AN ANALYSIS OF GEOTHERMAL ELECTRICAL POWER GENERATION AT BIG CREEK HOT SPRINGS LEMHI COUNTY, IDAHO

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CHAPTER 1

PRELIMINARY EVALUATION OF THE GEOTHERMAL POTENTIAL OF BIG CREEK HOT SPRINGS, LEMHI COUNTY, IDAHO

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ABSTRACT

The purpose of this study is to evaluate Big Creek Hot Springs as a source of electrical power for the Blackbird Cobalt Mine, approximately 13 miles south of the hot spring. This report includes an evaluation of the geothermal potential of Big Creek Hot Springs, a suggested exploration program and budget, an engineering feasibility study of power generation at Big Creek Hot Springs, an economic analysis of the modeled power generating system, and an appraisal of the institutional factors influencing development at Big Creek Hot Springs.

Big Creek Hot Springs is one of the hottest known geothermal systems in Idaho, with a surface temperature of 93°C (199°F). Geothermometer estimates of reservoir temperature range from 137°C (279°F) to 179°C (354° F). The hot springs occur at the intersection of northeast-trending Hot Springs Fault, and a northwest-trending physiographic feature. Detailed mapping is necessary in order to gain a thorough understanding of the structural controls and geothermal potential of the system. A reconnaissance examination of the area suggests that there may be potential for buried thermal anomalies along the entire strike length of Hot Springs Fault. The fluid production potential of Big Creek Hot Springs is unknown. Reservoir lithologies for the system are probably competent Precambrian metamorphic and metasedimentary rocks, capable of sustaining through-going fractures. The heat source for the Big Creek Hot Springs system is probably deep circulation of meteoric water along fractures.

The engineering feasibility study modeled an 11MWe advanced binary power plant. Assuming an average well flow rate of 400,000 lb/hr with an average fluid temperature of 300°F (149°C), the cost of power generation at Big Creek Hot Springs is 130 mill/kWh. The capital cost for the geothermal field, the power plant and transmission lines is $51,796,919. An economic analysis of this system suggests that if the mine uses 7MWe and the remaining 4MWe are sold to the Idaho Power Company at an avoided cost of 4.5¢ per KWh, the payback period for the original investment is 15 years, with an internal rate of return of 8.6%.

There are several institutional factors complicating development at Big Creek Hot Springs. The hot springs are on Forest Service land. A federal geothermal lease requiring approval from both the Forest Service and the Bureau of Land Management must be obtained. In addition, development of Big Creek Hot Springs must take into consideration the proximity of the River of No Return Wilderness Area.

INTRODUCTION AND ACKNOWLEDGEMENT

This analysis of the potential for the geothermal development at Big Creek Hot Springs is provided to Noranda Mining, Inc. under the auspices of the U.S. Department of Energy's User Assistance Program. The Earth Science Laboratory under DOE contract number DE-AC07-80ID12079 acted as coordinator for this project, and gratefully acknowledges the cooperation and participation of the Idaho Office of Energy and EG&G Idaho, Inc.

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Introduction

The geothermal potential of Big Creek Hot Springs is largely unknown and remains to be tested by geologic and geophysical investigations. However, the available data do allow some speculation as to the type of geothermal system present at Big Creek, and the temperature potential at depth. Exploration methods to assess the system are suggested in Chapter II of this report.

Regional Setting and Background Information

Big Creek Hot Springs (T. 23N, R. 18E, Sec 22, Lemhi County, Idaho) is the second hottest spring in Idaho. The location of this system is somewhat anomalous since most of the geothermal systems in Idaho are concentrated along the Snake River Plain. Likewise, many of the geothermal studies in Idaho have focused upon the Snake River Plain region; very little is known about most other systems in the state.

There is virtually no published information on Big Creek Hot Springs. Bennett's (1977) map of the Blackbird Mountain-Panther Creek area shows the hot spring and a northeast-trending fault, Hot Springs Fault, running through the system, (Figure 1), but does not discuss the geothermal potential of the area. Mitchell and others (in press) list chemical and geothermometry data for the system, note the presence of carbonate and siliceous deposits around active vents, and remark that the hot springs occur on the ridge top rather than along the base of the ridge as is the usual case in a fault-controlled system. Maley (1974) discusses the structure and petrology of the Panther Creek area, but does not deal specifically with Big Creek Hot Springs. Published gradient and heat flow maps for the state (Brott and others, 1976) show no thermal measurements for the Big Creek area. More recent investigations have not obtained data for this part of Idaho (Mitchell, verbal communication).

Reconnaissance Examination of Big Creek Hot Springs

A reconnaissance examination of Big Creek Hot Springs made on July 29, 1980, revealed that the hot spring system does not discharge along the top of a ridge as described by Mitchell and others (in press). Rather, the system consists of a linear set of spring vents trending N 40-45°W up-slope from the bed of the Hot Springs Creek. The system is apparently localized at the intersection of Hot Springs Fault and a N 40-45°W structure. The linear map of the area shown in Figure 3 (Bennett, 1977) reveals that the northeast trend of Hot Springs Fault, and a N 40-50°W orientation are dominant trends in the region. The intersection of these two structures might thus be a large-scale feature with sufficient fracture-controlled permeability to sustain a significant geothermal system.

There is potential for buried thermal anomalies along the entire strike length of Hot Springs Fault. Hot water may circulate in a significant portion of Hot Springs Fault but may only reach the surface along the limited area of intersecting northeast- and northwest-trending structures. Elsewhere along Hot Springs Fault, mineral deposition may have sealed shut any available fluid channelways, the geothermal fluids may lack sufficient hydraulic head to reach the surface, or channels to the surface, in the form of fault intersections, may be lacking.

An examination of the hot spring deposits confirms the report by Mitchell and others (in press) that both travertine and siliceous sinter are forming at Big Creek Hot Springs. Limited amounts of siliceous sinter were identified as recently formed deposits along some of the upper vents. The dominant hot spring deposit is, however, travertine.

Several cold water seeps were observed immediately adjacent to some of the hot spring vents. This suggests that the geothermal fluids are mixing with cold groundwater at very shallow levels. The United States Geological Survey, Water Resource Division (Boise, Idaho) recently collected both hot and cold water samples from active vents at Big Creek (Robert Lewis, verbal communication). The Earth Science Laboratory is presently trying to obtain these data from the USGS for geochemical modeling.

Heat Source for the Big Creek Hot Springs Geothermal System

There are two models of hydrothermal geothermal systems commonly used to describe geothermal systems in the western United States. The first type is the magma-driven system in which a magma body or a very young intrusive mass acts as the geothermal heat source. Magma-driven systems are restricted to areas of recent (generally less than one million years old) volcanism, and are characterized by very high reservoir temperatures. The Geysers field north of San Francisco, portions of the Imperial Valley geothermal district in southern California, and the Roosevelt Hot Springs system in southwestern Utah are examples of geothermal systems with magmatic heat sources. The lack of recent igneous activity in the Big Creek area suggests that a magmatic heat source for this system is extremely unlikely.

The second type of system is the fault-controlled variety in which cold, meteoric water seeps downward, is heated by conduction of heat due to the local geothermal gradient, and rises along faults where it may be exposed at the surface as a hot spring, geyser or fumarole. The temperature attained by fluids in a fault-controlled system depends upon the depth of fluid circulation and the local geothermal gradient.

Most of the geothermal systems in the western United States are fault-controlled. The traditional setting for a fault-controlled geothermal system is the Basin and Range Province, where thermal features commonly occur along range-front faults. Figure 2 is a schematic illustration of a basin and range, fault-controlled system. (It should be added that fluid circulation in fault zones is also important in geothermal systems with magmatic heat sources).

Although Big Creek Hot Springs is not in a traditional basin and range setting, the coincidence of Hot Springs Fault with the geothermal system (Bennett, 1977) strongly suggests that the Big Creek system is fault-controlled.

Geothermometer Data for the Big Creek Hot Springs Geothermal System

The geothermometer estimates of base reservoir temperature for Big Creek Hot Springs range from 137°C (chalcedony conductive geothermometer) to 179°C (Na-K-Ca geothermometer). Table 1 summarizes the geothermometry data for the system.

Table 1. Geothermometry Estimates of Base Reservoir Temperature for Big Creek Hot Springs, Idaho.

Geothermometer	Mitchell and others (in press)	Muffler (1979)
Quartz Conductive	161°C	157°C
Quartz Adiabatic	152°C	149°C
Chalcedony Conductive	137°C	N.A.
Na-K-Ca	173°C	179°C

Muffler (1979) reports that the most likely geothermometer estimate of reservoir temperature is 157°C.

