 6

East Mesa 58-30 (Shallow Zone)
5-Stage Kiel Frac 7/6/80

Frac Fluid:	10,300 bbl 10 lb H.P. Guar/1000 gal 2 lb XC Polymer/1000 gal 20 lb calcium carbonate/1000 gal (fluid loss additive)
Sand:	44,000 lb 100 mesh
Rate:	48 bpm
Interval:	4952'-5256' (304')
Formation:	325°F-50 md

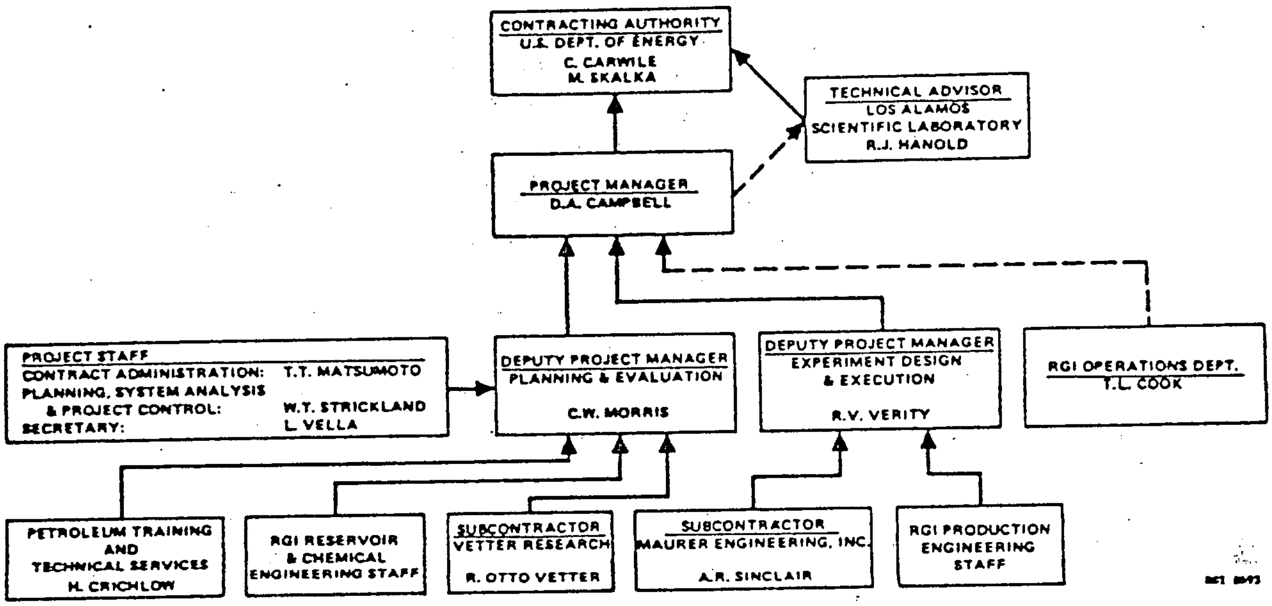


FIGURE 1. PROJECT ORGANIZATION, GEOTHERMAL RESERVOIR WELL STIMULATION PROGRAM

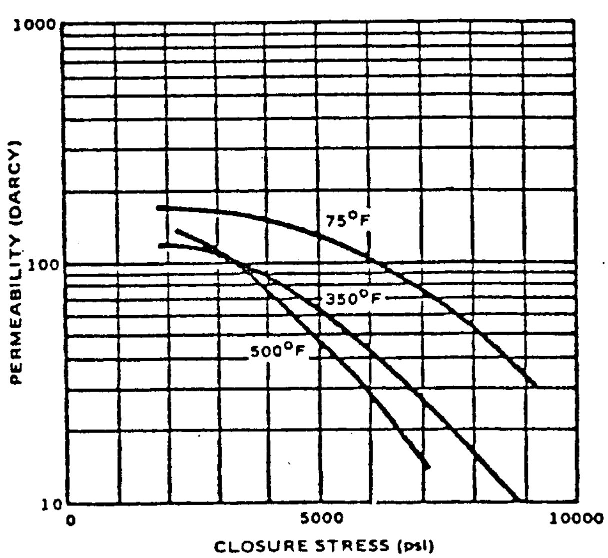


FIGURE 2. TEMPERATURE EFFECTS ON 20/40 BRADY TEXAS SAND

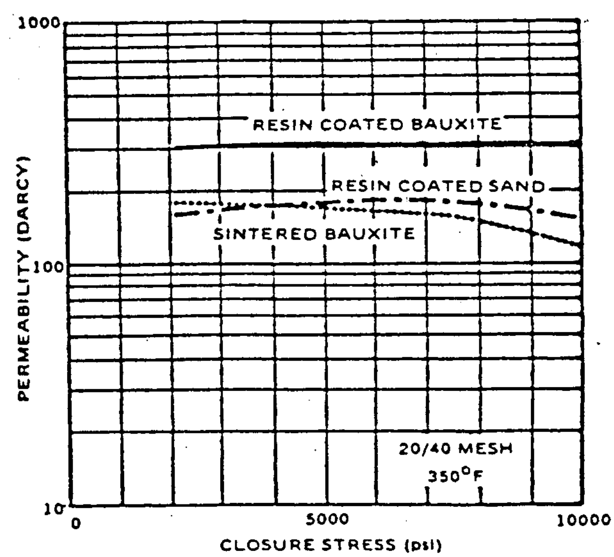


FIGURE 3. PERMEABILITY VS. CLOSURE STRESS FOR TEMPERATURE INSENSITIVE PROPPANTS

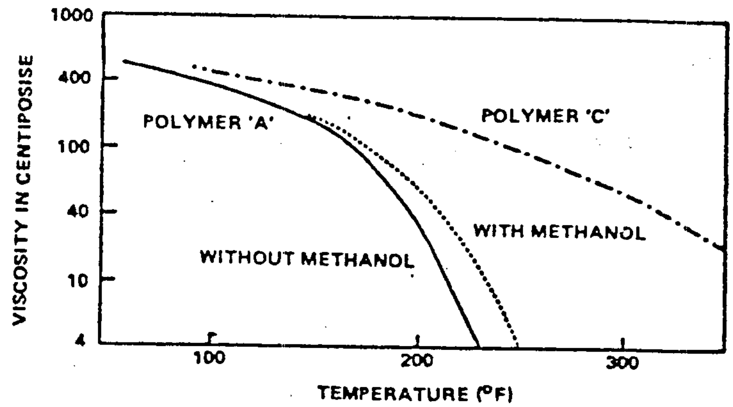


FIGURE 4. POLYMER-WATER FRAC FLUID VISCOSITY VS. TEMPERATURE

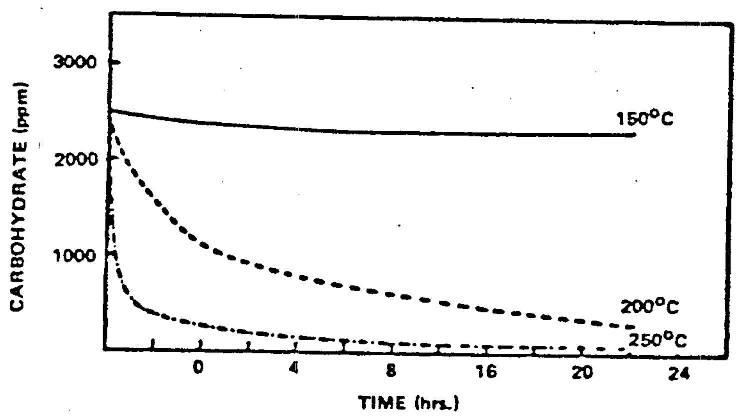


FIGURE 5. DIGRADATION OF HP-GUAR IN DEIONIZED WATER

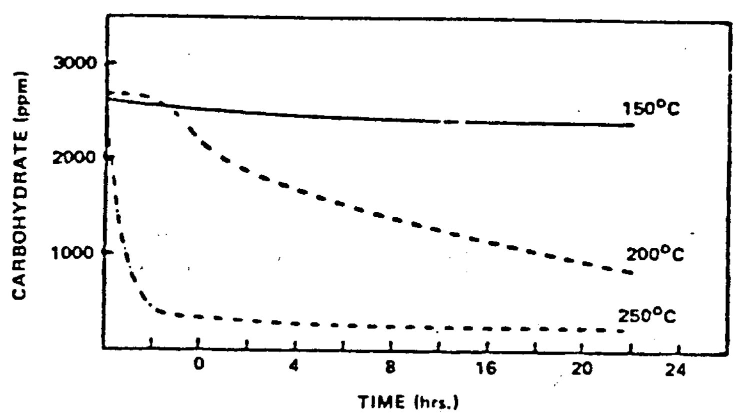


FIGURE 6. DEGRADATION OF HEC IN DEIONIZED WATER

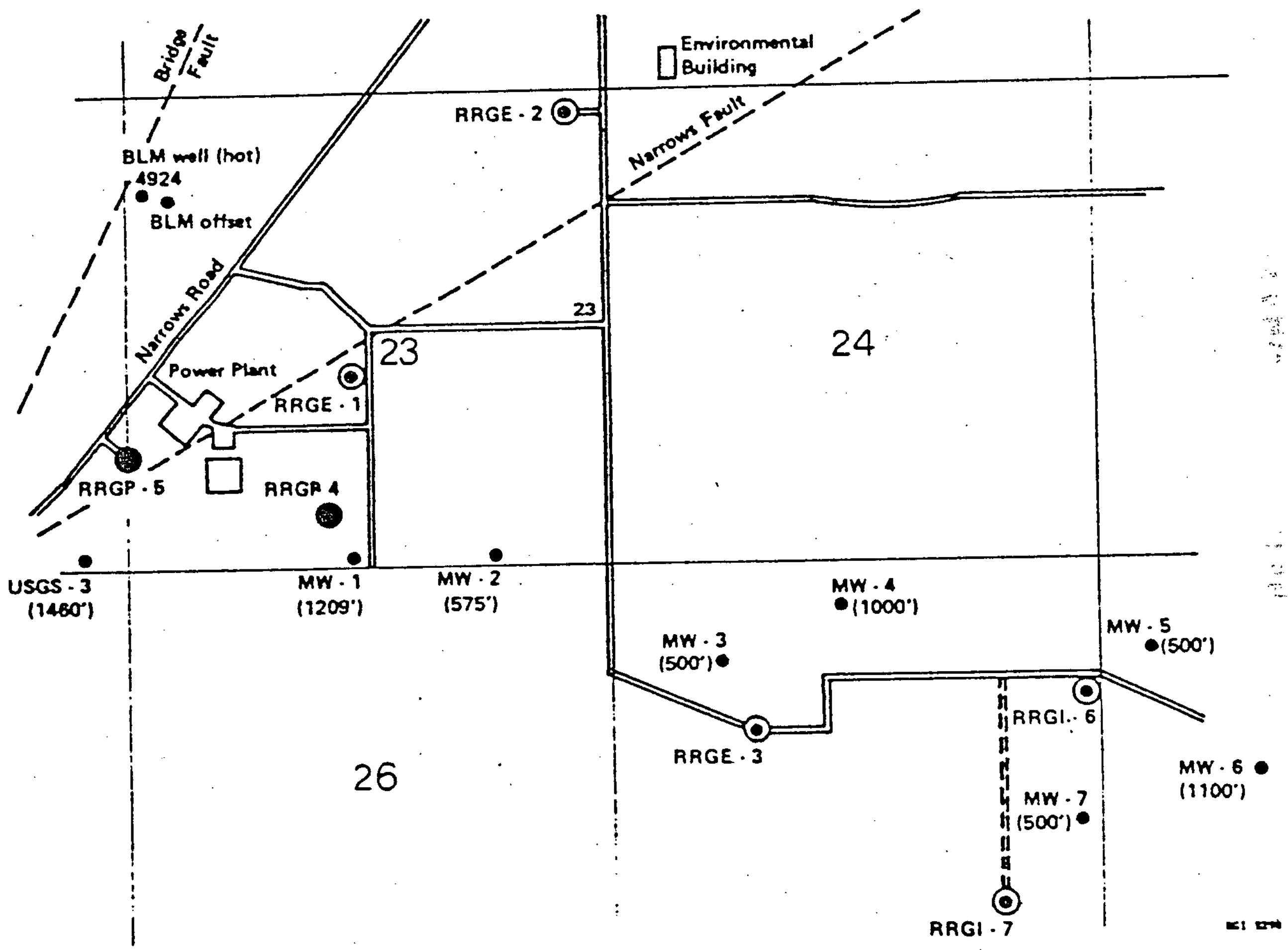


FIGURE 7. RAFT RIVER FACILITY WITH GEOLOGIC STRUCTURE AND WELL LOCATIONS

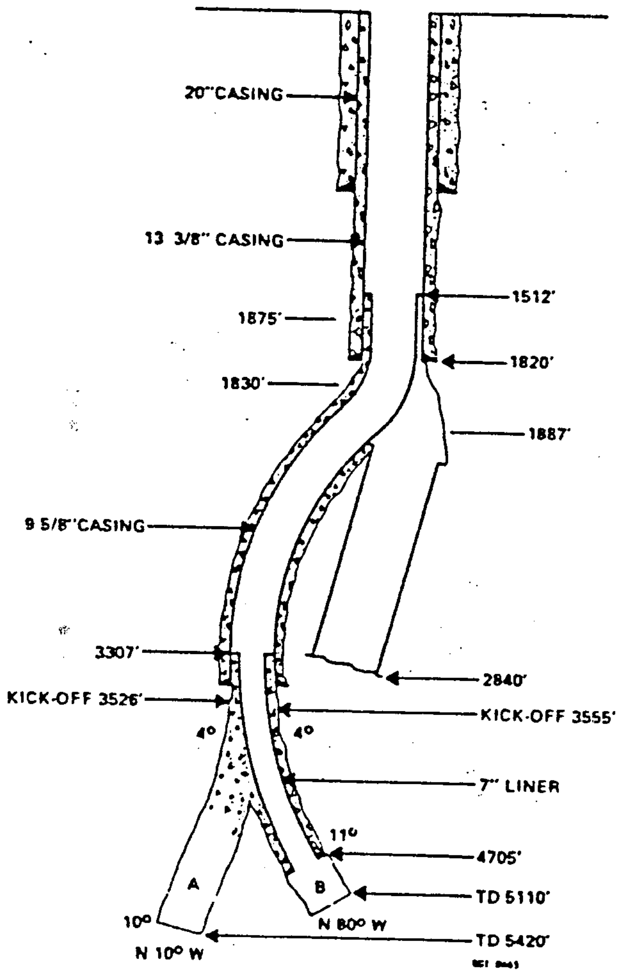


FIGURE 8. SCHEMATIC OF RAFT RIVER RRGP-4 WITH 7" LINER IN PLACE

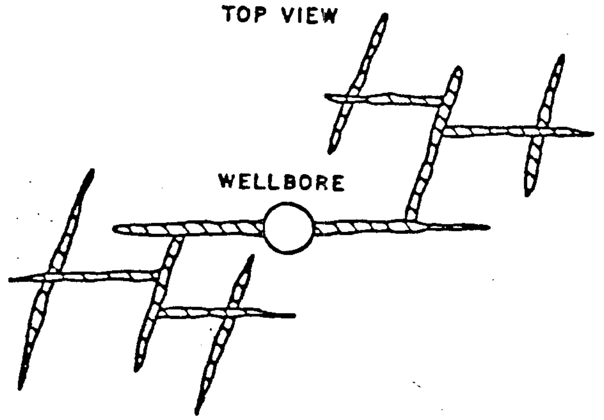


FIGURE 9. IDEALIZED SCHEMATIC OF A DENDRITIC FRACTURE (AFTER KIEL)

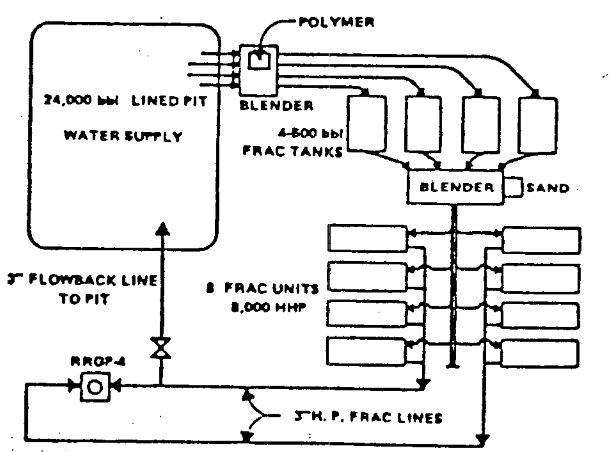


FIGURE 10. EQUIPMENT LAYOUT FOR RRGP-4 FRAC TREATMENT

APPENDIX I

TABLE 1. SUMMARY OF INSTALLED GEOTHERMAL POWER PLANTS

COUNTRY		No. of UNITS	TOTAL CAPACITY, MW	
1.	United States	17	929.2	(38.0%)
2.	Philippines	10	443.0	(18.1%)
3.	Italy	37	420.6	(17.2%)
4.	New Zealand	14	202.6	(8.3%)
5.	Japan	7	166.0	(6.8%)
6.	Mexico	4	150.0	(6.1%)
7.	El Salvador	3	95.0	(3.9%)
8.	Iceland	3	32.0	(1.3%)
9.	U.S.S.R.	1	5.0	(0.2%)
10.	Indonesia	2	2.25	(0.09%)
11.	China	7	1.936	(0.08%)
12.	Turkey	1	0.5	(0.02%)
	TOTALS	106	2448.086	MW

TABLE 2. CHINA

PLANT	YEAR	TYPE	RATING, MW
Fengshun			
Unit 1	1970	1-Flash	0.086
Unit 2	1971	Binary: i-C_4H_{10}	0.200
Unit 3	1981(?)	1-Flash	0.250
Huailai	1971	Binary: C_2H_5Cl; n-C_4H_{10}	0.200
Wentang	1971	Binary: C_2H_5Cl	0.050
Huitang	1975	1-Flash	0.300
Yingkou	1977	Binary: Freon; n-C_4H_{10}	0.100
Yangbajing			
Unit 1	1977	1-Flash	1.000
Unit 2	1981(?)	1-Flash	1.500
Unit 3	1982(?)	2-Flash	3.500
		TOTAL - INSTALLED AND PLANNED:	7.186 MW

TABLE 3. EL SALVADOR

PLANT	YEAR	TYPE	RATING, MW	
Ahuachapán				
Unit 1	1975	1-Flash	30.0	
Unit 2	1976	1-Flash	30.0	
Unit 3	1980	2-Flash	35.0	
Berlín	1985	2-Flash	50.0	
Chinameca	Future	Flash	100	(est.)
Chipilapa	Future	Flash	50	(est.)
San Vicente	Future	Flash	100	(est.)
		TOTAL - INSTALLED AND PLANNED:	145	MW

TABLE 4. ICELAND

PLANT	YEAR	TYPE	RATING, MW
Námafjall	1969	1-Flash	3*
Krafla			
Unit 1	1978	2-Flash	30
Unit 2	Future	2-Flash	30
Svartsengi			
Unit 1	1978	1-Flash	1
Unit 2	1978	1-Flash	1
		TOTAL-INSTALLED:	32 MW

*Dismantled after earthquake damage.