The various geothermometers listed in Table 1 are applicable in different geologic circumstances. As a rule, the chalcedony geothermometer is best applied in systems with reservoir temperatures of less than 100°C, although it may be useful in some situations with temperatures as high as 150°C (Fournier, 1972). The quartz conductive geothermometer assumes no steam loss due to boiling and is probably the best geothermometer for the Big Creek system. In contrast, the quartz adiabatic geothermometer assumes maximum steam loss. The Na-K-Ca geothermometer is useful in many situations in which equilibrium with feldspars has been attained, and in which no calcium has been lost due to precipitation of $CaCO_3$. The significant travertine deposits at Big Creek suggest that the Na-K-Ca geothemometer estimate is probably too high due to loss of calcium.

Geothermometers are a valuable tool in predicting reservoir temperature conditions provided that the following assumptions are met (Fournier and others, 1974):

1. Temperature-dependent reactions at depth control the concentration of the constituents used in the geothermometer.

2. The reservoir contains an adequate supply of the reactants.

3. Water-rock equilibrium is established in the reservoir.

4. The constituents used in the geothermometer do not reequilibrate with the confining rock as the water flows to the surface.

5. Mixing of thermal and nonthermal groundwater does not occure.

A comparison of geothermometer values with measured downhole temperatures for numerous systems in the Basin and Range (primarily southwestern Utah and northern Nevada), suggests that geothermometers provide a reliable estimate of reservoir temperature. In general, the geothermometer-predicted temperatures come within 20°C of measured downhole temperatures (unpublished Earth Science Laboratory report).

Application of mixing model geothermometers may be necessary at Big Creek Hot Springs since the presence of cold water springs adjacent to the hot water vents strongly suggests that geothermal fluids are mixing with cold, shallow groundwater prior to surface discharge. Mitchell and others (in press) report a quartz conductive (no steam loss) mixing model temperature of 173°C and a quartz adiabatic (maximum steam loss) temperature of 163°C. As noted above, the USGS has recently collected cold and hot water samples from Big Creek Hot

Springs. The Earth Science Laboratory will model these data when they become available.

The presence of siliceous sinter at Big Creek Hot Springs may suggest that waters at depth attain a temperature of at least 180°C, since sinter deposits are commonly assoicated with geothermal systems hotter than 180°C. However, the deposition of siliceous sinter should only be used as a qualitative geothermometer and does not guarantee reservoir temperatures in excess of 180°C.

Temperatures at Depth in the Big Creek Hot Springs Geothermal System

The geothermometers for the Big Creek Hot Springs System provide estimates of reservoir temperature conditions. It must be stressed, however, that geothermometers do not predict temperature at a given depth. In some systems the predicted reservoir temperature may only exist at great depth, beyond the economic limits of a drill hole. Thus, the geothermometry data do not permit estimation of the depth at which 157°C fluids might be found in the Big Creek geothermal system. On the other hand, projection of the geothermal gradient to depth does give a maximum depth at which a predicted target temperature might exist. Since there are no gradient data available for the Big Creek area, an average normal geothermal gradient of 35°C/km will be assumed. (Future thermal gradient measurements might reveal a higher gradient.) In order to attain a target temperature of 157°C (the most likely geothermometry estimate), meteoric fluids in the Big Creek geothermal system must circulate to a depth of 4.48 km (14,718 ft.) provided that conduction of heat due to the geothermal gradient is the only heat transfer mechanism.

Assuming that Big Creek Hot Springs is a fault-controlled geothermal system, 157°C water may be present at much shallower depths due to upward circulation of geothermal fluids along Hot Springs Fault, and the attendent upward-bowing of isotherms along the faults as illustrated in Figure 2. It should be noted that fault-controlled geothermal systems are commonly characterized by isothermal zones at depth along the fault. In these isothermal zones, temperature remains relatively constant with depth. Thus for the hypothetical system shown in Figure 2, moderate-temperature (250°F) water is obtainable at a relatively shallow depth along the fault zone. However, the 250°F isotherm persists to considerable depth. Relatively deep wells are required to intersect the 300°F isotherm along the fault, thereby reaching the target temperature as predicted by the geothermometers. Much greater drilling depths would be required to intersect the 300°F isotherm outside of the fault zone.

Flow Potential of the Big Creek Hot Springs Geothermal System

Unfortunately there are no techniques other than drilling and flow testing that estimate the fluid flow potential of a geothermal system. Moreover, there is no guarantee or way to predict that fluids will be available at the depth required to reach a target temperature. As such, the production characteristics of systems for which no pre-existing drilling and flow-testing data are available represent the largest unknown and risk-laden factor in geothermal exploration. Even in producing geothermal systems, the production potential of individual wells within one geothermal field can be quite variable due to the quality of the site drilled (dry holes exist in operating fields), and the drilling and completion techniques employed.

The permeability in most fault-controlled geothermal systems is commonly limited to fracture zones and fracture intersections. Thus, fault zones and fault intersections are usually the primary drilling targets. The reservoir rocks for the Big Creek geothermal system are probably Precambrian metamorphic and metasedimentary rocks. Exploration drilling in these units in the nearby Blackbird Mining District reveals considerable fracturing at depth (G. Hahn, verbal communication). This offers some encouragement that considerable fault-induced permeability may exist.

Additional Available Information

Lineament Study

Figure 3 is a modification of Bennett's (1977) linear map for the Blackbird Mountain-Panther Creek area. The northeast-trending linear labelled "Hot Spring" corresponds to a portion of Hot Springs Fault. This feature parallels the Salmon, Clear Creek and numerous other NE-trending linears. The prevalence of northeast-trending lineaments suggests that a northeast orientation may reflect a regional structural grain. The N 40-45^{o} W orientation of the hot spring vents at Big Creek Hot Springs also corresponds to a dominant structural trend in the region. The intersection of the northeast and northwest trends may have regional tectonic significance and may be deep-seated structures which might permit fluid circulation to great depths.

Aeromagnetic Data

Bennett (1977) also includes an aeromagnetic survey as a portion of the Blackbird Mountain-Panther Creek study. Figure 4, the aeromagnetic map for the area, shows a northeast-trending 170 to 200 gamma trough coincident with Hot Springs Fault and Big Creek Hot Springs. Bennett (1977) models this low as expressions of the augen gneiss unit. However, in the vicinity of Big Creek Hot Springs, the aeromagnetic low could also correspond to a zone of hydrothermally altered rock, marking the course of paleo- and/or recent geothermal fluids. This trough could also be due to topographic effects.

Summary

The Big Creek Hot Springs geothermal system appears to be an excellent geothermal prospect. The geothermal potential of the prospect is, however, presently unmeasured.

The geothermometers for the system suggest that the most likely maximum reservoir temperature is 157°C. The presence of siliceous deposits around the hot spring and the application of mixing model geothermometers may indicate a higher temperature resource.

The Big Creek Hot Springs geothermal system is apparently controlled by the intersection of northeast- and northwest-trending structures. A larger geothermal system may be at depth along the trend of Hot Springs Fault.

Big Creek Hot Springs is in an anomalous setting, removed from most of the geothermal systems in the state of Idaho. However, the presence of Owl Creek Hot Springs (T. 23N, R. 17E, Sec. 10), approximately 6.5 miles west-northwest of the Big Creek system suggests that this area may be a geothermal district, and may hold considerable geothermal resource potential.

CHAPTER 2

SUGGESTED GEOTHERMAL EXPLORATION STRATEGY FOR BIG CREEK HOT SPRINGS

by

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Introduction

The geothermal exploration program proposed herein for Big Creek Hot Springs is based upon a geothermal exploration strategy developed by Ward and others (1979) for the Basin and Range. Each step of the suggested exploration strategy is discussed briefly in this report; Ward and others (1979) should be consulted for further clarification. Where applicable, comments pertaining specifically to exploration at Big Creek Hot Springs have been included. Since Big Creek Hot Springs is not in a traditional Basin and Range setting, the proposed exploration strategy should be modified as necessary once additional geologic data for the Big Creek Hot Springs geothermal system become available. In particular, the selection of appropriate geophysical methods should be based upon the results of geologic studies in the area. The differences in geologic setting, lithologies present and topography between Big Creek Hot Springs and the average Basin and Range geothermal prospect may eliminate the usefulness of some standard geophysical exploration tools.

Table 1. Suggested Geothermal Exploration Strategy for Big Creek Hot Springs (modified after Ward and others, 1979)

	ACTIVITY	ESTIMATED COST
1)	Thermal Gradient Measurements - Existing Holes	$ 30 K
2)	Prospect Mapping (1:24,000)	15 K
3a)	Shallow Gradient Hole Drilling (20 to 30 holes)	100 K
	Temperature Logging	10 K
	Down-hole lithologic, mineralogic, alteration studies	5 K
	Down-hole fluid and solid geochemical studies	10 K
3b)	Dipole-dipole Resistivity Survey	30 K
4)	Prospect Evaluation - Target Modeling I	10 K
5)	Color Photos / Base Maps	10 K
6)	Detailed Prospect Mapping (1:6,000)	20 K
7)	Prospect Evaluation - Target Modeling II	10 K
8)	Deep Thermal Gradient Hole Drilling (3 holes)	240 K
	Geophysical logging	10 K
	Down-hole lithologic, mineralogic, alteration studies	30 K
	Hydrologic and Down-hole fluid and solid geochemical studies	15 K
9)	Prospect Evaluation - Target Modeling III	20 K
10)	Production Test Drilling and Brief Flow Testing (3 holes)	3750 K
	Geophysical Logging	20 K

Down-hole lithologic, mineralogic, and alteration studies	20 K
Hydrologic and down-hole geochemical studies	15 K
11) Prospect Evaluation - Target Modeling IV	40 K
	$ 4,410,000

DISCUSSION OF SUGGESTED EXPLORATION STRATEGY

1) Thermal Gradient Measurements - Existing Holes

Temperature gradients should be measured in any available, nearby water wells, oil and gas wells and mineral exploration holes. This is a relatively inexpensive way to obtain information on the regional background geothermal gradient, to collect hydrologic data and to highlight any thermal anomalies. This could be very important for the Big Creek goethermal system since the local gradient is unknown. The nearest published gradient and heat flow data (Brott and others, 1976) are about 65 miles south of Big Creek. If any drill holes are available in the Blackbird Mining District or elsewhere nearby, the Earth Science Laboratory might be able to arrange for temperature gradient and heat flow measurements.

2) Prospect Mapping

Prospect mapping at a scale of approximately 1:24,000 should be undertaken at an early stage to aid in siting the shallow thermal gradient holes, to identify possible structural controls for hot water circulation, to help plan geophysical surveys, and to develop preliminary conceptual models of the geothermal resource.

At Big Creek Hot Springs the specific goal of prospect mapping should be defining the nature of Hot Springs Fault (Bennett, 1977, Maley, 1974) and determining the role that this fault plays in controlling the geothermal system. To the extent possible, surface mapping should identify the orientation of this fault, ascertain whether the fault is permeable, and collect other pertinent structural data.

3a) Shallow Temperature Gradient Drilling

Shallow temperature gradient drilling is perhaps the most fundamental aspect of a geothermal exploration program since it provides the primary quantitative data indicating the presence or absence of a geothermal anomaly at depth. It is common to drill 20 to 30 shallow, 50 m to 160 m (160 ft. to 525 ft.) holes on a grid covering about 10 square miles (16 km^2). The objective of thermal gradient drilling is to obtain conductive thermal gradient measurements. Thus, the majority of these holes should not be drilled into geothermal fluid-bearing structures in which convective, isothermal gradients would be obtained. Cuttings should be retrieved for geochemical and lithologic analyses. Any available down-hole fluids should also be sampled for geochemical studies. In addition to measuring the thermal gradient, it may be useful to make heat flow determinations for some or all of the holes. This will require laboratory measurements of the thermal conductivity of drill cuttings. Any obtainable hydrologic data, such as depth to the water table, should be noted. The rugged topography and poor road access in the Big Creek Hot Springs area may limit the practical number of shallow gradient holes.

3b) Dipole-dipole Electrical Resistivity Survey

A dipole-dipole electrical resistivity survey is commonly used in geothermal exploration to identify buried high-angle structures such as faults. In some geothermal resource areas, low resistivity zones correspond to warm water structures and/or zones of hydrothermally altered rock. At Big

Creek Hot Srings, a resistivity survey may aid in mapping the areal extent of fluid-bearing units. It may be desirable to perform a resistivity survey concurrent with the shallow gradient drilling program. The results of the resistivity survey could then be used to guide the selection of additional thermal gradient hole sites.

4) Prospect Evaluation - Target Modeling I

Following the completion of the shallow thermal gradient drilling and the resistivity survey, all the available data should be integrated and evaluated, and a more precise target model should be defined. At this point the data should indicate whether the prospect merits additional exploration work.

5) Color Photos / Base Maps

In areas with poor base maps and aerial photography, it may be necessary to obtain low-altitude color aerial photography.

6) Detailed Prospect Mapping

It may be desirable to map portions of the prospect area in greater detail than 1:24,000 in order to identify the structural controls for the system.

7) Prospect Evaluation - Target Modeling II

Any detailed mapping data should be integrated with all other available data. The conceptual target model should be refined, and sites for the deep thermal gradient drill holes selected.

8) Deep Thermal Gradient Drilling

Approximately 3 holes ranging in depth from 500 m to 800 m (1640 ft. to 2625 ft.) should be drilled to evaluate the thermal regime at greater depths, and to test the viability of the target concept. The average cost for each hole, including logging, is about $80,000. In addition to a temperature log, a minimum of resistivity, SP and gamma logs should be obtained. Hydrologic data should be collected. Cuttings should be retrieved for lithologic and geochemical studies. Lithologic logging should be correlated with surface structural mapping, and cross sections incorporating all available data should be drawn. Information obtained during drilling should also be used in hydrologic studies of fluid recharge for the system and potential production characteristics (porosity and permeability) of the reservoir.

9) Prospect Evaluation - Target Modeling III

The target concept should again be refined, integrating all data with the results of the deep thermal gradient drilling. Drill sites for deep production test drilling should be selected.

10) Production Test Drilling and Brief Flow Test

Approximately three production test wells should be drilled, logged and flow tested. The depth of geothermal production wells varies from system to system, but averages 1525 m (5000 ft.). Based on the data presently available for the Big Creek geothermal system, 1525 m (5000 ft.) is a reasonable target depth at which fluids of about 300°F might be encountered (see Chapter I). The average cost for drilling, logging and briefly testing a 1525 m deep well is about $1,250,000. (See Appendix I, Geothermal Production Well Drilling Costs). As outlined in Step 8, lithologic and geochemical studies should be performed on cuttings and fluids obtained from the hole. Hydrologic models should be refined using data gathered during drilling, logging, and testing.

11) Prospect Evaluation - Target Modeling IV

A conceptual model of the geothermal reservoir should be built using all available data. The production potential of the reservoir should now be assessed and tested, if warranted, with long-term flow testing and reservoir engineering.

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APPENDIX I. GEOTHERMAL PRODUCTION WELL DRILLING COSTS

Summary

Well cost data from a total of 32 geothermal wells were gathered, escalated to a common chronological base of January 1980 and plotted in Figure B-1. A least squares data regression analysis was run on these data points to get the representative cost functions for both hard and soft rock drilling. These functions are also plotted on Figure B-1.

Discussion

Data sources for this compilation were 15 wells from applications for Geothermal Loan Guaranties (proprietary data), 6 wells from the industry coupled drilling program, 6 wells from the PON program, 4 Raft River wells (those which were drilled under relatively normal conditions) and the INEL deep well. The costs of these wells were escalated to January 1980 at the rate of 20% per year, a rate which is consistent with both INEL experience and that of Republic Geothermal (private communication with Tom Cook, RGI) over the last 4 years. Drilling was characterized by the rock formations encountered as being hard rock, soft rock or alluvial, or intermediate.

The deep well costs provided include all costs of drilling and completion including short term productivity testing, but exclude wellhead equipment, which has been included as part of the field surface equipment capital cost of Attachment A.

As an aid to the use of this data, functions were developed for both hard and soft rock drilling using a least squares data regression. Data points for intermediate toughness rock was factored into both hard rock and soft rock drilling functions with a 50% weight factor. Four different equation forms were used in this data regression analysis. Power functions had the highest coefficients of determination for both hard rock and soft rock drilling (.75 and .68 respectively) and were selected as representative for both cases. The resulting functions for drilling costs are given below.