TABLE 5. ITALY

PLANT*	YEAR	RATING, MW
Lardarello		
Unit 2	c.1946	69.0
Unit 3	1969	120.0
Gabbro	1960	15.0
Castelnuovo	n.a.	50.0
Serrazzano	n.a.	47.0
Lago 2	n.a.	33.5
Sasso Pisano	n.a.	15.7
Monterotondo	n.a.	12.5
Travale	1973	15.0
Piancastagnaio	1969	15.0
Others (8 units)	-	27.9
	TOTAL - INSTALLED:	420.6 MW

*All plants use dry steam; turbines are either condensing or noncondensing.

TABLE 6. JAPAN

PLANT	YEAR	TYPE	RATING, MW
Matsukawa	1966	Dry Steam	20
Otake	1967	1-Flash	10
Onuma	1973	1-Flash	10
Onikobe	1975	1-Flash	25
Hatchobaru	1977	2-Flash	50
Kakkonda	1978	1-Flash	50
Otake Pilot*	1978	Binary: $i\text{-}C_4H_{10}$	1
Nigorikawa Pilot*	1978	Binary: R-114	1
Suginoi (Hotel)	1980	1-Flash	1
Mori	1981(?)	1-Flash	50
Kuzeneda	Future	Flash	50 (est.)
Kumamoto	Future	2-Flash	55 (est.)
		TOTAL - INSTALLED AND PLANNED:	216 MW

*Tests complete; plants dismantled.

TABLE 7. MEXICO

PLANT	YEAR	TYPE	RATING, MW
Cerro Prieto I			
Unit 1	1973	1-Flash	37.5
Unit 2	1973	1-Flash	37.5
Unit 3	1979	1-Flash	37.5
Unit 4	1979	1-Flash	37.5
Unit 5	1982	2-Flash	30.0
Cerro Prieto II			
Unit 1	1983	2-Flash	220
Unit 2	1983	2-Flash	220
		TOTAL - INSTALLED AND PLANNED:	620 MW

TABLE 8. NEW ZEALAND

PLANT	YEAR	TYPE	RATING, MW
Wairakei			
Station A	1958-62	Multiflash	102.6
Station B	1962-63	2-Flash	90.0
Kawerau	1961	1-Flash	10.0
Ohaki			
Unit 1	1985	2-Flash	50.0
Unit 2	1986	2-Flash	50.0
Unit 3	Future	2-Flash	50.0
		TOTAL - INSTALLED AND PLANNED:	302.6 MW

TABLE 9. PHILIPPINES

PLANT	YEAR	TYPE	RATING, MW
Tiwi			
Unit 1	1978	2-Flash	55.0
Unit 2	1979	2-Flash	55.0
Unit 3	1979	2-Flash	55.0
Unit 4	1980	2-Flash	55.0
Unit 5	1982	2-Flash	55.0
Unit 6	1982	2-Flash	55.0
Mak-ban (Makiling-Banahaw)			
Unit 1	1979	2-Flash	55.0
Unit 2	1979	2-Flash	55.0
Unit 3	1980	2-Flash	55.0
Unit 4	1980	2-Flash	55.0
Palimpinon (pilot)			
Unit 1	1980	1-Flash	1.5
Unit 2	1980	1-Flash	1.5
Palimpinon			
Unit 1	1982	2-Flash	37.5
Unit 2	1983	2-Flash	37.5
Unit 3	1983	2-Flash	37.5
Tongonan			
Unit 1	1982	2-Flash	37.5
Unit 2	1982	2-Flash	37.5
Unit 3	1982	2-Flash	37.5
		TOTAL - INSTALLED AND PLANNED:	778 MW

TABLE 10. UNITED STATES - CALIFORNIA ONLY

PLANT	YEAR	TYPE	RATING, MW
The Geysers			
PG&E 1-12,15	1960-79	Dry Steam	663.0
PG&E 13,14	1980	Dry Steam	245.0
PG&E 16-21	1982-1984	Dry Steam	660.0
NCPA 1	1983	Dry Steam	66.0
NCPA 2	1981	Dry Steam	110.0
SMUD GEO 1	1984	Dry Steam	55.0
Bottle Rock	1984	Dry Steam	55.0
South Geysers	1984	Dry Steam	55.0
East Mesa			
Magmamax	1980	Dual Binary: i-C_4H_{10}; C_3H_8	11.2
Republic			
Unit 1	1982	1-Flash	10.0
Unit 2	1984	2-Flash	66.0*
Brawley			
Unit 1	1980	1-Flash	10.0
Salton Sea			
SCE	1982	1-Flash	10.0
SDG&E 1	1982-83	2-Flash	26.0
SDG&E 2	Future	2-Flash	56.0
Republic	1984	1-Flash	49.0
Heber			
SCE	1983	2-Flash	50.0
SDG&E	1984-86	Binary	65.0
South Brawley			
DWR	1985	1-Flash	55.0
Westmorland			
MAPCO/Republic	Future	2-Flash	57.0
Susanville			
GeoProducts 1	1984	Hybrid: Wood waste/geofluid	55.0
		TOTAL - INSTALLED AND PLANNED:	2363.2 MW

*Includes 10 MW Unit 1.

TABLE 11. UNITED STATES - EXCEPT CALIFORNIA

PLANT	YEAR	TYPE	RATING, MW
Puna, HI	1980	1-Flash	3.0
Raft River, ID	1981	Double Binary: $i\text{-}C_4H_{10}$	5.0
Baca No. 1, NM	1982(?)	1-Flash	50.0
Roosevelt H.S., UT			
UP&L 1	1983	1-Flash	20.0
UP&L 2	Future	2-Flash	50.0
UP&L 3	Future	2-Flash	50.0
Northern Nevada	1983	Binary	10.0
White Mts., NH	Future	Hot Dry Rock	65.0
		TOTAL - INSTALLED AND PLANNED:	88.0 MW

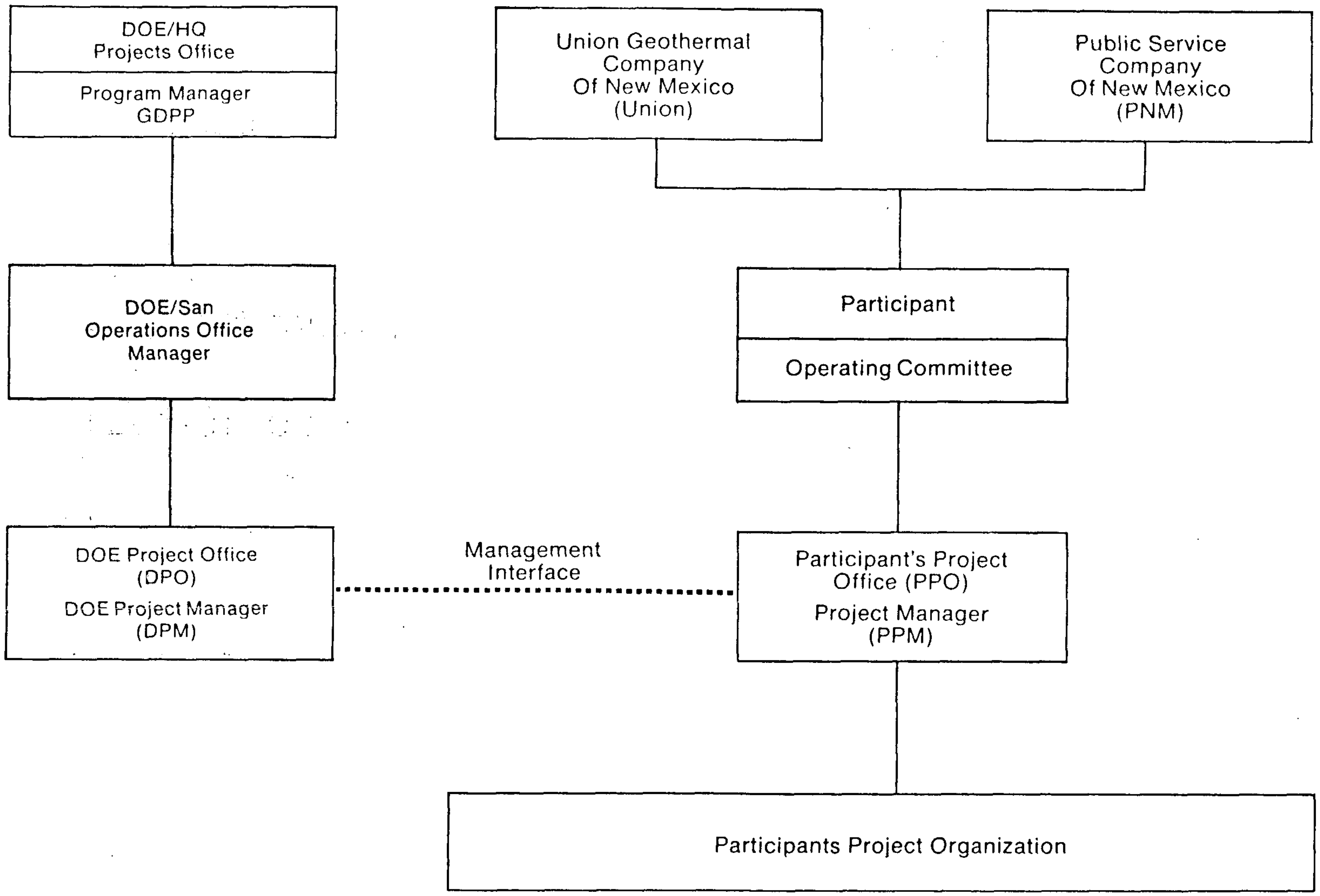
TABLE 12. OTHER COUNTRIES

COUNTRY	PLANT	YEAR	RATING, MW	
Chile	El Tatio	Future	15	
Costa Rica	Miravalles 1	1985	55	(est.)
	Miravalles 2	1987	55	(est.)
Guatemala	Amatitlán	Future	50	(est.)
Honduras	Pavana	Future	50	(est.)
Indonesia	Kamojang	1978	0.25	
	Kamojang	Future	100	(est.)
	Dieng	1980	2	
Kenya	Olkaria	1982	15	
	Olkaria	Future	30	(est.)
Nicaragua	Momotombo	Future	30	(est.)
Panama	Cerro Pando	Future	30	(est.)
Portugal (Azores)	São Miguel	1981	3.0	
Turkey	Kızıldere	Future	14	(est.)
USSR	Pauzhetka	1967	5	
	Other sites	Future	78	(est.)

APPENDIX J

BACA GEOTHERMAL DEMONSTRATION PLANT

PROJECT ORGANIZATION



INTRODUCTION

- PROJECT NAME — Baca Geothermal Demonstration Plant (Named After the Baca Location)
- PROJECT LOCATION — Valles Caldera, Jemez Mountains (80 Miles North of Albuquerque and 19 Miles West of Los Alamos)
- VALLES CALDERA — Valley(s) of the "Boiler"
- HISTORY
  - — Volcanic Region, Climaxing Mid-Pleistocene Time
  - — Valles Caldera is About 1 Million Years Old
  - — Most Recent Eruption 100,000 Years Ago
- RESERVOIR
  - — Hydro-Dominated
  - — 550°F Down Hole Temperature
  - — Approximately 6,000 Ft. Well Depth

BACA GEOTHERMAL DEMONSTRATION PROJECT OBJECTIVES

The Objectives of the Project, in Support of the Overall Goal to Stimulate Development of Geothermal Energy, are as follows:

- Demonstrate Reservoir Performance Characteristics of a Specific Liquid-Dominated Hydrothermal Reservoir.
- Demonstrate the Validity of Reservoir Engineering Estimates of Reservoir Productivity (Capability and Longevity).
- Demonstrate a Conversion System Technology at Commercial Scale.
- Initiate Development of a Resource of Large Potential.
- Act as a "Pathfinder" for the Regulatory Process and Other Legal and Institutional Aspects of Geothermal Development.
- Provide a Basis for the Financial Community to Estimate the Risks and Benefits Associated With Geothermal Investments.
- Demonstrate Social and Economic Acceptability and the Readiness of State-of-the-Art Technology for Producing Electric Power From a Liquid-Dominated Hydrothermal Resource.

PRINCIPAL GEOTHERMAL FEATURES OF THE BACA LOCATION

- Rhyolite Volcanics Widely Distributed in Space and Time
- Large Areas of Hydrothermally Altered Rock
- Occurrence of Several Hot Springs, Fumaroles, and Gas Seeps
- Abnormally High, Near-Surface Temperature Gradients Distributed Over About 50 Square Miles in Western Half of Caldera

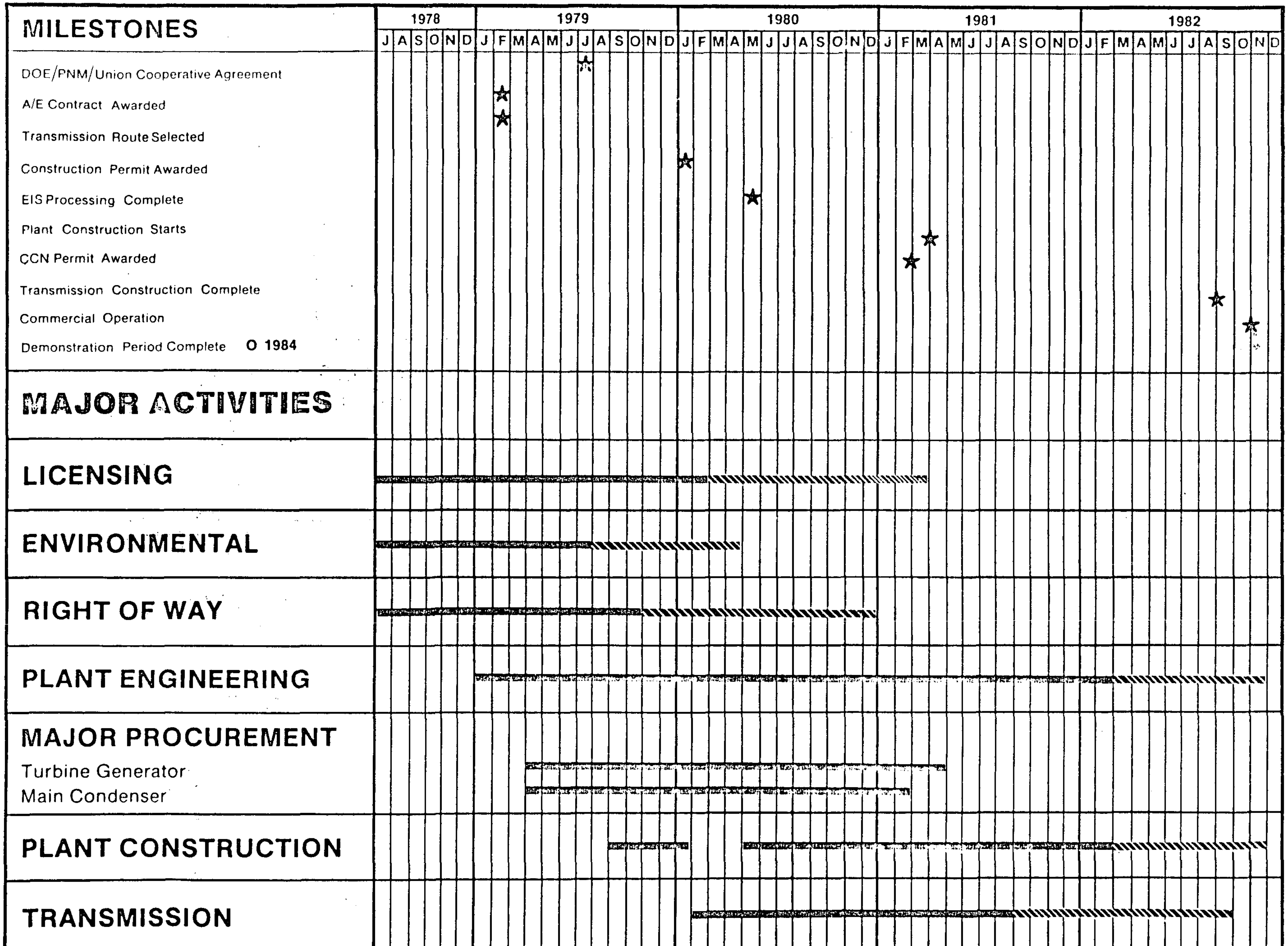
PLANT SITE INFORMATION

• NUMBER & UNIT SIZE	— One (1), 50,000 kW
• SITE LOCATION	— Redondo Creek Area
• TERRAIN	— Moderately Rugged
• ELEVATION	— 8,730 Ft. Above Sea Level
• CLIMATE	— Hot Dry Summers and Cool Snowy Winters
• TRAVEL	— Via New Mexico Highway 4 and Approximately 3 Miles of Dirt Roads
• INCLEMENT WEATHER	— December, January, and February

BACA GEOTHERMAL SCHEDULE

	INITIAL	REVISED
PROJECT START	11/78	—
START CONSTRUCTION	3/80	4/81
TURBINE ROLL	1/82	10/82
COMMERCIAL OPERATION	3/82	11/82