Hard Rock:

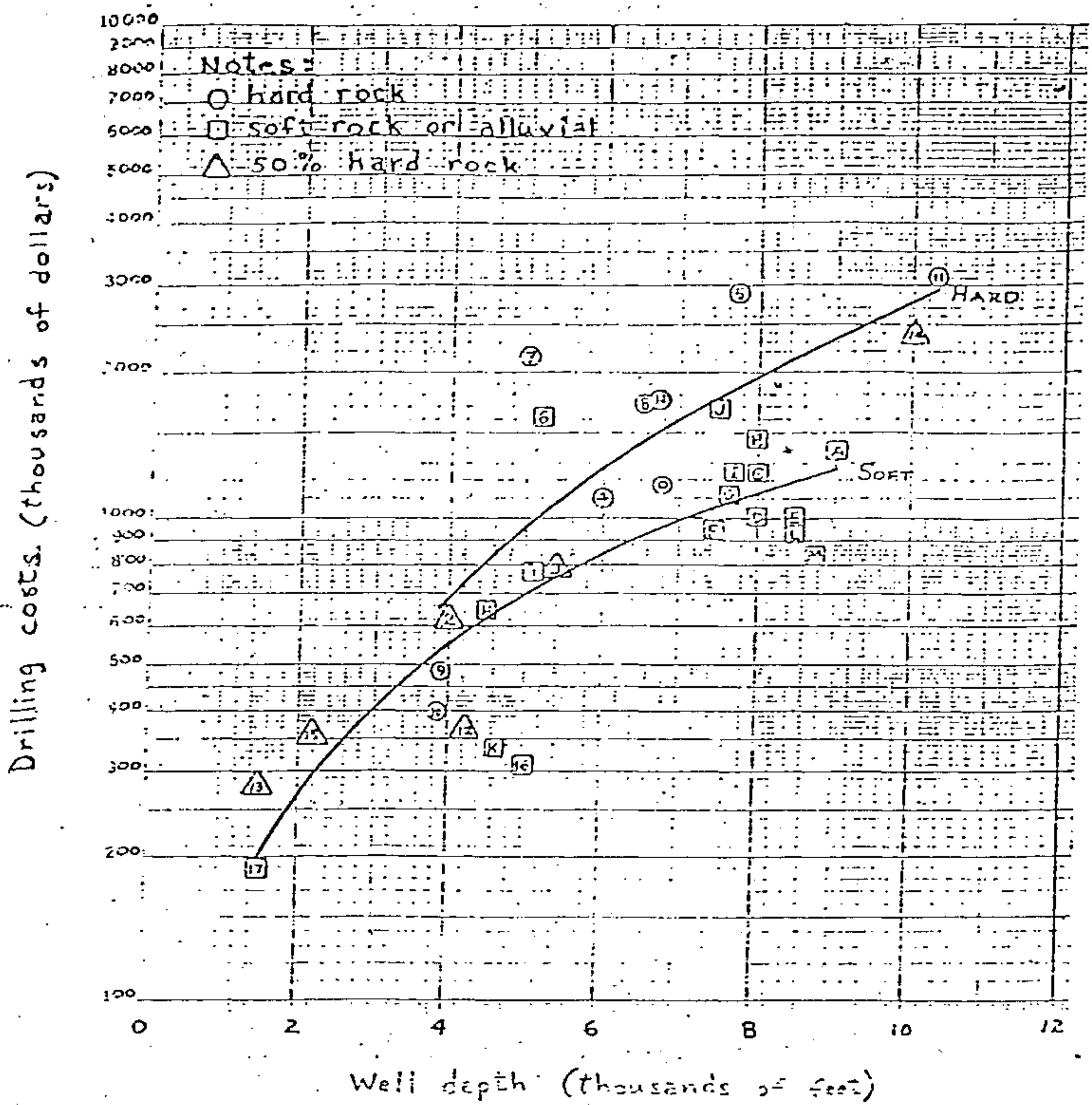
$$\text{Cost} = 2.887\ (\text{depth})^{1.496}$$

Soft Rock:

$$\text{Cost} = 102.8\ (\text{depth})^{1.035}$$

where the depth is in feet and the cost is in January 1980 dollars.

FIG. B-1 Well Costs (Jan. 1980)



SOFT: $COST = 102.3\,(DEPTH)^{1.035}$

HARD: $COST = 2.887\,(DEPTH)^{1.435}$

GEOTHERMAL WELL DRILLING ESTIMATES BASED ON PAST WELL COSTS

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ABSTRACT

Well costs vary roughly exponentially with well depth. Plots indicating this have been made using data from nineteen geothermal wells of varying depths. These plots indicate both the average costs to drill wells and the costs to drill wells without problems. Average well costs are above estimates based on the assumption that the well proceeds according to plan. The average costs should be considered for planning programs in which large numbers of wells are involved. Estimates based on the assumption that the well can be drilled according to plan may be used for planning programs involving one or two wells, but the average costs should be considered in contingency planning.

INTRODUCTION

This is an attempt to look at well construction costs statistically, using actual costs of completed geothermal wells as the basis. The data base consists of nineteen wells drilled as part of the Department of Energy geothermal programs managed by the DOE Idaho and Nevada Operations Offices. Eight of the wells were completed at Raft River, seven were completed under the DOE Industry Coupled Program, three were completed under the Project Applications Program, and one was completed at the Idaho National Engineering Laboratory site near the eastern end of the Snake River Plain. There are a variety of well types, geological environments, depths and bore hole sizes represented, and although this is a small sample, trends can nevertheless be seen.

The objectives of this study are to provide general guidance for the geothermal well field developers, public or private individuals or groups considering the geothermal option, proposal writers or evaluators, and geothermal policy makers. Of course, when estimating the cost of a particular well, one should list the tasks to be done and the material to be purchased, estimate the cost of each and aggregate, so that the peculiarities of the site, anticipated production, and other variables can be taken into account. Data presented here should be used only as a general guide although there is one other important use. Aggregated estimates like the one just described are usually valid only if things proceed according to plan. Some have said that actual well costs often depend on two aspects of well drilling which are not quantifiable: the luck of the driller and the determination of the operator. Looking at past experience, which is the approach taken here, at least gives one some idea as to the levels these two unquantifiables have pushed past drilling costs.

DRILLING COSTS VS. DEPTH

Drilling costs versus depth are shown in figure 1. NOTE: The vertical scale is logarithmic. Logarithmic plots tend to create the illusion that little scatter of the data exists when in fact there is a considerable scatter. However, the logarithmic scale was used because of the general exponential trend of the data and to facilitate a linear regression analysis.

The mean regression line shown in figure 1 is not representative of costs which would result from an aggregated estimate obtained by listing tasks and materials, estimating their costs and aggregating. These estimated well costs are approximated by the heavy dashed line at the bottom. The mean line simply represents the average real costs of the nineteen wells in the sample, and this in turn is a strong function of the problems encountered and the determination of the owners to complete the wells. Note that aggregated estimate approximated by the dashed line is below all the well costs. This may at first seem irregular until one considers that this type of estimate is almost always optimistic because, by nature of the estimating procedure, only predictable tasks and material purchases are considered, and contingencies are not included.

Wells indicated by the circular symbols and the diamond symbol were paid for entirely by DOE; wells indicated by the square symbols were funded mostly by DOE and partly by private or local public entities. Wells indicated by the triangular symbols were paid for mostly by private concerns, most of whom have an oil background. Referring to figure 1 with this in mind, it is interesting to note that public or private ownership of the well had little to do with costs.

Note that the determination of the operators to complete three of the wells in spite of adverse drilling conditions resulted in anomalously high costs. In fact, they are so far above the mean that a statistician would consider them "outliers" and discard them. This was done, and figure 2 shows the effect of this action. Note that the mean lowered noticably. Also note that one well was considerably lower in cost then the others. This was due partly to this well being an injection well and partly to lack of problems encountered. This well was also eliminated as an "outlier". Without these four "outliers the standard deviation was lowered as shown in figures 1 and 2.