BACA GEOTHERMAL SCHEDULE



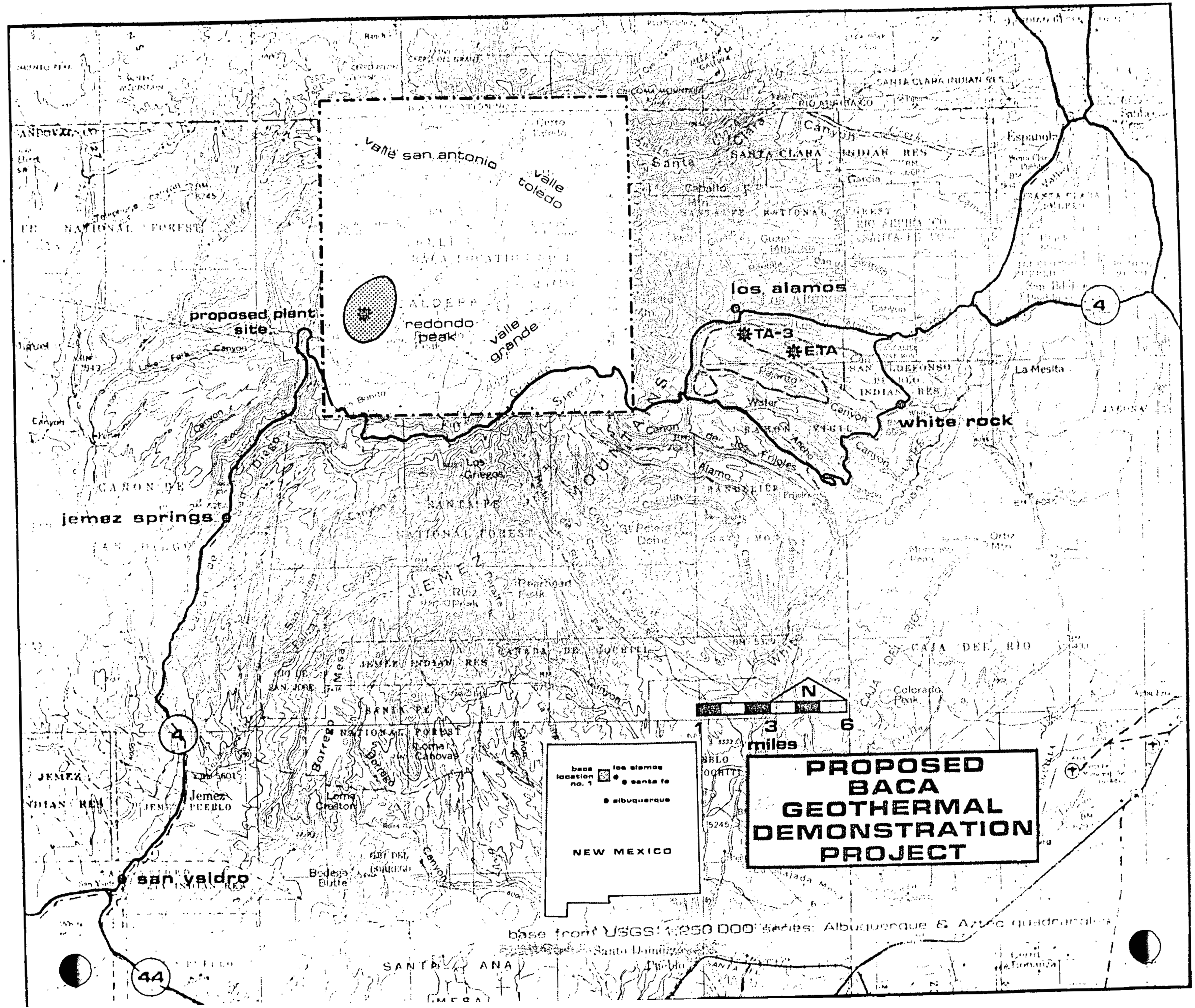
BACA UNIT 1 NMPSC ACTION

LICENSING SCHEDULE OF EVENTS

EVENT	INITIAL	ACTUAL
• Petition NMPSC	6/79	2/80
• File Testimony NMPSC	6/79	5/80
• Interim Relief Filing	N/A	5/80
• Interim Relief Hearing	N/A	7/80
• Main Hearing Before NMPSC	10/79	8/80
• Main Hearing Concluded	10/79	11/80
• Order Issued (Anticipated)	4/80	3/81

BACA PROJECT—DOE DELAYS

EVENT	INITIAL	ACTUAL
• Proposal Submitted to DOE	1/31/78	1/31/78
• PNM-Union Selection Announced	3/78	7/6/78
• Issue of Draft EIS	4/6/79	7/9/79
• Conduct Hearings on EIS	Not Scheduled	8/30/79
• Public Comment Period Ends (EPA and DOI Comments Received One Week Late)	6/21/79	9/7/79 9/14/79
• Release of Final EIS	7/8/79	10/22/79
• Mandatory 30-Day Waiting Period	8/6/79	—
• Record of Decision (Under New CEQ Guidelines)		5/5/80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valle toledo
proposed plant site
redondo peak
valle grande
los alamos
TA-3
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white rock
jemez springs
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baca location no. 1
los alamos
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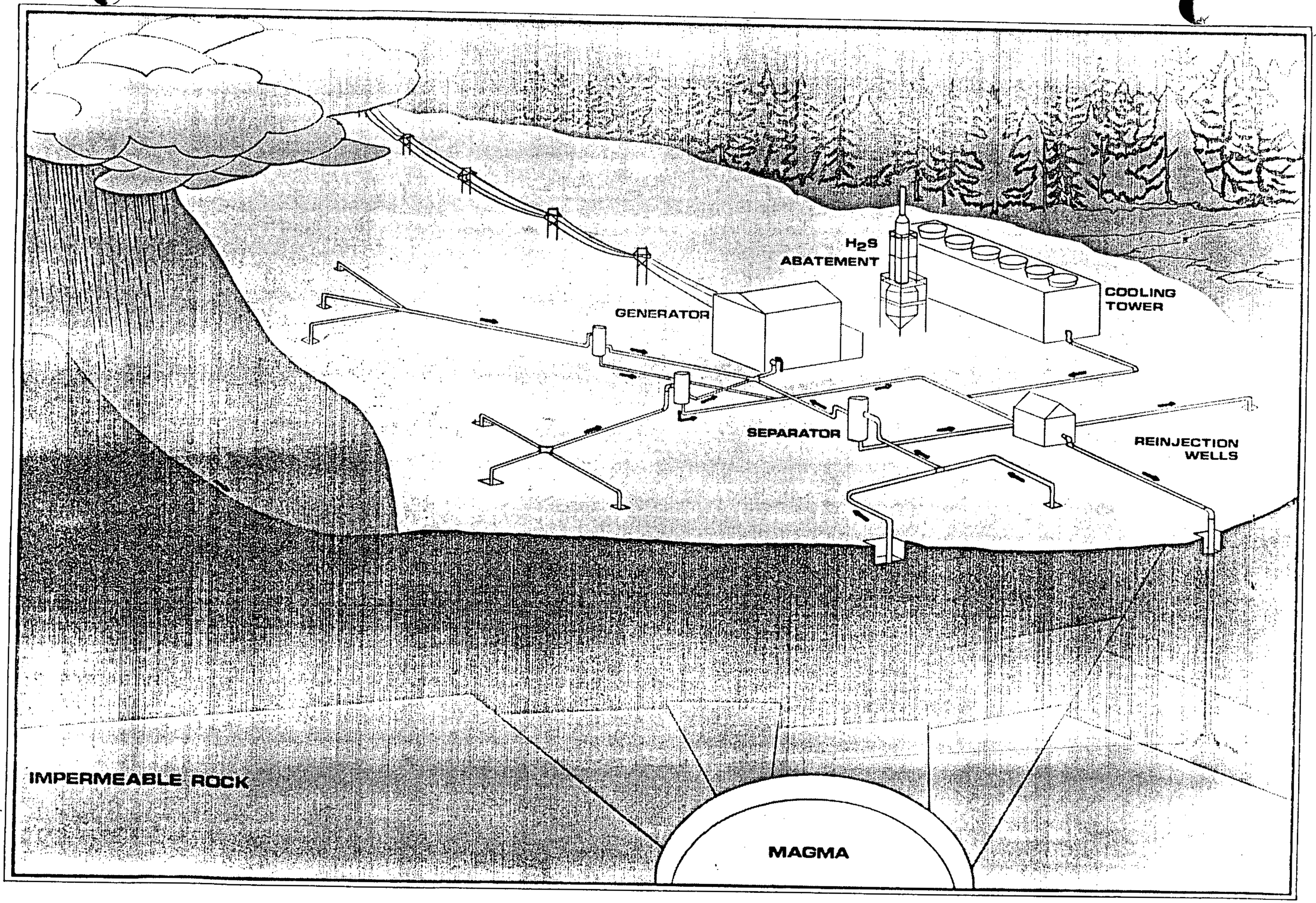
albuquerque
NEW MEXICO
PROPOSED BACA GEOTHERMAL DEMONSTRATION PROJECT
base from USGS 1:250 000 series: Albuquerque & Aztec quadrangles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WELLS
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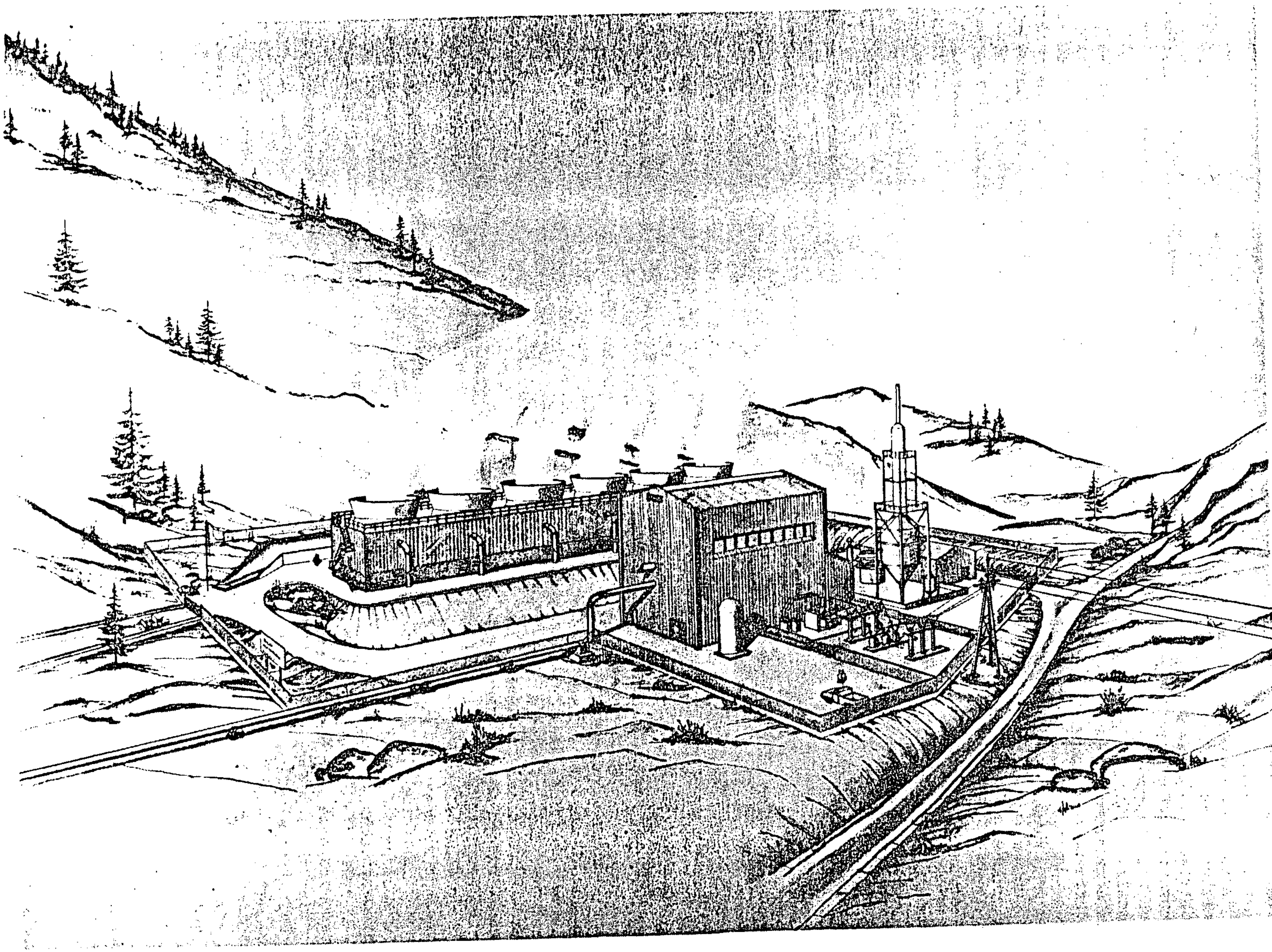
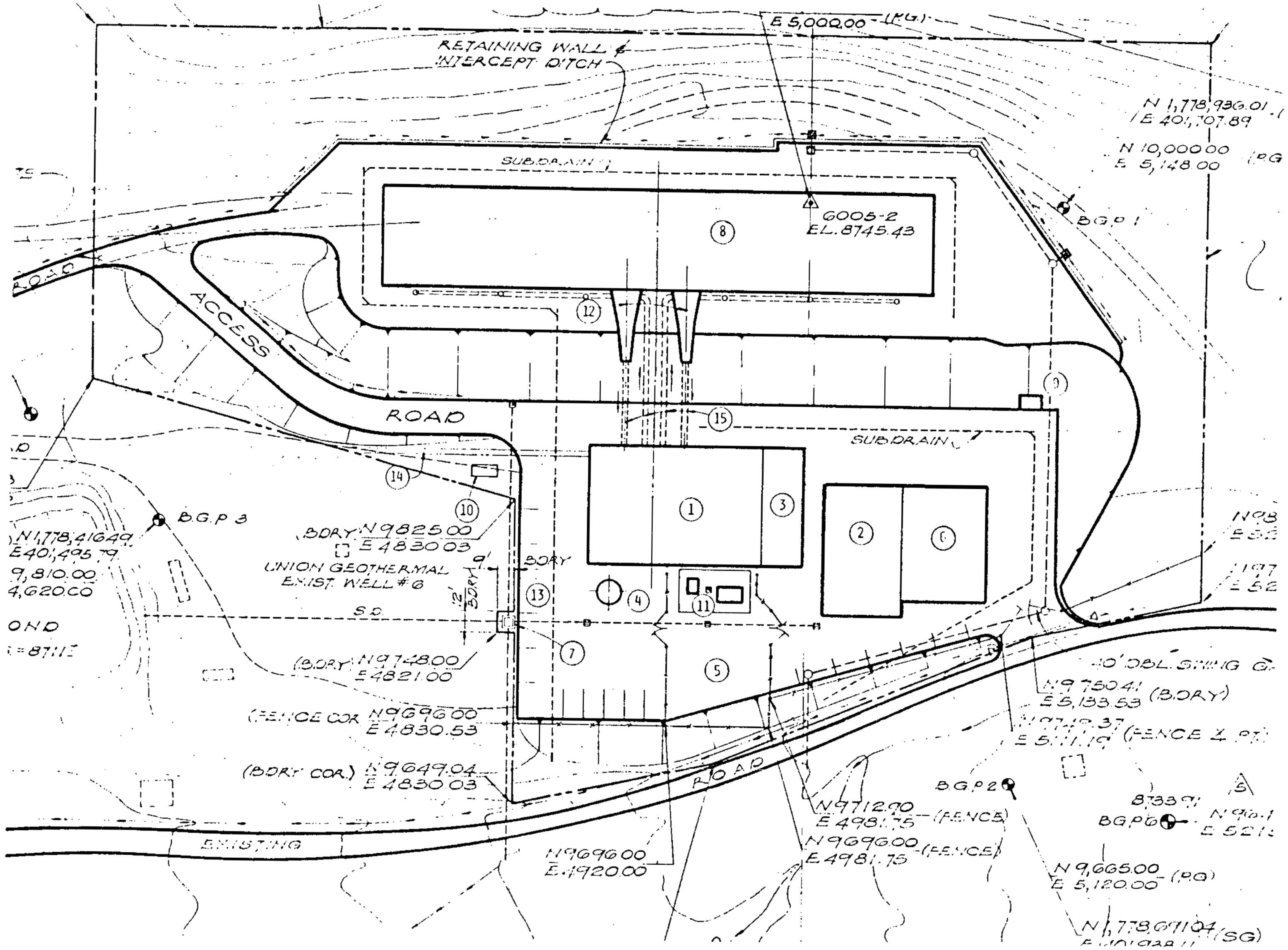
MAGMA