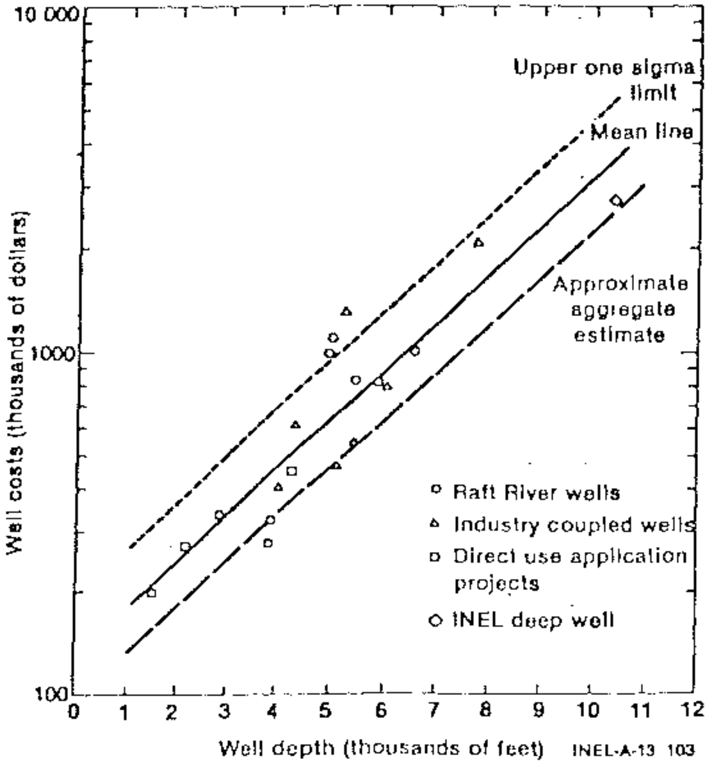

Figure 1 Well costs versus depth. All data included. Corrected to 1978 prices.

Figures 1 and 2 can be useful to various interests but in different ways. Policy makers interested in predicting costs for projects involving large numbers of wells will probably get best results by using the mean from Figure 2. Whereas, a developer contemplating one or two wells may wish to use the heavy dashed line, but consider the mean or the standard deviation coupled with information on expected drilling conditions in deciding on appropriate contingencies or for planning alternatives because once drilling has started, decisions must be made quickly.

DATA BASE DESCRIPTION

Table I shows well costs on which this paper was based. All well costs are for completed wells including the well head, special completion techniques such as acidizing, logging and all problem solving operations such as fishing, directional drilling, etc. Any flow testing which occurred after removing the drill rig was not included.

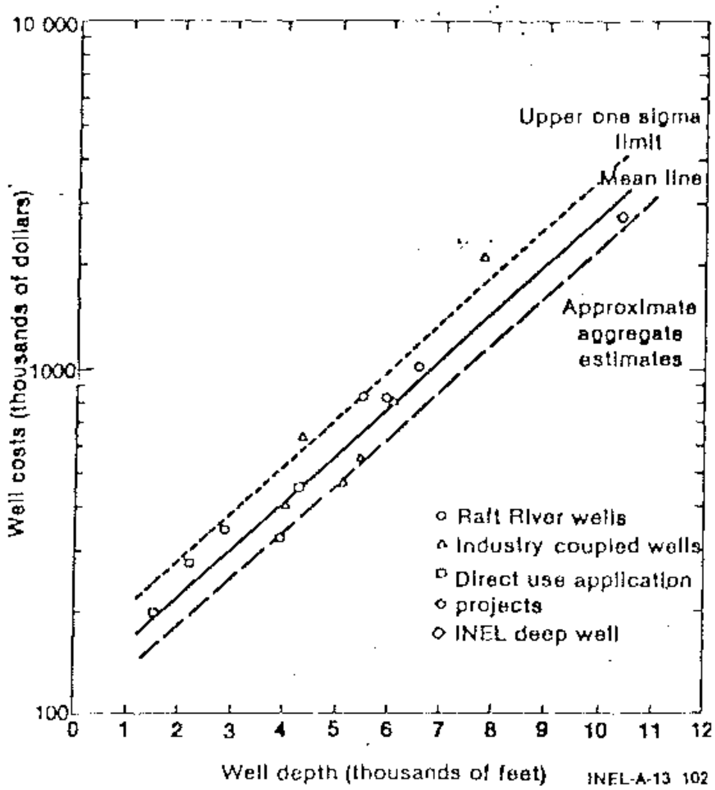

Figure 2 Well costs versus depth. "Outliers" excluded. Corrected to 1978 prices.

Two of the Raft River wells were multilegged wells. The depth on these wells could have been determined by adding all the legs together. However, the decision was made (somewhat arbitrarily) to use the depth of the deepest leg as the well depth.

Cost breakdowns were available for some of the wells. See table II. Unfortunately the breakdowns were not all made using uniform procedures, so there are some blanks and interpretations are difficult. Breakdowns are available for all three of the "outliers" which were omitted from figure 2 for excessive cost. They are Raft River #1, Raft River #5 and Industry Coupled #7. Unfortunately a breakdown was not available for the low "outlier," Raft River #7. Industry Coupled #6 was not discarded as an "outlier," but was, nevertheless, an expensive well.

The unusually high costs for Industry Coupled #6 and #7 were in drilling fluids, cementing and added rig time due to loss of circulation and caving to porous formations. This also occurred in INEL #1 but to a much lesser degree. Raft River #1 and #2 were high in drilling and miscellaneous costs. Raft River #1 experienced a collapsed casing and Raft River #2 was drilled 500 feet into hard basement rock for geological research.

TABLE I TOTAL WELL COSTS
(Corrected to 1978 Prices)

Description	Year Drilled	Depth (feet)	Casing Diameter (inches)/Depth (feet)	Cost (1000's)	Inflation Factor	Costs Corrected to 1978 (1000's)
Raft River #1	75	5007	13-3/8 to 3634	810	1.38	1,118
Raft River #2	76	6561	13-3/8 to 4227	800	1.26	1,008
Raft River #3	76	*5917 *5532 *5853	13-3/8 to 1385: 9-5/8 to 4255	662	1.26	834
Raft River #4A	77	2840	13-3/8 to 1820	305	1.12	342
Raft River #4B	78	*5427 *5115	13-3/8 to 1820: 9-5/8 to 3457	830	----	----
Raft River #5	78	4925	13-3/8 to 1500: 9-5/8 to 3408	995	----	----
Raft River #6	78	3888	13-3/8 to 1698	325	----	----
Raft River #7	78	3858	13-3/8 to 2044	275	----	----
Industry Coupled #1	74	4300		385	1.63	628
Industry Coupled #2	76	5100		370	1.26	466
Industry Coupled #3	75	4000		290	1.38	400
Industry Coupled #4	78	5400		550	----	----
Industry Coupled #5	78	6000	Bore diameter at surface was	800	----	----
Industry Coupled #6	78	7735	17-1/2 inches narrowing to	2,079	----	----
Industry Coupled #7	78	5200	8-3/4 inches at target depth.	1,232	----	----
Project Applications #1	79	1500	16 to 700: 7-7/8 to 1300	214	.93	199
Project Applications #2	79	2176	10-3/4 to 800: 7, 500 to 2176 (perphorated)	296	.93	275
Project Applications #3	78	4266	10-3/4 to 1000: 7-5/8 to 3722: 5 to 3900	452	----	----
INEL #1	79	10356	13-3/8 to 3359: 9-3/8 to 6796	2,960	.93	2,753

* Multilegged wells.

TABLE II COST BREAK DOWN
(Not Corrected to 1978 Prices)

Well Identification	Project Applications #2	Industry Coupled #6	Industry Coupled #7	Raft River #1	Raft River #3	Raft River #5	INEL #1
Well Depth	2176	7735	5200	5007	5917	4925	10356
Item Description							
Location Preparation	491	67,044	81,888	16,600	14,300	11,400	227,800
Mobilization and Demolilization	36,000	----	----	37,700	45,700	9,000	350,000
Drilling	72,910	687,131	404,201	319,600	185,400	418,800	749,750
Drill Bits	6,938	107,755	46,400	23,200	59,100	35,200	70,592
Drilling Fluid	26,958	181,643	104,149	3,500	4,000	----	92,710
Cementing	28,904	554,149	329,066	95,000	74,800	52,500	252,301
Equipment Rentals	5,208	111,321	70,467	56,900	69,900	72,700	89,168
Transportation	----	102,635	70,363	9,300	----	----	1,810
Supervision	26,260	36,400	24,600	In Drilling Cost	In Drilling Cost	21,900	71,400
Logging	12,510	----	----	58,200	58,000	123,000	51,330
Casing	23,435	159,481	72,780	91,400	83,600	45,700	339,585
Well Head	15,664	25,878	12,466	41,000	37,000	44,000	74,304
Miscellaneous	40,984	45,964	15,270	57,600	30,400	160,500	589,544
TOTAL	296,262	2,079,401	1,232,150	810,000	662,200	994,700	2,960,294

CHAPTER 3

PRELININARY EVALUATION OF AN ADVANCED BINARY POWER PLANT FOR BIG CREEK HOT SPRING

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INTRODUCTION

The INEL has performed an engineering and economic feasibility study of the electric power generating potential of the Big Creek Hot Springs geothermal system in Lemhi County, Idaho. This study has been performed in cooperation with the University of Utah Research Institute (UURI) through the Technical Assistance Program. A plant size of 11 MWe net was considered with the power to be used by the nearby Blackbird Cobalt Mine and the town of Cobalt, Idaho. An advanced binary power generation cycle was determined to be the most efficient for this resource. Costs presented in this report are in second-quarter 1980 dollars.

SUMMARY

This preliminary evaluation of the Big Creek Hot Springs geothermal system is based upon electric power generation using an advanced binary cycle. Cycle optimization studies show a mixture of propane (95%) and hexane (5%) to be an effective working fluid for this plant. Due to the terrain in this area, this report proposes locating the power plant adjacent to Panther Creek where the geothermal fluid would be piped from the Big Creek Hot Springs area. Power would then be transmitted along Panther Creek approximately 13 miles to where it would tie into the Idaho power grid which supplies power to the Blackbird Mine and the town of Cobalt. This evaluation also assumes that by the use of directional drilling, multiple geothermal wells can be located on the same well pad.

Cost estimates were made for average well flow rates of 200,000 lb/hr and 400,000 lb/hr with an average resource temperature of 300°F (149°C). The results show that the cost of power at the lower flow rate would be about 160.2 mill/kWh and 122.2 mill/kWh at the higher flow rate. If a well life of 15 years is assumed, these costs would be increased by 15.5 mill/kWh and 8.6 mill/kWh respectively to cover the cost of replacement wells.

DISCUSSION

A. General

This report presents a preliminary engineering and economic study performed by the INEL for a geothermal power plant located at the Big Creek Hot Springs geothermal system in Lemhi County, Idaho. The proposed plant will produce 11 megawatts (net) of electricity which will be used to power operations at the Blackbird Cobalt Mine and supply additional power to the Town of Cobalt, Idaho.

B. Power Plant Performance

The resource temperature at Big Creek Hot Springs has been estimated to be approximately 300°F (149°C) by UURI. This temperature was arrived at by using a quartz conductive geothermometer. As shown in Figure 1, the net brine effectiveness (net power output per unit brine flow) at the anticipated temperature range of this resource is significantly higher for conventional binary systems than for dual flash steam systems. By utilizing mixtures of working fluids, an advanced binary cycle has been developed which has a net brine effectiveness approximately 40% greater than the conventional binary cycle at this resource temperature. This fluid is a mixture of propane (95%) and hexane (5%) and was selected as an optimum working fluid for the design temperature of the plant with the aid of the INEL computer code THERPP. Figure 2 is a pressure-enthalpy diagram of the working fluid cycle complete with the vapor dome for this mixture.

Figure 3 is a simplified power plant system diagram showing flow rates, temperatures, pressures and enthalpies for the geothermal fluid, working fluid, and cooling water. These parameters were used to evaluate the heater and condenser loads.

The heaters utilized for this system are of counterflow design with a heat transfer area of approximately 140,000 square feet. To minimize the physical size of these heaters, finned tubes were used. Three heaters 8 feet in diameter and 70 feet long will be required to meet the heat load requirements.