RETAINING WALL &
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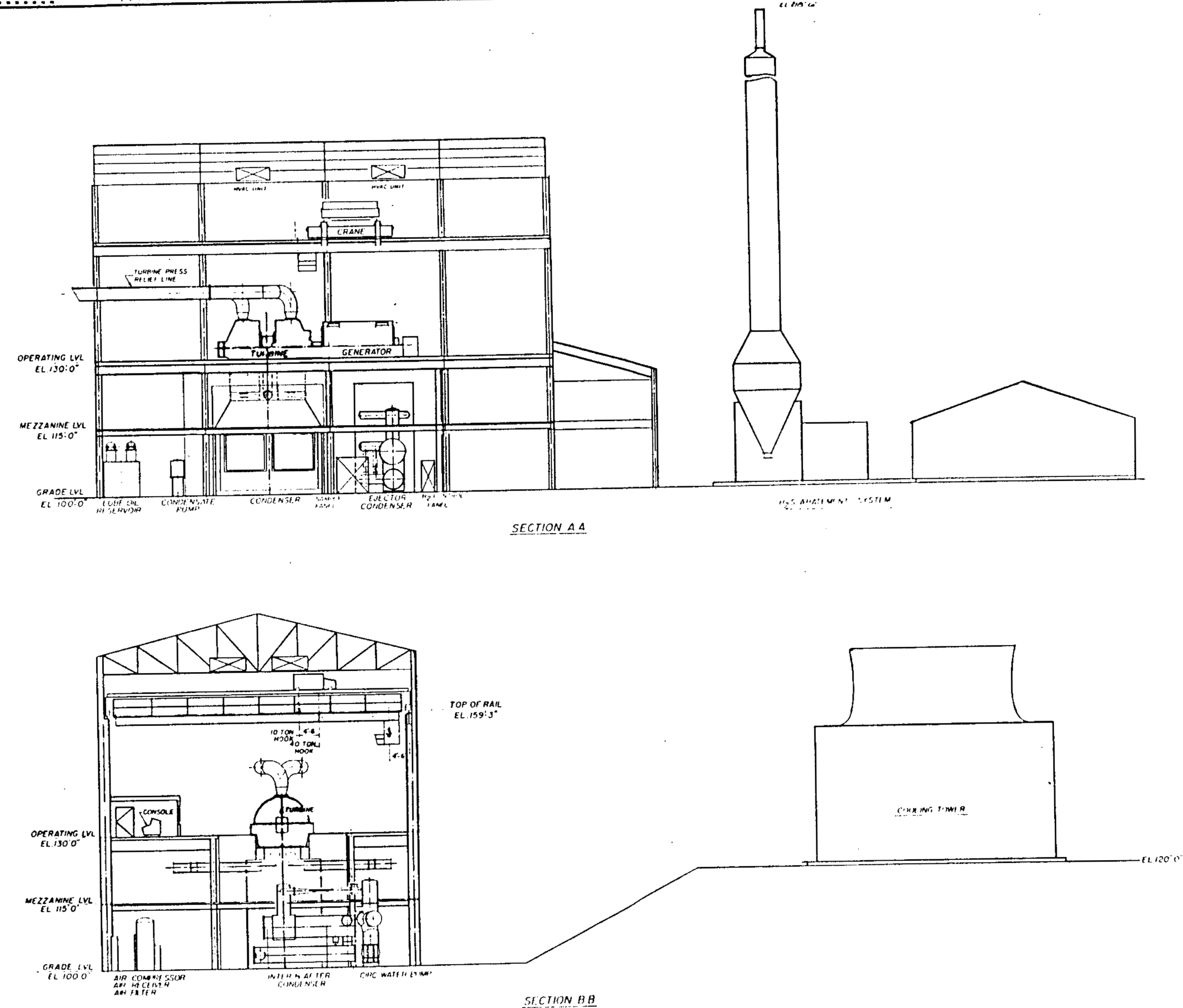
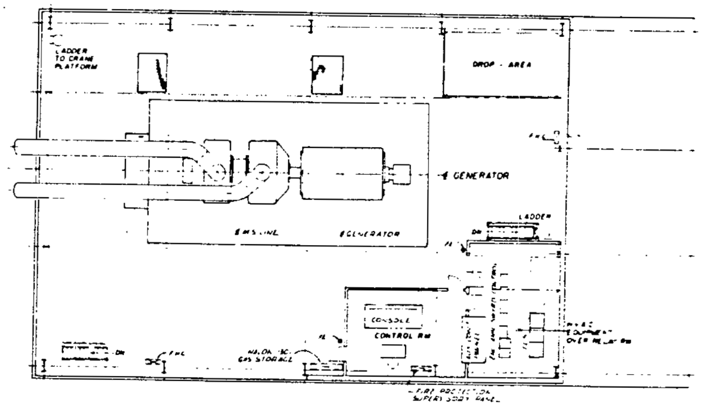
EXIST. WELL #6
BDRY
S.D.
(BDRY N9748.00
E 4821.00
(FENCE COR N9696.00
E 4830.53
(BDRY COR.) N9649.04
E 4830.03
ROAD
EXISTING
N9696.00
E 4920.00
N9712.90
E 4981.75 (FENCE)
N9696.00
E 4981.75 (FENCE)
B.G.P 2
BG.P6
N 9,665.00
E 5,120.00 (PG)
N9750.41
E5,133.53 (BDRY)
(FENCE & PT)

SITE PLAN

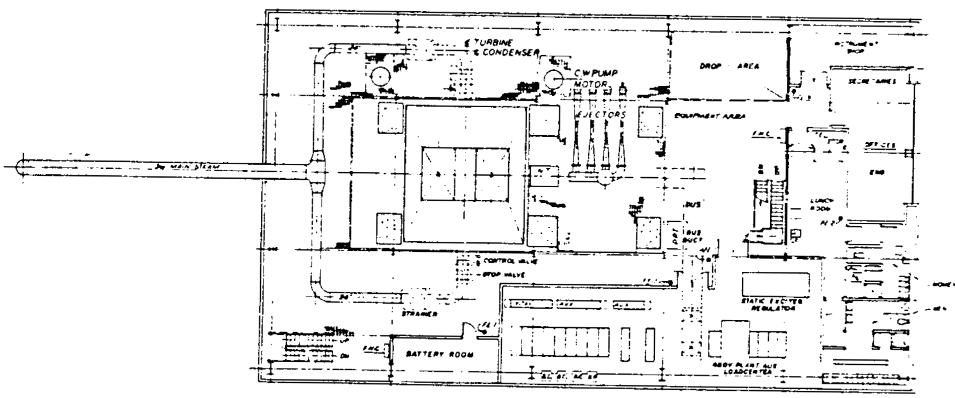


PUBLIC SERVICE COMPANY OF NEW MEXICO
BACA GEOTHERMAL PROJECT UNIT 1

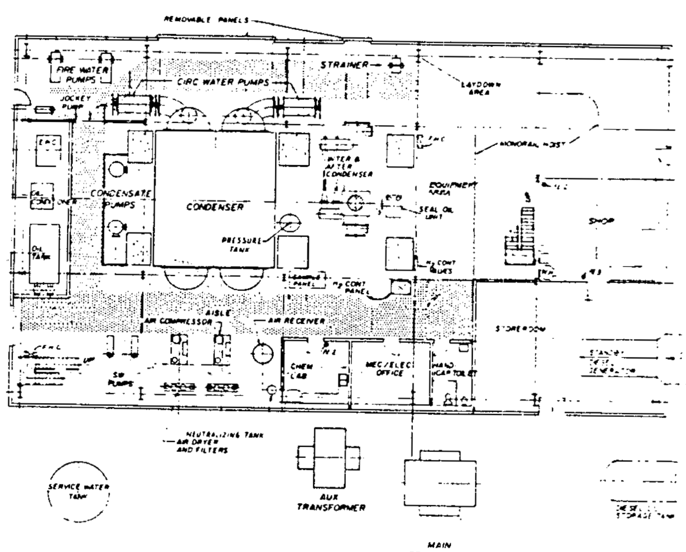
GENERAL A[illegible]NGEMENTS
SECT[illegible] & B-B



OPERATING LEVEL EL 130'-0"

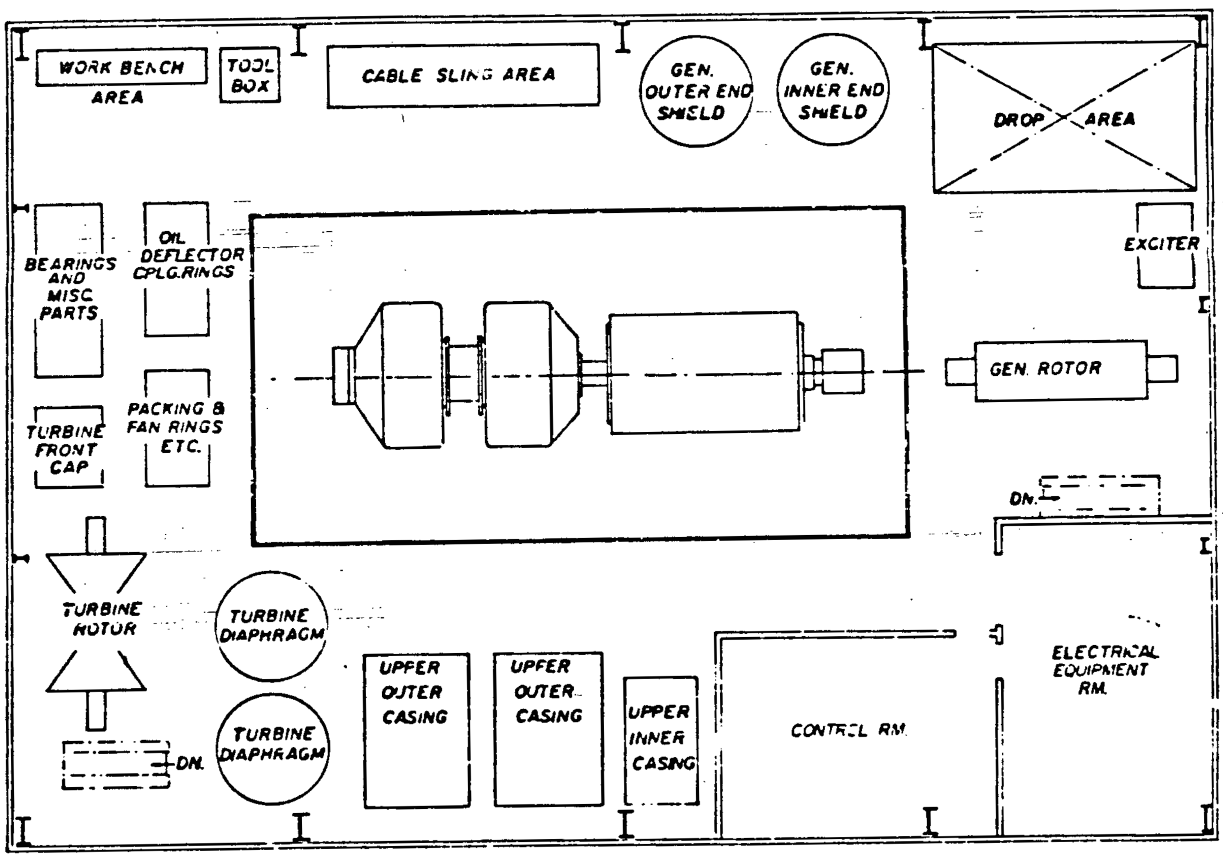


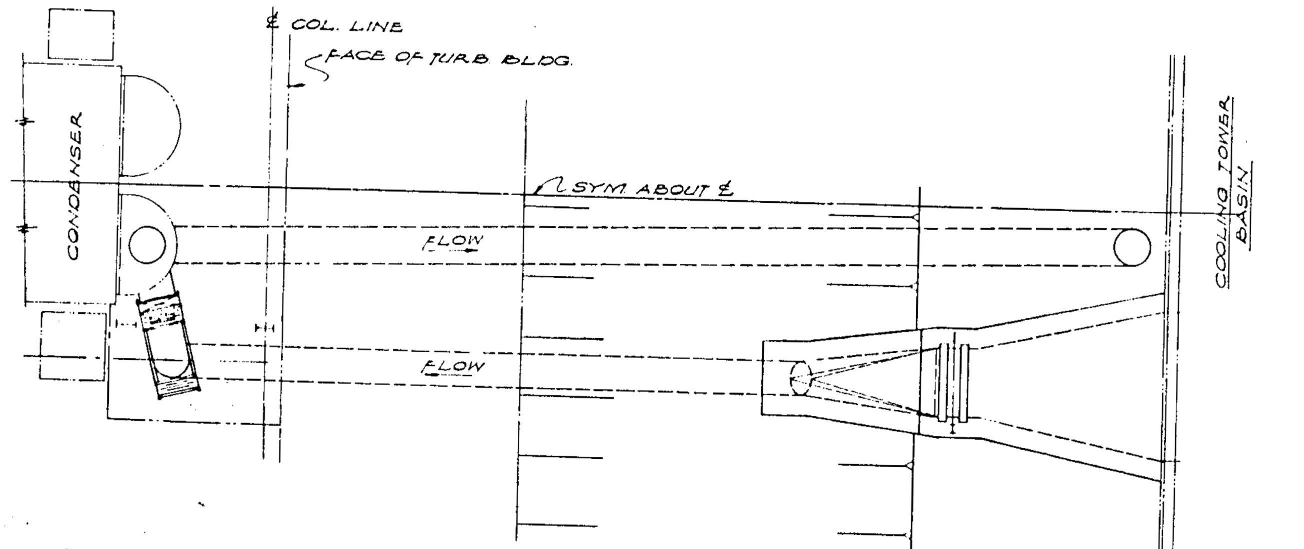
MEZZANINE LEVEL EL 115'-0"



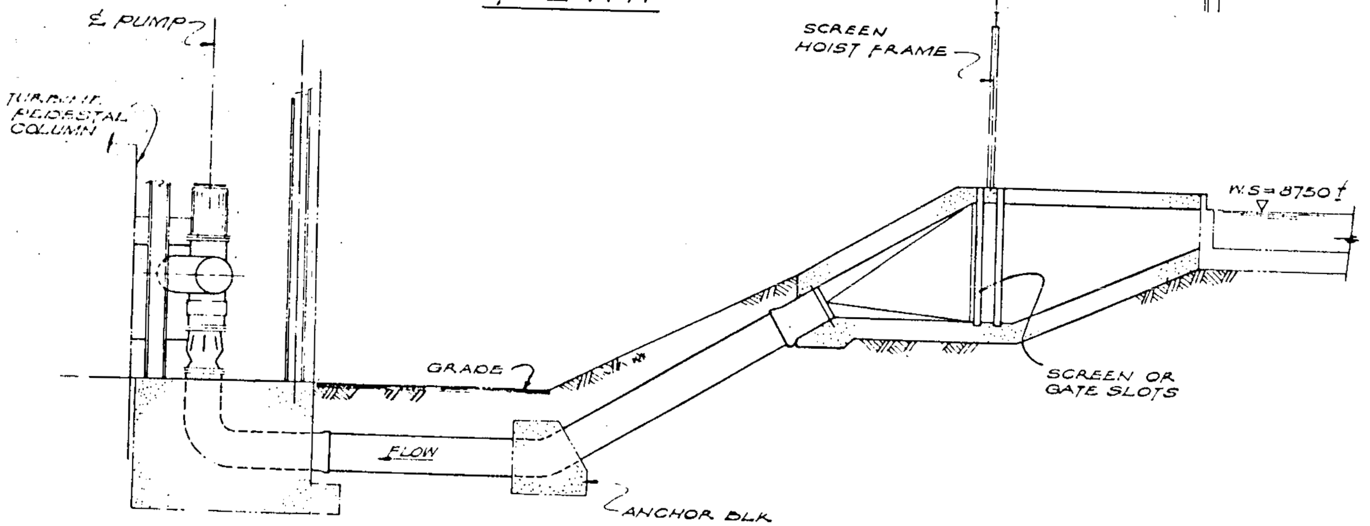
POWER BUILDING GENERAL ARRANGEMENT

TURBINE LAYDOWN AREA





P L A N



S E C T I O N

CIRCULATING WATER SYSTEM

GEOTHERMAL STEAM DATA

	CONCEPTUAL DESIGN	PRELIMINARY DESIGN
• TURBINE ENTRY PRESSURE/ TEMPERATURE POINT OF MEASUREMENT	Downstream of Throttle Valve (103 psia/330° F)	Inlet of Wye Strainers (113 psia/337° F)
• TURBINE EXHAUST BACKPRESSURE	4 Inches HG AB	4 Inches HG AB
• CHEMICAL ANALYSIS OF STEAM	35 MG/L	7-15 MG/L
• NON-CONDENSIBLE GASES (H_2S)*	204 PPM	300 PPM

*All Other Properties Remain the Same

DETAIL DESIGN PERFORMANCE

Turbine Generator Output at Generator Loads	50,000 kW
Auxiliary Power	2,069
H = Net Power to High Voltage Line	47,931

Geothermal Steam Consumption/NKW = 925,100 lbs/h* = 19.30 lbs/NKWH

TURBINE GENERATOR PERFORMANCE

Turbine entry pressure (psia) } Inlet of steam strainers	113
Turbine entry temperature (F) } Inlet of steam strainers	337
Steam flow (lbs/hr)	849,800
Expansion efficiency (percent)	75.7
Mechanical losses (percent)	1.9
Generator efficiency (percent)	98.7
Turbine back pressure (inches Hg absolute)	4

CONDENSER PERFORMANCE

Condenser pressure (inches Hg absolute)	4
Condensate flow (lbs/hr)	894,230
Extracted gases (includes water vapor (lbs/hr))	25,476
Cooling water flow (lbs/hr)	32,000,000

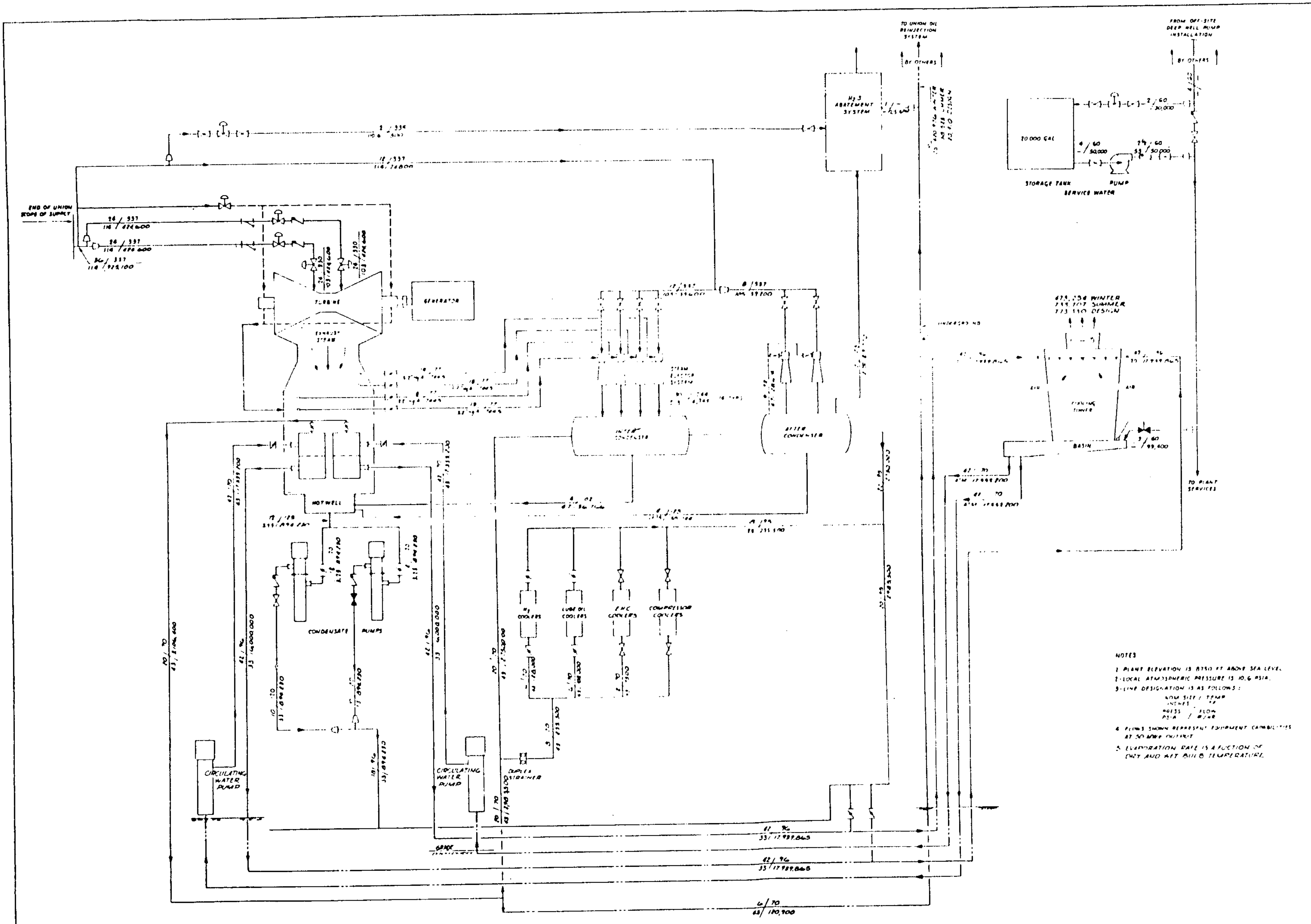
COOLING TOWER PERFORMANCE

Range (F)	26
Approach (F)	14
Design wet bulb temperature (F)	56
Design dry bulb temperature (F)	70
Circulating water pumps flow (lbs/hr)	35,879,370

MASS FLOW BALANCE

Geothermal Steam Consumption (lbs/hr)	925,100
Cooling Tower Water Consumption (lbs/hr)	773,330
Noncondensables (lbs/hr)	27,738
Condensate Reinjection (lbs/hr)	120,910
H_2S Abatement Steam Consumption (lbs/hr)	500

*Includes 74,800 lbs/hr ejector steam.