FIGURE 1

Net Brine Effectiveness

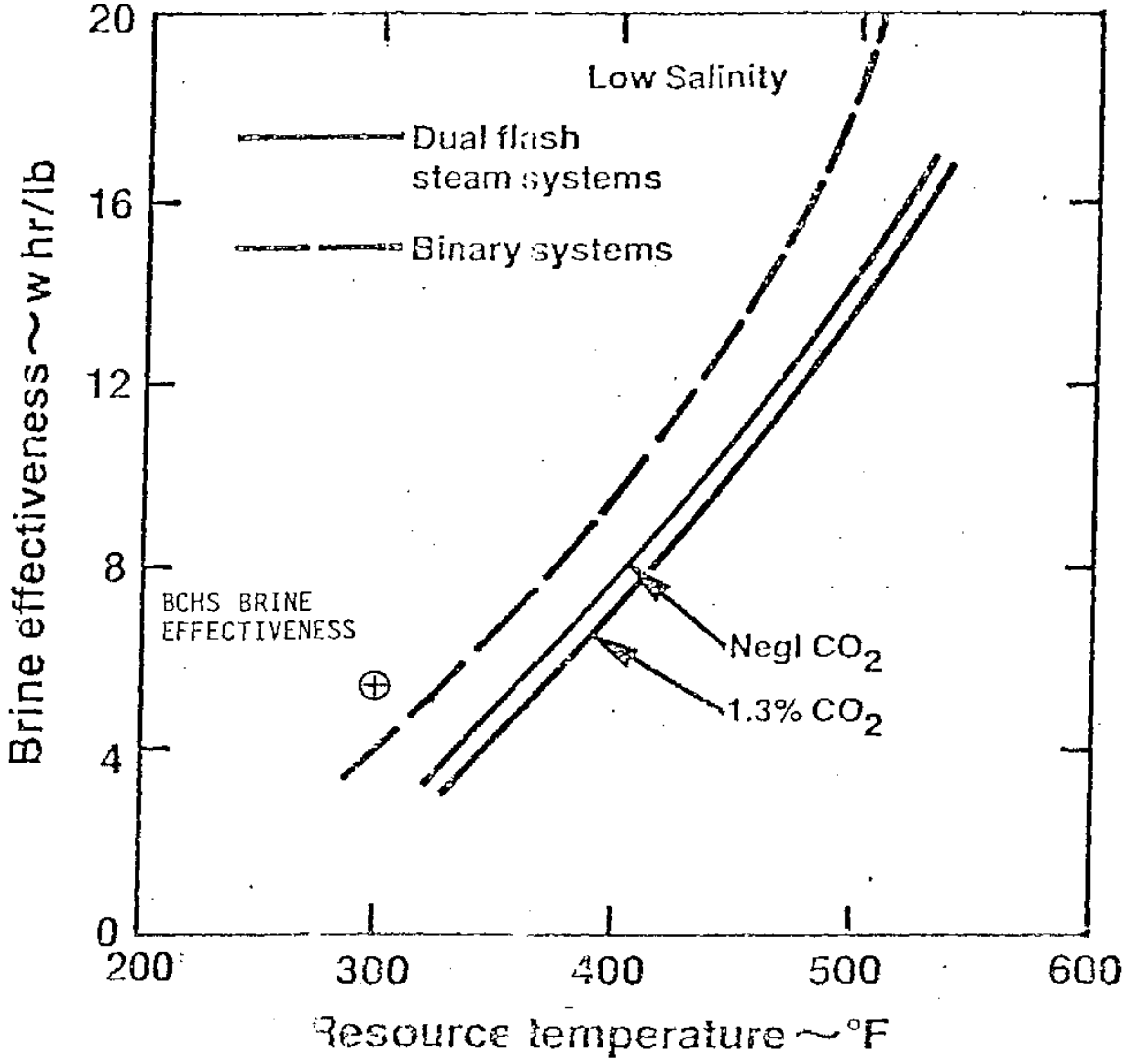

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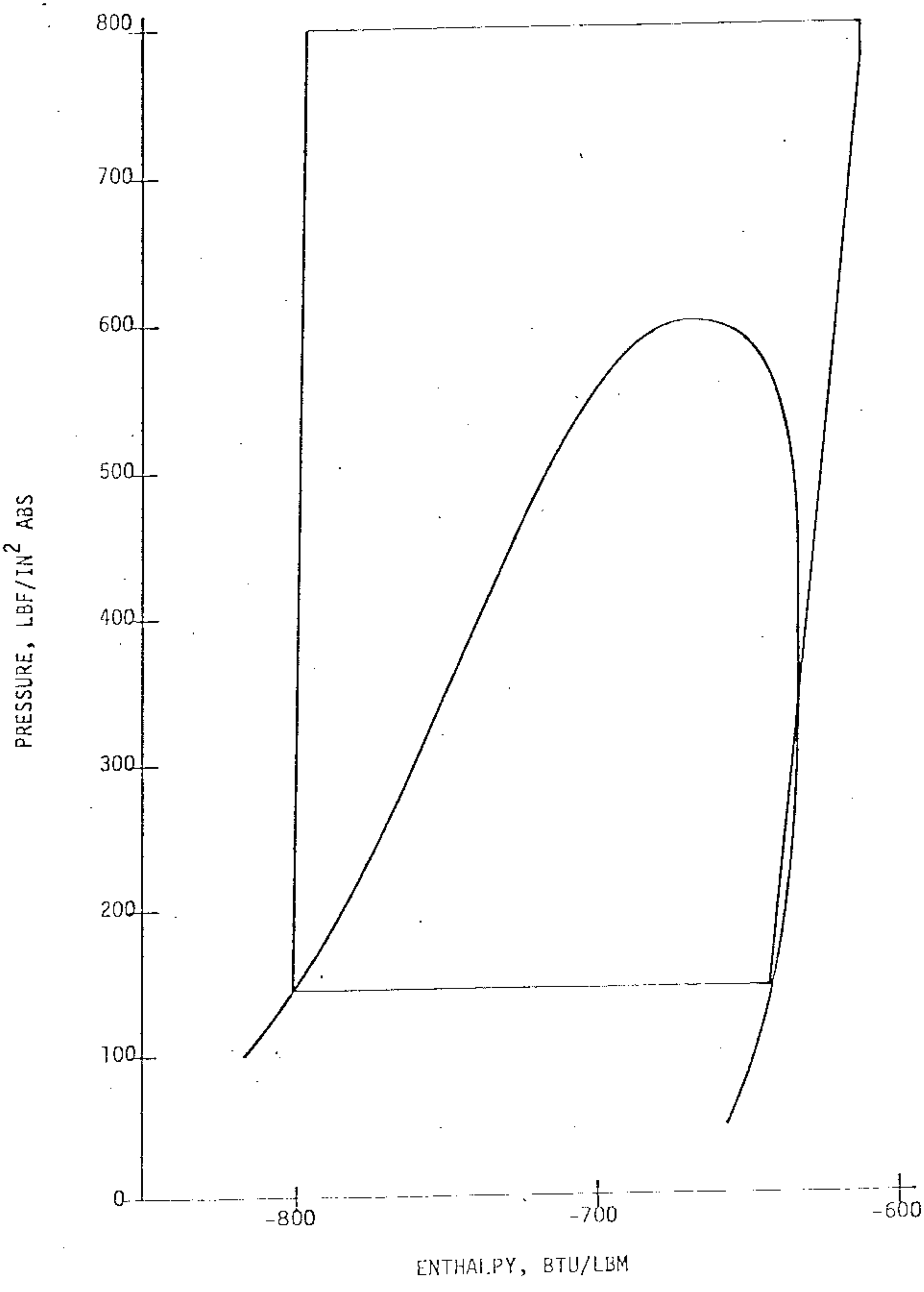
FIGURE 2. - Pressure - Enthalpy Diagram for Big Creek Hot Springs Working Fluid Cycle



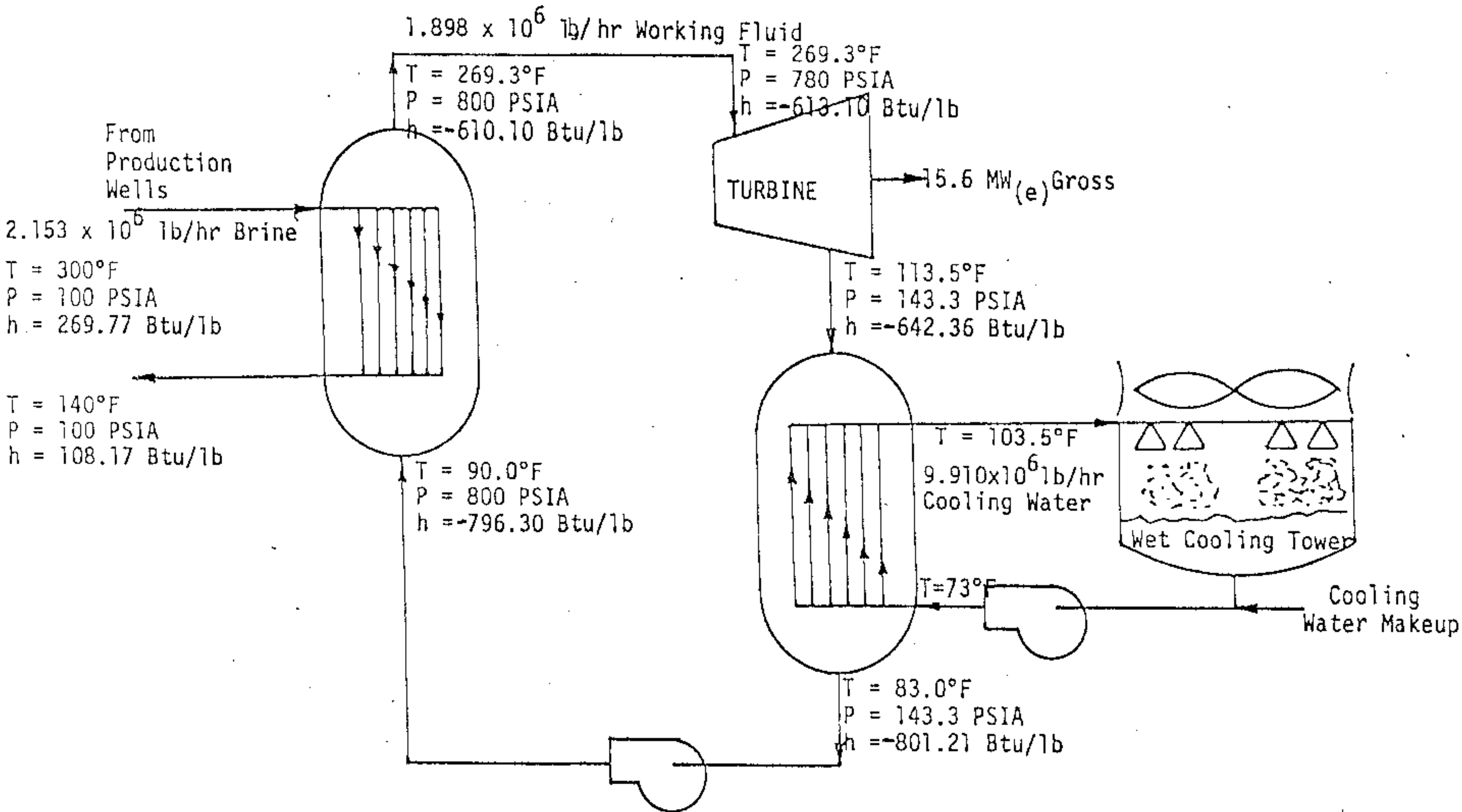


FIGURE 3. Proposed System Diagram for the Big Creek Hot Springs Geothermal System

The condensers specified are similar to the heaters in that they are also counterflow with finned tubes. Approximately 200,000 square feet of heat transfer area is required to condense the working fluid to the parameters shown on Figure 2. Two units are required with diameters of 16 feet and 12 feet, both being 70 feet long.

Due to the anticipated difficulty of constructing the power plant near the geothermal field, INEL proposes erecting the plant adjacent to Panther Creek and piping the brine from the well field to the power plant. A sketch of this plant illustrating the major components is shown in Figure 4.

The plant capital costs total $25,490,000 and are broken down in Table 1. Many of these costs were scaled from the Geothermal Loan Guarantee Program data base and are presented in second quarter 1980 dollars.

Plant O&M costs are listed in Table 2. The staff costs have been reduced on the assumption that many of the miscellaneous plant maintenance tasks can be absorbed by the Blackbird Mine staff.

Since nearby Panther Creek freezes over in the winter, INEL proposes drilling a fresh water well near the power plant to provide cooling water makeup.

C. Field System

The field system for the Big Creek Hot Springs geothermal system was costed for two average well flow rates; 200,000 lb/hr and 400,000 lb/hr. These costs were based on having multiple production wells (up to six) directionally drilled from each well pad. The required well depth was estimated by UURI to be 6000 feet. At the lower flow rate eleven production wells are required, while six will be necessary at the higher flow rate.