FLOW DIAGRAM

SUPPORTING FACILITIES

- TURBINE
- CONDENSER AND EJECTOR CONDENSERS
- EJECTORS
- ELECTRICAL EQUIPMENT
- COMPRESSED AIR SYSTEM
- SERVICE WATER
- FIRE WATER

OPERATIONS AND MAINTENANCE FACILITIES

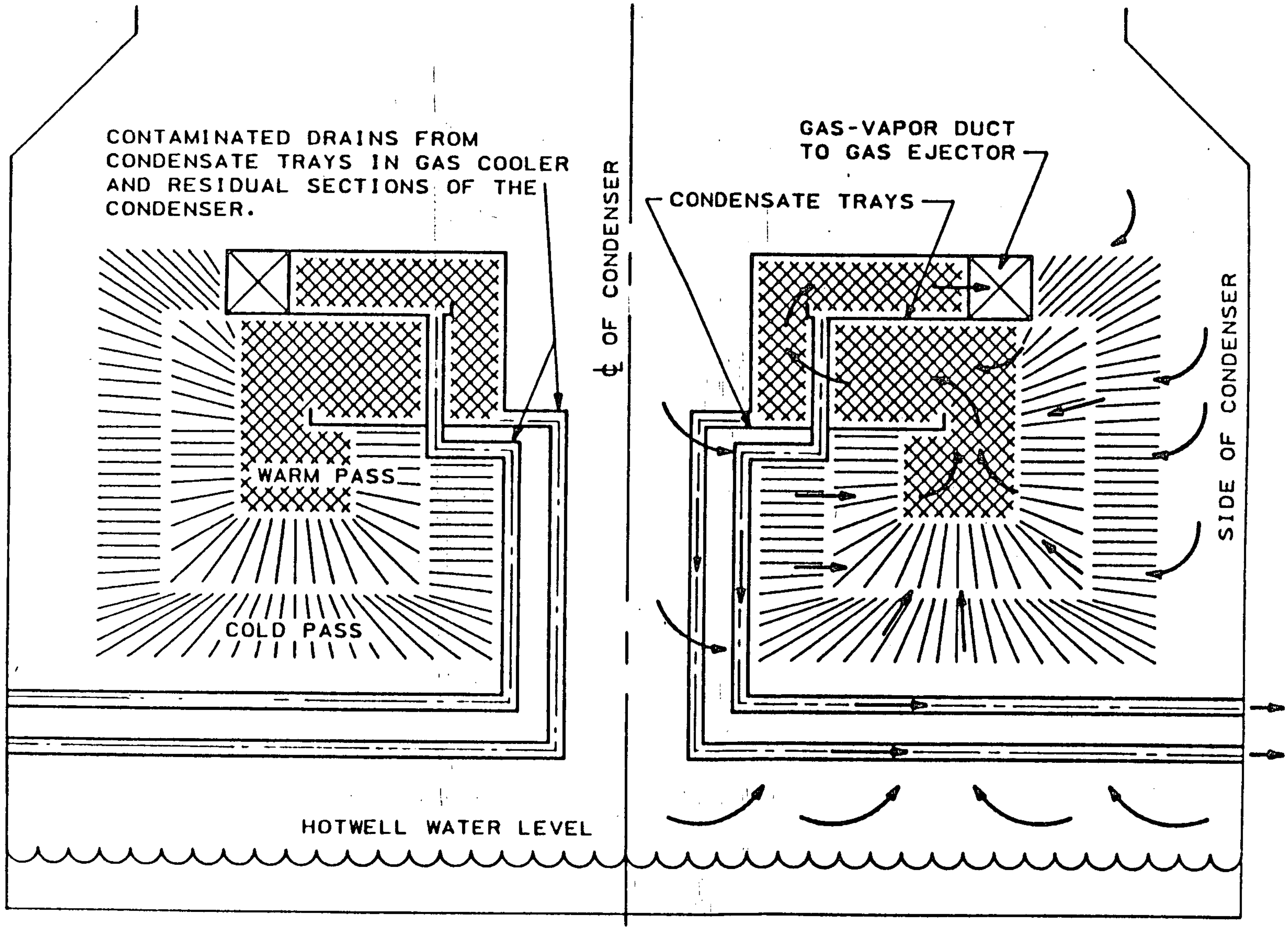
- CONTROL ROOM
- CHEMISTRY LAB
- STOREROOM AND WAREHOUSE
- MECHANICAL/ELECTRICAL SUPERINTENDENT OFFICE
- STATION OFFICES
- INSTRUMENT SERVICE SHOP
- BRIDGE CRANE
- MAINTENANCE SHOP

MAJOR TRADE-OFF STUDIES

STUDY	RECOMMENDED SELECTION	COST ADVANTAGE (PRESENT WORTH)
• CROSS FLOW/COUNTER FLOW COOLING TOWER	COUNTER FLOW	$1,400,000
• COOLING WATER TEMPERATURE (70°, 80° & 90°F)	70°F	APPROX. $160,000 - $1,800,000
• SINGLE/DOUBLE AIR FLOW COOLING TOWER	DOUBLE	$1,429,000
• COOLING TOWER SUBSTATION INDOORS/OUTDOORS	INDOORS	$68,000
• SITE LAYOUT STUDY (8 SCHEMES)	SCHEME H	APPROX. $30,000 to $300,000*
• CIRCULATING WATER PUMP ARRANGEMENT	VERTICAL PUMP INDOORS	$180,000
• SOLID STATE/ELECTRO MECHANICAL RELAYS	SOLID STATE	STAND-OFF
• STAINLESS STEEL/FIBERGLASS REINFORCED PIPE (FRP)	FRP	$200,000*
• GAS REMOVAL (2 STGE VAC. PPS/STEAM EJECTORS)	STEAM EJECTORS	P.W. FUEL COST FAVORED VACUUM PUMPS FIRST COST & RELIABILITY HEAVILY FAVORED EJECTORS

* FIRST COST DOLLARS

ECOLAIRE CONDENSER



<u>END VIEW OF TUBE BUNDLES</u>

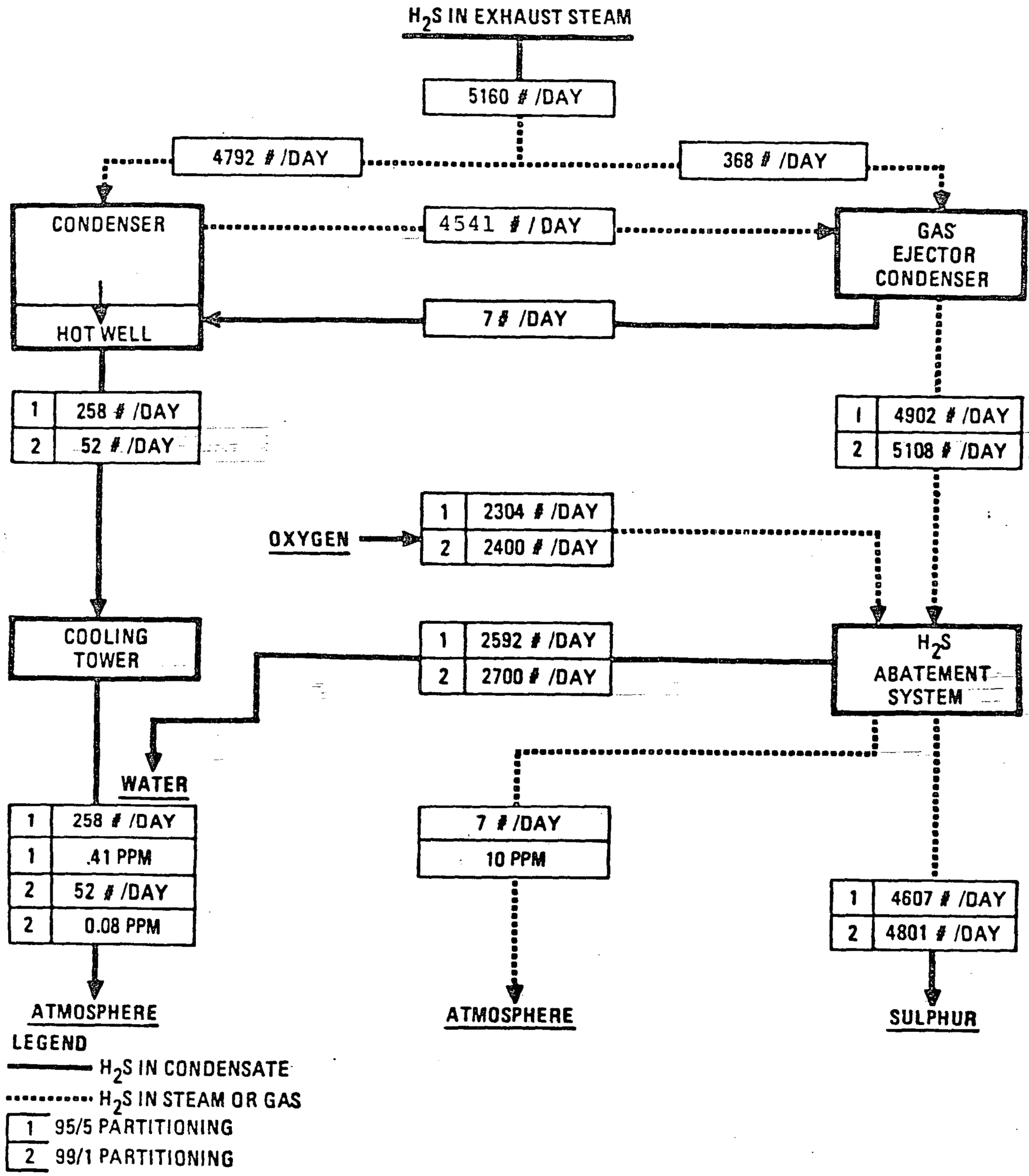
FACTORS AFFECTING PARTITIONING

- CO_2 CONTENT
- NH_3 CONTENT
- CONDENSER DESIGN
- GAS/CONDENSATE CONTACT TIME

COMPARATIVE H_2S PARTITIONING

	PG&E UNIT 15	BACA
• CO_2, PPM	1652	29,500
• NH_3, PPM	145	-
• H_2S, PPM	188	215
• RATIO, CO_2/H_2S	8.8	137
• RATIO, NH_3/H_2S	0.77	0
• PARTITIONING, %	67/33	EXPECTED 90/10

H$_2$S FLOW DIAGRAM



CLEAN ROOM

- ATMOSPHERIC CONTAMINATION
- MATERIALS SUSCEPTIBLE TO H_2S ATTACK
- METHODS OF CORROSION PREVENTION
- CLEAN ROOM DESIGN
- EQUIPMENT LOCATED IN CLEAN ROOM

USE OF FRP PIPE AND TANKS

- PIPING SYSTEMS CONSTRUCTED OF FRP
  - CIRCULATING WATER/COOLING WATER
  - NONCONDENSIBLE GAS DISCHARGE
  - CONDENSATE
  - BELOW GRADE DRAIN AND SEWER LINES
  - BURIED FIRE WATER LINES
  - BURIED AND EXTERIOR EXPOSED SERVICE WATER PIPING
- FRP TANKS
  - SERVICE WATER STORAGE TANK
  - DIESEL OIL STORAGE TANK
- COST COMPARISON VS. CONVENTIONAL MATERIALS
- OTHER ADVANTAGES

TURBINE BLOW-OFF PIPING

- PURPOSE

  TO SAFELY ROUTE STEAM DISCHARGE FROM TURBINE CASING, SHEAR DIAPHRAGMS TO OUTSIDE OF THE BUILDING.

- CONDITION CAUSING RUPTURE OF DIAPHRAGMS

  OVER PRESSURE OF TURBINE CASING DUE TO POSSIBLE INABILITY OF FULL CLOSURE OF TURBINE STOP AND CONTROL VALVES.

- RESULTING PROTECTION

  - PERSONNEL SAFETY

  - STEAM DAMAGE TO PLANT ELECTRICAL EQUIPMENT

POWER PLANT PERFORMANCE

TURBINE GENERATOR OUTPUT		50,000 KW
AUXILIARY POWER		
COOLING TOWER	608	
CIRCULATING WATER PUMPS	656	
MISCELLANEOUS AUXILIARIES	582	
TRANSFORMER LOSSES	223	2,069
NET POWER OUTPUT		47,931

GEOTHERMAL STEAM CONSUMPTION - 19.3 LBS/KWH

BACA GEOTHERMAL DEMONSTRATION PROJECT

COST SUMMARY

Initial DOE Contract
July 14, 1978
($ x 1000)

WBS	UNION	PNM	DOE	TOTAL
1.1	42,000		32,000	**74,000**
1.2		26,000	24,500	**50,500**
TOTAL	**42,000**	**26,000**	**56,500**	**124,500**

Current Cost Estimate
December 17, 1980
($ x 1000)

WBS	UNION	PNM	DOE	TOTAL
1.1	56,500		36,500	**93,000**
1.2		26,000	30,500	**56,500**
TOTAL	**56,500**	**26,000**	**67,000**	**149,500**

MAJOR CONTRACTS AND PURCHASE ORDERS

• SITE PREPARATION	$ 252,000
• TURBINE GENERATOR	4,423,000
• CONDENSER AND GAS REMOVAL EQUIPMENT	1,075,000
• GENERAL PLANT CONSTRUCTION	9,316,000
• H_2S ABATEMENT	2,883,000
• COOLING TOWER	2,431,000
• OTHER EQUIPMENT, MATERIAL AND FACILITIES	5,059,000
• EPCM SERVICES	4,335,000
TOTAL	$29,774,000

Costs shown do not include Construction Shutdown, Schedule Delays and Contingency and Escalation.

POWER PLANT ESTIMATE SUMMARY

AS OF 9/1/80

($1,000's)

Description	Preliminary Estimate	3/1/80 Estimate	9/1/80 Forecast
Plant Material and Equipment	$10,608	$10,361	$10,335
Building Fire Protection	47	144	144
Building HVAC	24	150	150
Freeze Protection	100	100	100
Cooling Tower	1,312	2,431	2,496
H_2S Abatement System	2,792	2,738	2,983
Site Preparation	234	252	252
Construction	6,873	9,316	13,212
SUBTOTAL	$21,990	$25,492	$29,672
Contingency and Escalation	5,669	2,301	2,464
SUBTOTAL	$27,659	$27,793	$32,136
Bechtel Contract (EPCM)	4,288	4,335	5,205
TOTAL	$31,947	$32,128	$37,341

MAJOR COST INCREASE IMPACTS

3/1/80 ESTIMATE - 9/1/80 FORECAST

($1,000's)

<u>PLANT MATERIAL AND EQUIPMENT</u>	
• MAJOR EQUIPMENT PRICING	(419)
• DESIGN IMPROVEMENTS	101
• CONSTRUCTION SHUTDOWN/DELAY COSTS	292
<u>COOLING TOWER</u>	
• CONSTRUCTION SHUTDOWN/DELAY COSTS	65
<u>H_2S ABATEMENT SYSTEM</u>	
• PEABODY CONTRACT PRICE	145
• CONSTRUCTION SHUTDOWN/DELAY COSTS	100
<u>CONSTRUCTION</u>	
• QUANTITY UPDATE	141
• DESIGN IMPROVEMENTS	30
• LATE CONSTRUCTION AWARD	308
• GC-1 STANDBY COSTS	420
• CONSTRUCTION SHUTDOWN/DELAY COSTS	2,997
<u>CONTINGENCY AND ESCALATION</u>	
• CONSTRUCTION SHUTDOWN/DELAY COSTS	163
<u>BECHTEL CONTRACT</u>	
• DESIGN IMPROVEMENTS	62
• LATE CONSTRUCTION AWARD	115
• CONSTRUCTION SHUTDOWN/DELAY COSTS	693
TOTAL	$5,213

APPENDIX K

HEBER BINARY PROJECT

45 MEGAWATT
DEMONSTRATION PLANT

PROJECT OVERVIEW

- 65 MW (GROSS), 45 MW (NET) BINARY CYCLE DEMONSTRATION PLANT
- HEBER RESERVOIR, IMPERIAL VALLEY, CALIFORNIA
- OPERATION MID-1985 (TWO-YEAR DEMONSTRATION)
- PARTICIPANTS:
  - DEPARTMENT OF ENERGY
  - ELECTRIC POWER RESEARCH INSTITUTE
  - SAN DIEGO GAS & ELECTRIC (PROJECT MANAGER)
  - IMPERIAL IRRIGATION DISTRICT
  - SOUTHERN CALIFORNIA EDISON COMPANY
  - CALIFORNIA DEPARTMENT OF WATER RESOURCES
- HEAT SUPPLY - CHEVRON RESOURCES COMPANY (UNIT OPERATOR)
  - UNIT OWNERS:

    CHEVRON RESOURCES COMPANY

    UNION OIL COMPANY

    NEW ALBION RESOURCES COMPANY
- GOAL - ULTIMATE COMMERCIAL OPERATION

PROJECT FUNDING

PARTICIPANT	FUNDING
• DEPARTMENT OF ENERGY*	50.0%
• SAN DIEGO GAS & ELECTRIC	32.8%
• ELECTRIC POWER RESEARCH INSTITUTE	10.0%
• IMPERIAL IRRIGATION DISTRICT	4.0%
• SOUTHERN CALIFORNIA EDISON COMPANY	2.0%
• DEPARTMENT OF WATER RESOURCES	1.2%

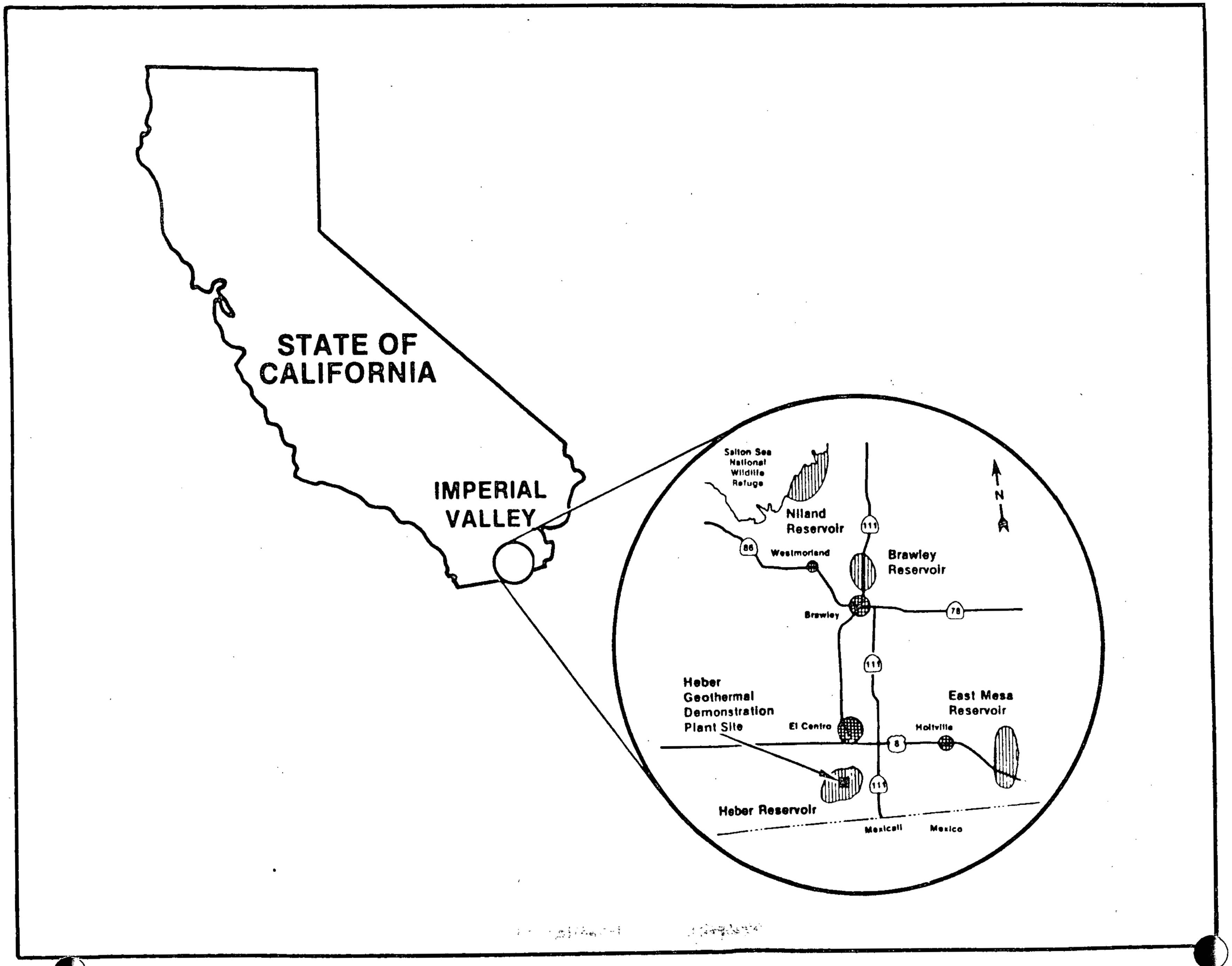
*DOES NOT INCLUDE ACTIVITIES FUNDED 100% BY DOE.

JUSTIFICATION FOR THE PROJECT

- <u>GOALS</u>
  - ESTABLISH TECHNICAL AND ECONOMIC VIABILITY OF THE BINARY CYCLE
  - DEMONSTRATE ENVIRONMENTAL ACCEPTABILITY
  - TRANSFER DATA TO INDUSTRY
- <u>INCENTIVES</u>
  - DEVELOP ALTERNATE ENERGY RESOURCE
  - EXTENSIVE LOW-TO-MODERATE TEMPERATURE RESOURCES
  - MORE EFFICIENT RESOURCE UTILIZATION
  - FEWER ENVIRONMENTAL IMPACTS
  - ENCOURAGE RESERVOIR EXPLORATION AND DEVELOPMENT
  - BROAD UTILITY INTEREST

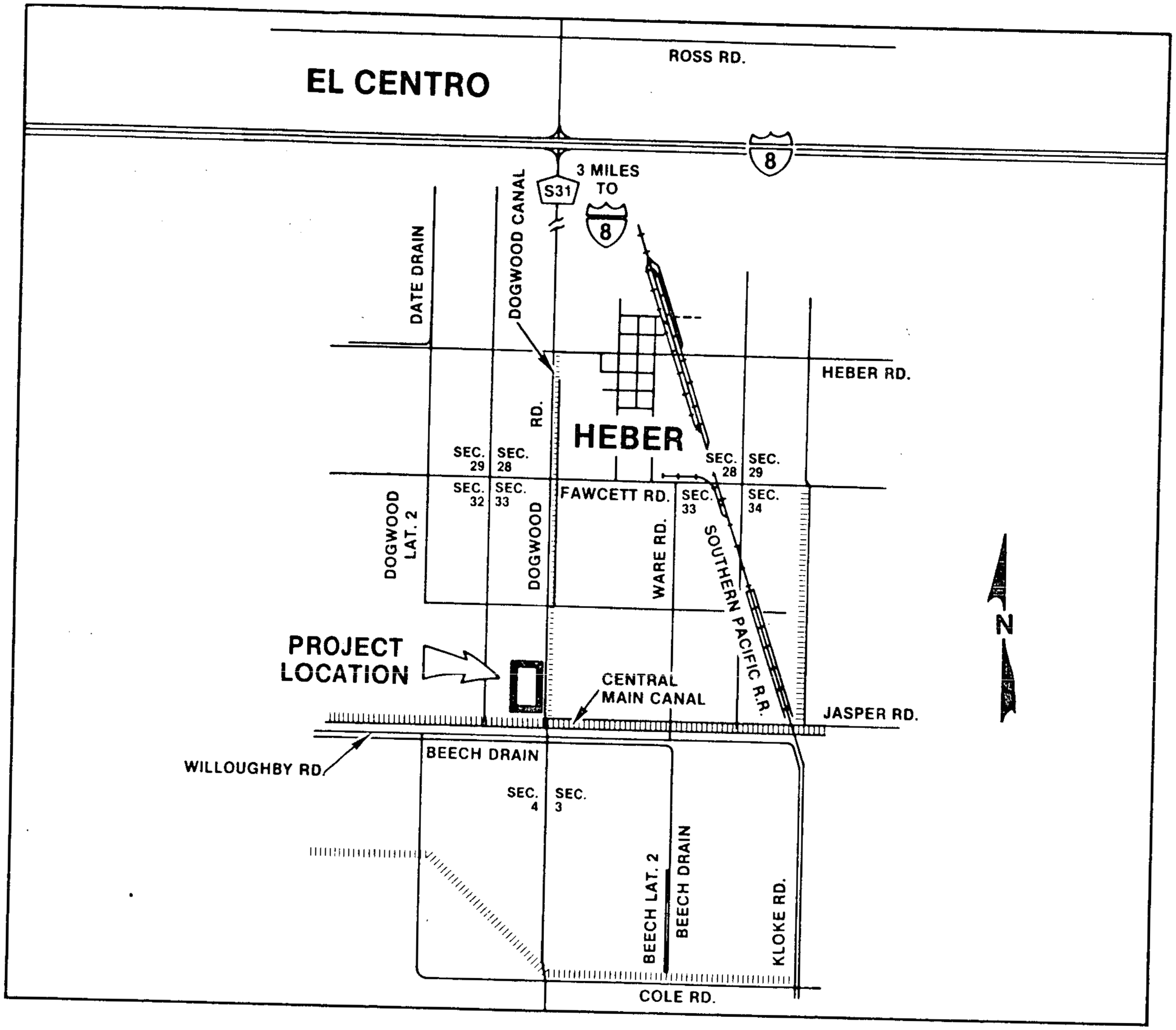
HISTORY OF PROJECT

1975	•	EPRI-SPONSORED HOLT/PROCON STUDY
1976	•	DISCUSSIONS WITH ERDA FOR SOLE SOURCE FUNDING
1977	•	ERDA DECIDES AGAINST SOLE SOURCE FUNDING
1978	•	SDG&E FIRST PROPOSAL SUBMITTED
	•	DOE SELECTS FLASH PROJECT
	•	HEBER PROJECT SHELVED
1979	•	CONGRESS REQUESTS DOE TO FUND BINARY
	•	MEETINGS BETWEEN SDG&E AND DOE
	•	SDG&E SECOND PROPOSAL SUBMITTED
1980	•	DOE SELECTED HEBER SITE
	•	EPRI FUNDING APPROVED
	•	COOPERATIVE AGREEMENT WITH DOE
	•	OTHER PROJECT AGREEMENTS
1981	•	ENGINEERING STARTED



PROJECT LOCATION

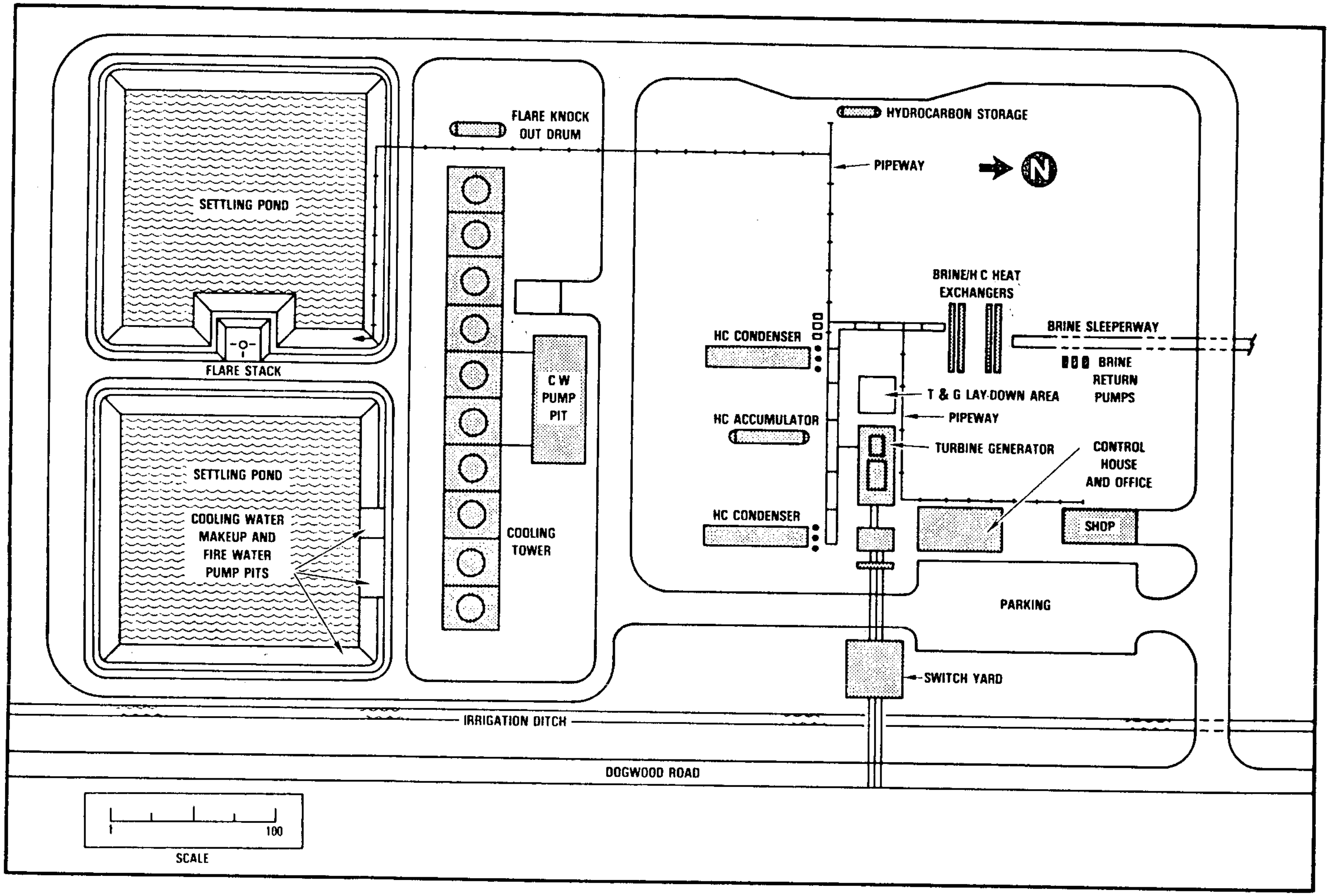
PROJECT LOCATION HEBER GEOTHERMAL DEMONSTRATION PLANT



WORK ACCOMPLISHED

- Conceptual Design
  - Review and assessment of EPRI Heber study reports
  - Direct flash vs. binary
  - Two phase vs. single phase brine supply
  - Working fluid selection
  - Turbine exhaust piping
  - Wet vs. wet/dry cooling
  - Hydrocarbon pumping configurations
  - Plot plan development
  - Heat transfer materials selections
  - Make-up water silt removal
  - Two half-capacity turbines vs. one full-capacity turbine
- Conditional Use Permit
- Cooling Water Supplies
- Environmental Impact Report/Environmental Assessment
- Geotechnical Update and Soils Studies

POWER PLANT LAYOUT



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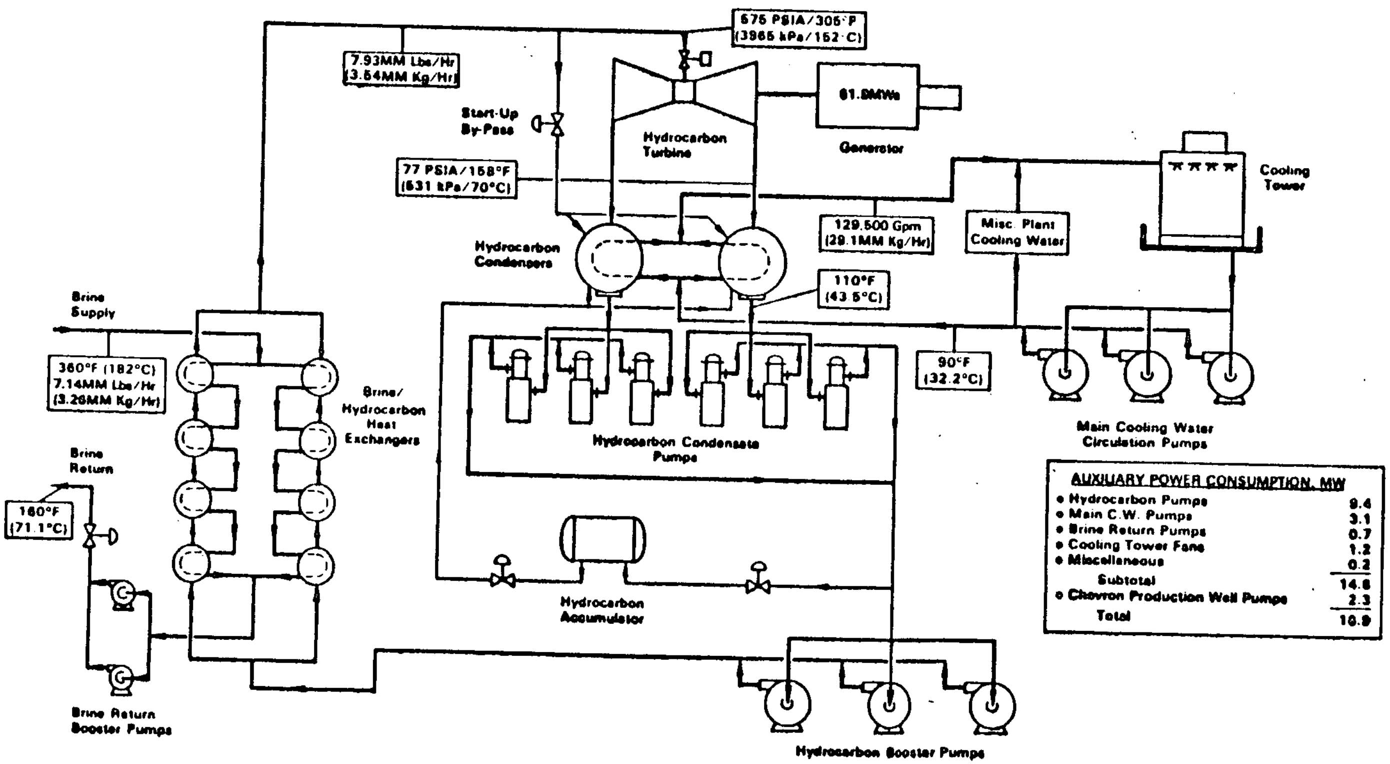
SDGE
1/81

POWER CYCLE SCHEMATIC- START OF RUN

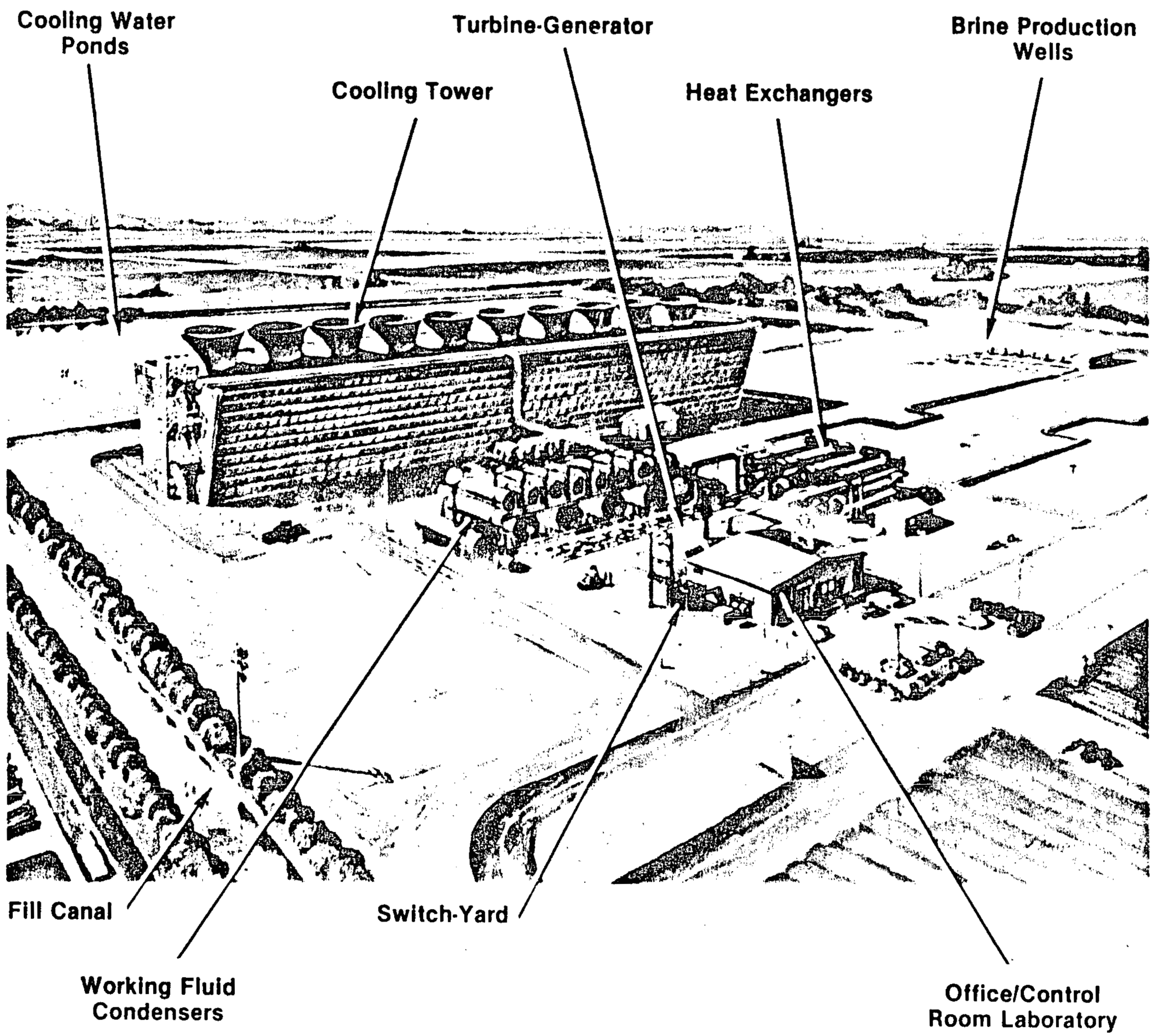


CURRENT ACTIVITIES

- COMMENCED ENGINEERING (JANUARY, 1981)
  - DESIGN GUIDE
  - SCHEDULE/CASH FLOW
  - CONCEPTUAL DESIGN REVIEW
  - OPTIMIZATION STUDIES
- ENVIRONMENTAL
  - SUBSIDENCE NETWORK/BASELINE MEASUREMENTS
  - BASELINE METEOROLOGICAL MEASUREMENTS
  - NEW RIVER DATA
- OTHER CONSULTANTS
  - AVAILABILITY ENHANCEMENT
  - DATA MANAGEMENT
- OTHER ACTIVITIES
  - INJECTION PIPELINE RIGHT-OF-WAY
  - CALIFORNIA ASSEMBLY BILL 51
  - FEDERAL FUNDING FOR FY 1982

PROJECT SCHEDULE

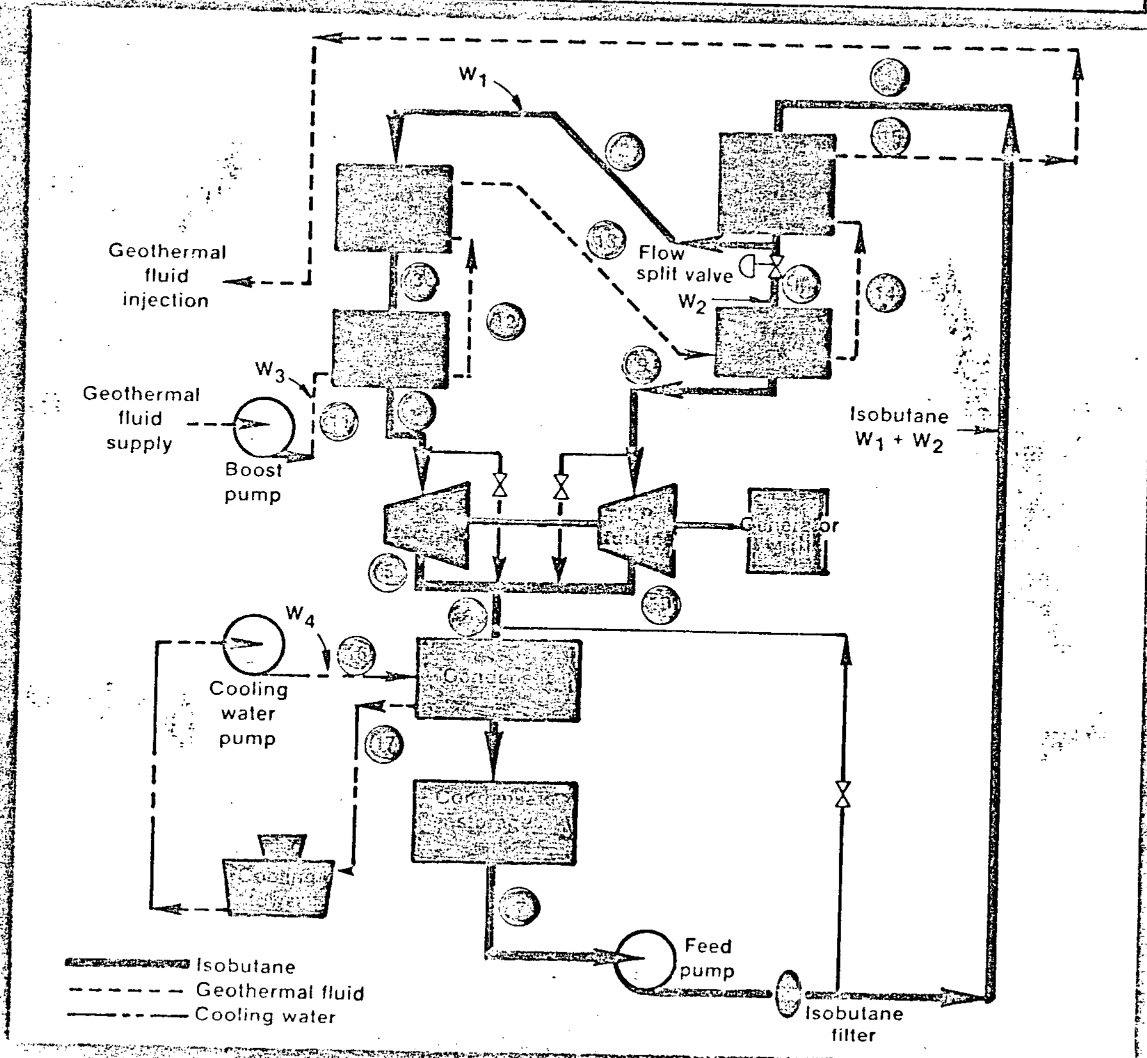
JANUARY 1981	COMMENCE ENGINEERING
APRIL 1981	CONCEPTUAL DESIGN REVIEW
JULY 1981	TURBINE GENERATOR PURCHASE ORDER
APRIL 1982	DEFINITIVE COST ESTIMATE
APRIL 1982	FINAL POWER CYCLE REVIEW
JUNE 1982	PHASE I COMPLETION
OCTOBER 1982	COMMENCE CONSTRUCTION
DECEMBER 1982	FINAL DESIGN REVIEW
NOVEMBER 1984	COMMENCE SYSTEM/EQUIPMENT START-UP
JUNE 1985	COMMENCE DEMONSTRATION
JUNE 1987	COMPLETE DEMONSTRATION



ARTIST'S RENDERING

APPENDIX L

Raft River 5 MW(e) Geothermal Pilot Plant Dual Boiling Cycle



Isobutane System	Geothermal Water System	Cooling Water System
W1 = 6.13×10^5 lbm/hr	W3 = 1.04×10^6 lbm/hr	(1) W4 = 7.53×10^6 lbm/hr
W2 = 3.21×10^5 lbm/hr		
1 105 F	11 290 F	16 75 F
2 180 F	12 250 F	17 95 F
3 240 F	13 222 F	
4 240 F (381.6 psia)	14 190 F	
5 130 F	15 144 F	
6 128 F		
7 101 F (77.5 psia)(2)		
8 180 F		
9 180 F (203.0 psia)		
10 123 F		

Notes:
(1) Flowrate is sized for 100% bypass around turbine
(2) Condenser pressure nominal for 65 F wet bulb temperature

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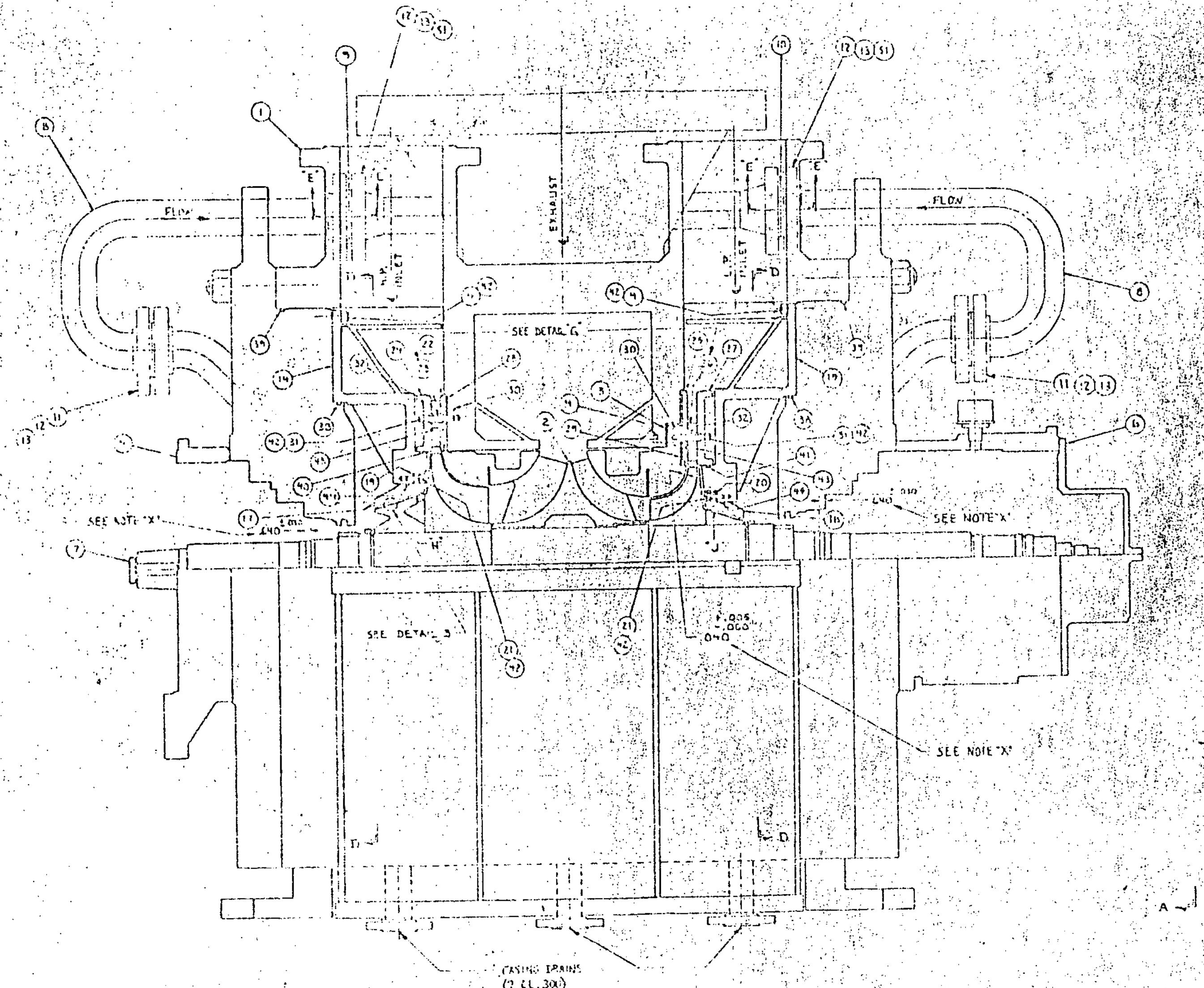
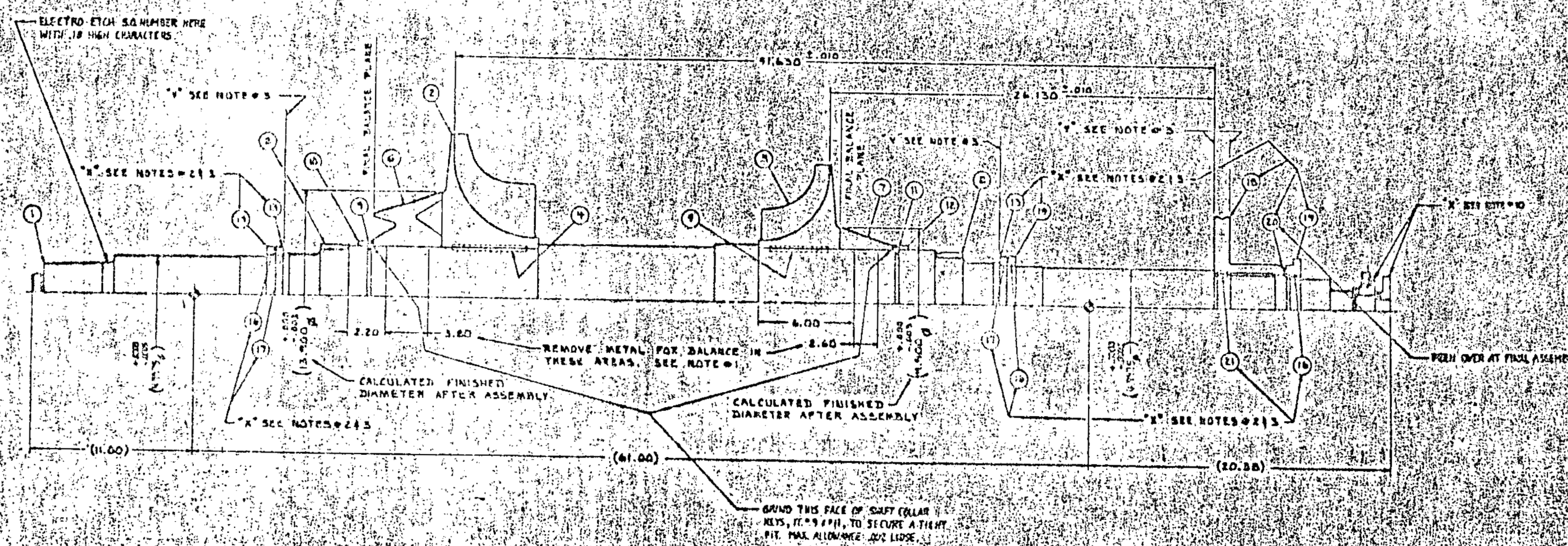
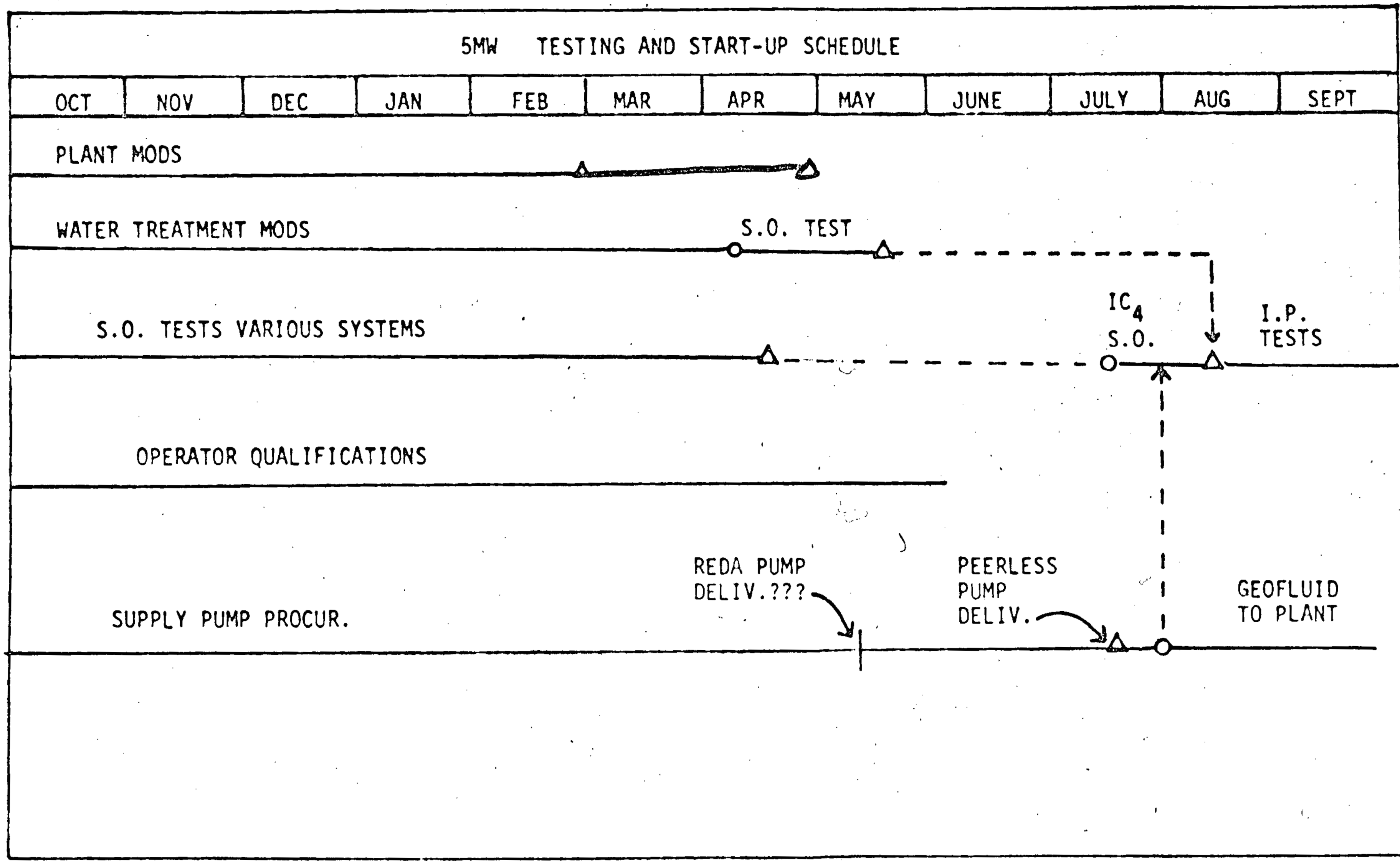
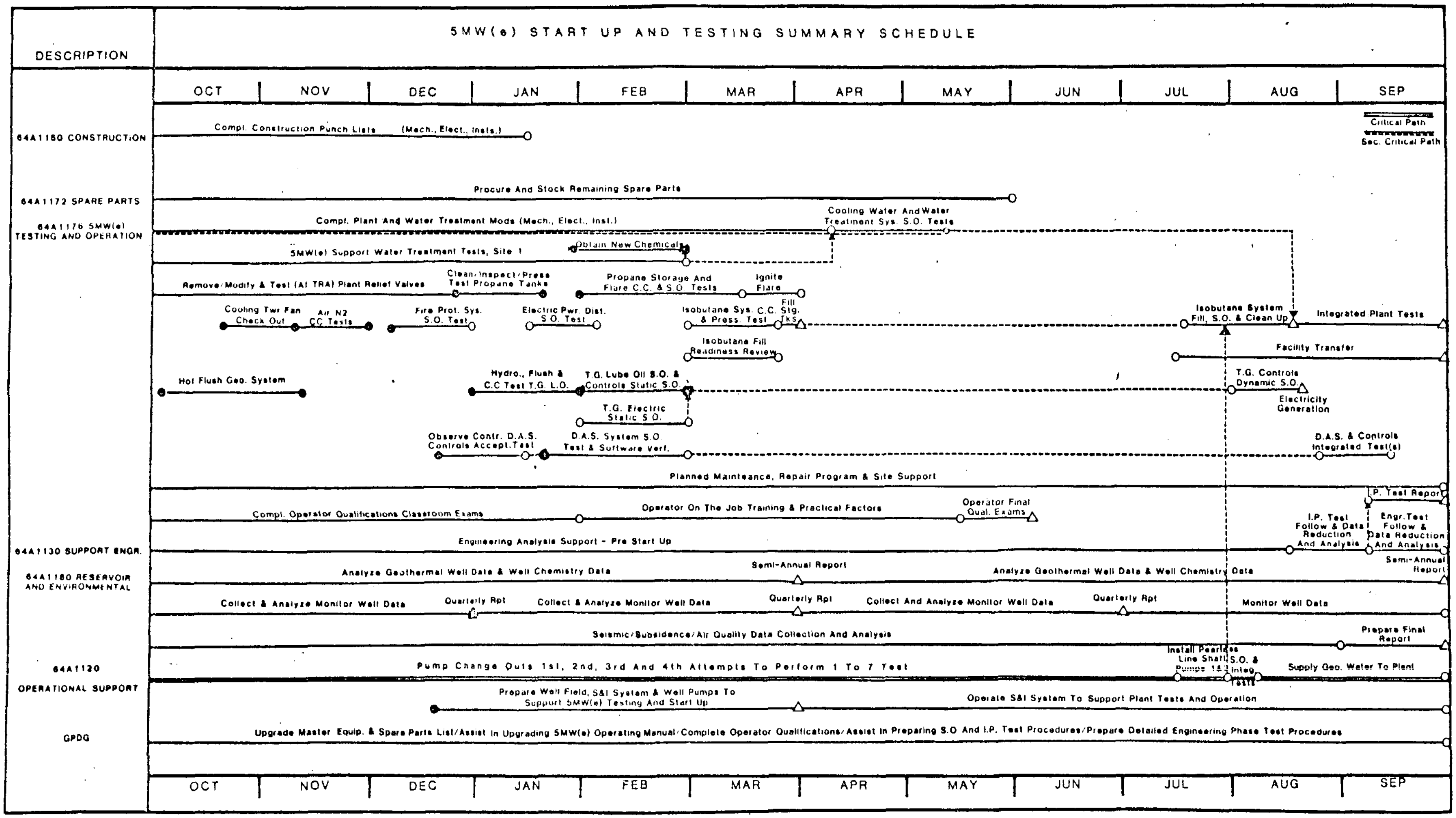
Turbine Assembly



Rotor Assembly




5MW TESTING AND START-UP SCHEDULE
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
PLANT MODS
WATER TREATMENT MODS
S.O. TEST
S.O. TESTS VARIOUS SYSTEMS
IC4 S.O.
I.P. TESTS
OPERATOR QUALIFICATIONS
SUPPLY PUMP PROCUR.
REDA PUMP DELIV.???
PEERLESS PUMP DELIV.
GEOFLUID TO PLANT


5MW(e) START UP AND TESTING SUMMARY SCHEDULE
DESCRIPTION
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Critical Path
Sec. Critical Path
64A1150 CONSTRUCTION
Compl. Construction Punch Lists (Mech., Elect., Insts.)
64A1172 SPARE PARTS
Procure And Stock Remaining Spare Parts
64A1176 5MW(e) TESTING AND OPERATION
Compl. Plant And Water Treatment Mods (Mech., Elect., Inst.)
Cooling Water And Water Treatment Sys. S.O. Tests
5MW(e) Support Water Treatment Tests, Site 1
Obtain New Chemicals
Remove/Modify & Test (At TRA) Plant Relief Valves
Clean/Inspect/Press Test Propane Tanks
Propane Storage And Flare C.C. & S.O. Tests
Ignite Flare
Cooling Twr Fan Check Out
Air N2 CC Tests
Fire Prot. Sys. S.O. Test
Electric Pwr. Dist. S.O. Test
Isobutane Sys. C.C. & Press. Test
Fill Stg. Tks
Isobutane System Fill, S.O. & Clean Up
Integrated Plant Tests
Isobutane Fill Readiness Review
Facility Transfer
Hot Flush Geo. System
Hydro., Flush & C.C Test T.G. L.O.
T.G. Lube Oil S.O. & Controls Static S.O.
T.G. Controls Dynamic S.O.
Electricity Generation
T.G. Electric Static S.O.
Observe Contr. D.A.S. Controls Accept.Test
D.A.S. System S.O Test & Software Verf.
D.A.S. & Controls Integrated Test(s)
Planned Mainteance, Repair Program & Site Support
I.P. Test Report
Compl. Operator Qualifications Classroom Exams
Operator On The Job Training & Practical Factors
Operator Final Qual. Exams
I.P. Test Follow & Data Reduction And Analysis
Engr.Test Follow & Data Reduction And Analysis
64A1130 SUPPORT ENGR.
Engineering Analysis Support - Pre Start Up
64A1180 RESERVOIR AND ENVIRONMENTAL
Semi-Annual Report
Analyze Geothermal Well Data & Well Chemistry Data
Analyze Geothermal Well Data & Well Chemistry Data
Semi-Annual Report
Collect & Analyze Monitor Well Data
Quarterly Rpt
Collect & Analyze Monitor Well Data
Quarterly Rpt
Collect And Analyze Monitor Well Data
Quarterly Rpt
Monitor Well Data
Seismic/Subsidence/Air Quality Data Collection And Analysis
Prepare Final Report
64A1120 OPERATIONAL SUPPORT
Pump Change Outs 1st, 2nd, 3rd And 4th Attempts To Perform 1 To 7 Test
Install Peerless Line Shaft Pumps 1&2
S.O. & Integ. Tests
Supply Geo. Water To Plant
Prepare Well Field, S&I System & Well Pumps To Support 5MW(e) Testing And Start Up
Operate S&I System To Support Plant Tests And Operation
GPDG
Upgrade Master Equip. & Spare Parts List/Assist In Upgrading 5MW(e) Operating Manual/Complete Operator Qualifications/Assist In Preparing S.O And I.P. Test Procedures/Prepare Detailed Engineering Phase Test Procedures
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

RAFT RIVER PUMP HISTORY

INST. NO.	WELL	MFR.	SET DEPTH (FT)	HP	RUN TIME (HOURS)	COMMENTS
1	1	REDA	620	320	112	DNF TOO LARGE FOR DEPTH
2	3	REDA	773	320	1,359	CABLE SHORT
3	2	PEERLESS	802	250	1,060	DNF-WORN TAILSHAFT BEARING
4	5	REDA	1,000	320	568	DNF-BAD BEARINGS & CABLE
5	1	CENTRILIFT	2,021	650	114	SEAL MATERIAL FAILURE
6	2	CENTRILIFT	1,860	500	0	CABLE HEAD LEAK
7	3	CENTRILIFT	1,110	250	0	DNF-REMOVED FOR FACTORY MODS
8	5	REDA	1,098	320	85	MOTORS & PUMP FAILED: SAND
9	1	CENTRILIFT	2,021	650	8.5	CABLE FAILURE
10	3	CENTRILIFT	1,042	250	815	ROTOR BEARING FAILURE
11	2	CENTRILIFT	1,884	500	11 MIN	EXCESS EPOXY-STATOR BURN
12	2	CENTRILIFT	1,884	500	14 MIN	FAILED ROTOR BEARING & SEAL LEAK
13	1	REDA	2,020	600	541.5	ACCIDENTAL ELECTRICAL MALFUNCTION
14	5	REDA	1,098	320	0	WATER IN MOTOR
15	1	REDA	1,978	2-340 HP EA	4.25	WATER IN MOTOR
16	5	REDA	1,098	320	19.5	DNF - STILL IN WELL

PUMP STATUS AND PLANS

	CURRENT STATUS	PROCUREMENT		
		PEERLESS	REDA	CENTRILIFT
WELL 1	NO PUMP	JULY 1981	LASL PUMP BEING REPAIRED DUE MAY, 1981	(2)
WELL 2	NO PUMP	JULY 1981	MAY 1981(1)	(2)
WELL 3	PEERLESS IN PLACE (20.5 HRS)		MAY 1981(1)	(2)
WELL 5	REDA OIL FIELD (19.5 HRS)	-		-

(1) CONTINUOUSLY SLIPPED SINCE LAST SPRING, DOUBTFUL DATE.

(2) TO BE ESTABLISHED. – would like a pump for well No. 1 for 1–7 [illegible]

APPENDIX M

MATERIALS CONSIDERATION IN THE DESIGN OF GEOTHERMAL POWER PLANTS

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Materials Concerns in Flashed Steam Geothermal Plants: Production and Two-Phase System

- Casing and surface equipment should meet standards for "sour service" to avoid sulfide stress cracking (SSC).
- Two-phase fluid causes severe erosion of valves and elbows.
  - Valves require stellite hardfacings, or alternately sacrificial valves can be used, as is the practice at Ahuachapan.
  - Blind tees successfully replace elbows (Salton Sea, Cerro Prieto).

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Materials Concerns in Flashed Steam Geothermal Plants:

Steam Transmission System

- Condensate in steam lines contains corrosive ions and dissolved gases.
  - Elimination of cold spots reduces condensate and subsequent corrosion (Larderello).
  - Traps and final demister protect pipeline and turbine (Cerro Prieto, Wairakei).
  - Rapid shut-down and venting prevent pooling of corrosive areated condensate (Wairakei).
- Corrosion resistant valves are required.
  - Carbon steel body, 300 series internal trim with stellite hardfacing, non-austenitic stainless steel stem give 10,000-80,000 hours service (Larderello).

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Materials Concerns in Flashed Steam Geothermal Plants:

Turbines

- Most turbines are bladed with 12 Cr stainless steel heat treated to HRC < 22 to avoid SSC (Cerro Prieto, The Geysers, Otake, Hatchobaru, Wairakei, Matsukawa, Ahuachapan).
  - Corrosion fatigue in geothermal steam is 2 to 2.5 times more severe than in boiler quality steam (Otake, The Geysers). Also severe at other plants.
  - Thicker, heavier blades and lower tip speeds are required.
  - Blade failure is more prevalent in turbines supplied with superheated steam (Larderello, The Geysers) than in turbines fed saturated steam (Ahuachapan, Cerro Prieto, Wairakei, Otake).
  - Arsenic levels of > 200 ppm have been encountered in turbines at The Geysers. The effect, if any, of this hydrogen embrittlement agent is not defined.

Materials Concerns in Flashed Steam Geothermal Plants:

Heat Rejection System

- Most existing and proposed plants use steam condensate for cooling water make-up.
- Aeration and concentration of the condensate cause serious corrosion problem in the cooling systems of all operating plants.
- Carbon steel and aluminum alloys are unsatisfactory (Cerro Prieto, Otake, Hatchobaru, Larderello, The Geysers, Wairakei).
- In many cases, Type 304 will be unsatisfactory.
  - It will pit at typical cooling system temperatures and chloride levels (low ppm).
  - Stress corrosion cracking risk occurs above 122°F.
- Austenitic grades containing more than 20% chromium and 4 percent molybdenum; ferritic grades such as XM 27 and 26 Cr-3 Mo; Inconel 625; or titanium will be required in many cases.

Materials Concerns in Flashed Steam Geothermal Plants:

Heat Rejection System (Continued)

- Microbial action converts hydrogen sulfide to sulfuric acid, increasing corrosivity (Cerro Prieto, Ahuachapan).
- Bio-fouling will cause pitting of many alloys.
- Copper ions from copper-treated cooling tower wood will increase corrosiveness. Control by:
  - continuous addition of copper inhibitor, or
  - avoidance of copper-treated wood.
- Condensate is aggressive to cements and concrete.
  - use sulfate resistant cement, or
  - line with coal-tar epoxy or PVC, or
  - line with polymer concrete.

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Materials Concerns in Flashed Steam Geothermal Plants:

Facility Impacts

- Atmospheric hydrogen sulfide rapidly destroys copper and silver contacts, and zinc coatings.
  - All electrical contacts must be gold, tin, cadmium, chromium, or platinum plated.
  - Rubber covered copper wire is unsatisfactory.
  - Maintenance of sulfide-free clean rooms is not practical (Wairakei, The Geysers).
  - Instrument air supply must be filtered to remove hydrogen sulfide to protect copper instrument components.
  - Galvanizing is unsatisfactory for structures, fences.

- The plant atmosphere is very harsh for conventional painting practices. Italians have developed a painting practice with a 5 year life.

Materials Concerns in Geothermal Binary Plants:

Production System and Heat Exchanger

- Casing, downhole, and surface equipment should meet "sour service" standards to avoid sulfide stress cracking.

- Downhole pumps will be required in most systems.
  - Suitable bearing materials not identified
  - Suitable high temperature seals not identified

- Surface contact HX material should:
  - be resistant to oxygen intrusion,
  - be resistant to SCC and SSC, and
  - be resistant to pitting

- Insufficient DCHX experience to identify materials requirements.

Materials Concerns for Geothermal Binary Plants:

Secondary (Binary) Loop and Turbine

- Binary working fluid will contain corrosive geothermal species.
  - Carry-over of moisture and solids is inevitable in DCHX systems (LBL-500, APL).
  - Brine inleakage "fact of life" in surface contact systems (Magma).
- Two binary turbine failures investigated:
  - one due to inadequate design,
  - one due to foreign body ingestion or corrosive process.
- Binary components should be resistant to catastrophic failure modes in geothermal fluid.

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Materials Concerns for Geothermal Binary Plants:

Heat Rejection System

- Many binary plants will be forced to use cooled geothermal water for cooling tower make-up.
- Concentration, by evaporation, and aeration make this water extremely corrosive.
- Corrosion inhibition for carbon steel has been shown to be extremely costly (Raft River).
- Alternate materials are currently under investigation.
- Hydrogen sulfide emissions will cause Facility Impacts similar to Flashed Steam Plant.

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Geothermal Corrosion Engineering

- Component Failure Analysis
  - Failure analysis of failed geothermal components
  - Materials performance analysis of non-failed components
  - DOE funded with DOE consent

- Geothermal Materials Assessment
  - Site or project-specific review of geothermal chemistry, operating parameters, preliminary design, and material selection
  - Utilization of Radian's Geothermal Corrosion Data Base to assure the suitability of materials and design decisions from a corrosion engineering aspect

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HANDBOOK AND NEWSLETTER

- **Geothermal Materials Review**
  - Quarterly geothermal materials newsletter
  - Distributed free to subscribers
  - For subscription contact William Robnett, Radian Corporation

- **Materials Selection Guidelines For Geothermal Energy Utilization Systems** (January 1981)
  - Chemistry, corrosion experience from 46 resources in eight countries
  - Power generation and direct utilization
  - More than 100 geothermal environments
  - More than 250 materials (metals and non-metals)
  - Will be automatically sent to current Newsletter subscribers
  - Will be available from NTIS as DOE/RA/27026-1

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