1. Heaters - 8' Dia. x 70' long
2. Turbine
3. Generator
4. Condensers - 12' & 16' Dia x 70' long
5. Condensate Tank - 10' Dia x 55' long

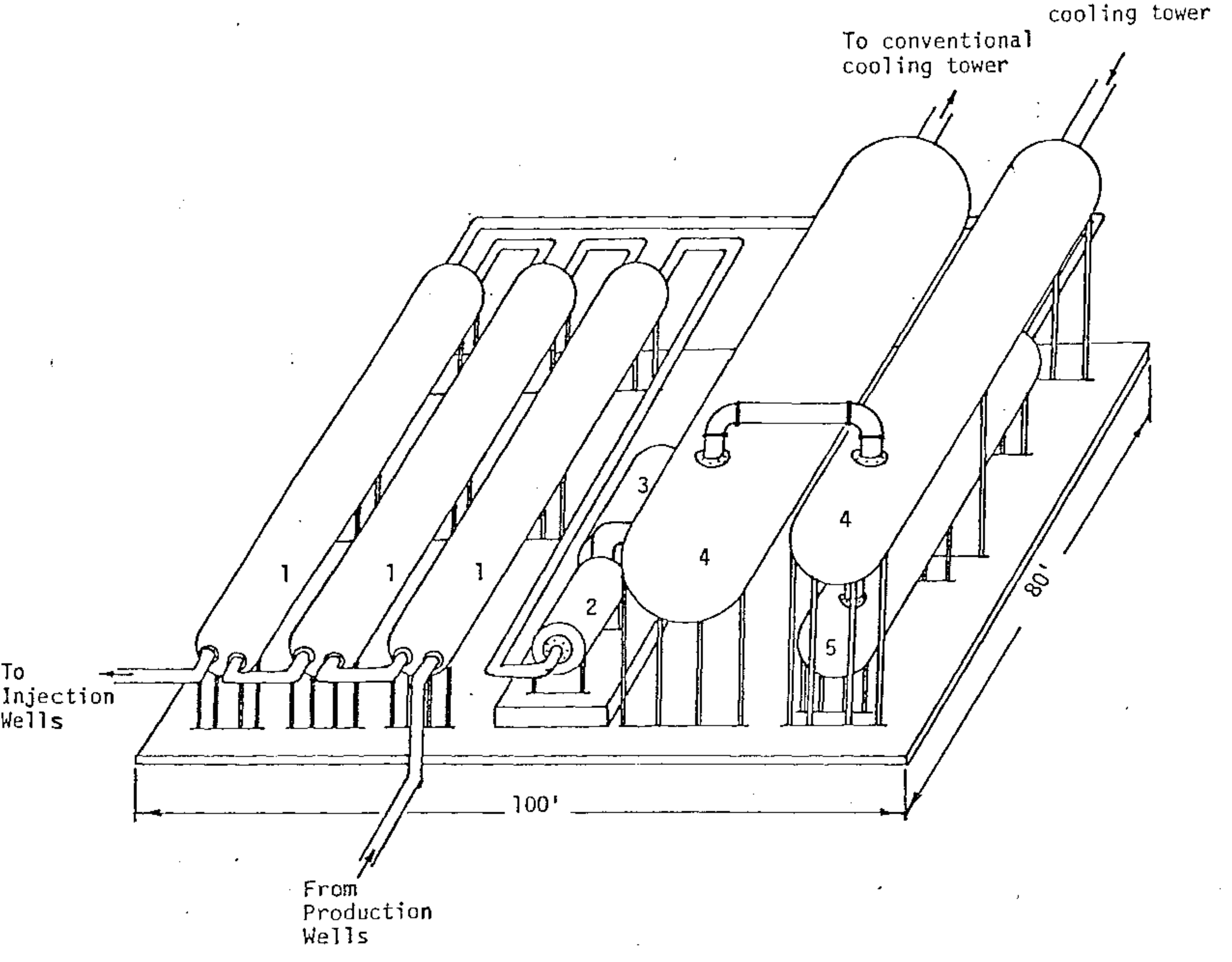


Figure 4. Process Area for Big Creek Hot Springs Geothermal Power Plant

Table 1. 11 MW(e) Net Binary Plant for Big Creek Hot Springs (2nd Quarter 1980 $'s)

	Equipment	Labor	Total
Land & Land Rights			100,000
Structures & Improvements			
Plant Site Preparation			200,000
Foundations & Structures			1,000,000
Subtotal			1,300,000
Major Equipment			
Turbine Generator	2,550,000		
Condensers	3,000,000		
Cooling Water Piping	321,000		
Cooling Tower & Basin			447,100
Cooling Water Pumps	40,000		
Heat Exchangers	1,839,000		
Condensate Tanks	86,400		
Subtotal	7,836,400		
Construction & Small Equipment			
Crane	144,000		
Electrical & Switchgear	1,134,000		
I&C	1,000,000		
Working Fluid Piping & Valves	490,000		
Brine Piping & Valves	162,000		
Misc. Tanks & Piping	200,000		
Fire Protection System	150,000		
Misc. Mechanical Equipment	600,000		
Spare Parts & Tools	125,000		
Reinjection Pumps	0		
Reinjection Filters	370,000		
Feed Pumps	225,000		
Fresh Water Well			5,000
Subtotal	4,600,000		
Sales Tax @ 3%			373,100
Labor & Labor OH, 30% of Equip.		3,730,900	
Total Direct Costs, Excl. Land Rights			18,292,500
Contractor Markup & Constr. Mgt. (15%)			2,743,900
Contingency (10%)			2,103,600
Design			2,000,000
Plant Startup			250,000
TOTAL			25,490,000

Table 2. Annual Power Plant O&M Costs (2nd Quarter 1980 $'s)

Staffing	293,333
4 Operators	
1 Laborer	
1 Superintendent	
Equipment Maintenance	216,468
Water Treatment	5,000
Miscellaneous	25,000
Total	539,801

Downhole pumps will be installed to assure the geothermal brine remains in the liquid state thus preventing any problems which could arise with two-phase flow in the production piping. This production piping is proposed to run approximately one mile from the well pads to the power plant located near Panther Creek. The size of this line is 20 inch NPS.

The field system costs for the previously mentioned flow rates are given in Table 3. Injection pumps are not included in these figures since the 800 foot elevation difference between the well field and power plant is assumed to provide sufficient head for injection. The injection wells will be located adjacent to the plant.

Field O&M costs are listed in Table 4. The staffing costs listed are reduced based on the assumption that many of the miscellaneous field maintenance tasks can be absorbed by the Blackbird Mine staff. This would, however, depend on who the field developer is and the working relationship maintained between the developer and the mine.

Average well life for this project is assumed to be 15 years, at which time the wells will have to be redrilled or replaced. The costs for these wells are listed in Table 4 as an average annual amount.

D. Transmission System

To transmit the power from the power plant to Blackbird Mine, it is proposed to run power line poles approximately 13 miles along Panther Creek to where the lines can tie into the Idaho power grid. The cost of this transmission system is estimated to be about $560,000. This is based on using 50 foot poles on 200 foot spans, with 1/0 stranded wire used to carry 24.9 kv at 255 amperes, 3 phase.

Table 3. 11 MW(e) Net Binary Field System Costs for Big Creek Hot Springs (2nd Quarter 1980 $'s)

	Average Well Flow Rate (lbm/hr)					
	200,000			400,000		
	Equip.	Labor	Total	Equip.	Labor	Total
Production Piping			1,075,236			786,346
Injection Piping			20,000			20,000
Production Wellhead "X-mas Trees"	709,544	212,863	922,407	387,024	116,107	503,131
Production Well Valves, I&C	279,323	83,797	363,120	152,358	45,707	198,065
Injection Well Valves, I&C	205,560	61,668	267,228	123,336	37,001	160,337
Downhole Pumps			1,058,200			876,000
Sales Tax (3% of materials)			66,381			41,872
Contractor Markup & Constr. Mgt. (15%)			565,886			387,863
Contingency (10%)			433,846			297,361
Design (5%)			238,615			163,549
Well Cost (at $1.296 x 10^6/well)			20,736,000			11,664,000
TOTAL			25,746,919			15,098,524

Table 4. Annual Field System O&M Costs
(2nd Quarter 1980 $'s)

	Average Well Flow Rate (lbm/hr)	
	200,000	400,000
Staffing	213,333	213,333
1 Roustabout 1 Foreman 1/2 Mechanical Engineer 1/2 Production Engineer		
Surface Equipment Maintenance	100,218	68,690
Production Well Maintenance	264,000	144,000
Injection Well Maintenance	281,500	168,900
Subtotal	859,051	594,923
Production Well Replacement	979,000	534,000
Injection Well Redrilling	215,000	129,000
Total	2,053,051	1,257,923

E. Summary

Table 5 summarizes the total cost of power in mills per kilowatt-hour. These prices are based on a 30 year plant life with an annual operating factor of 80%. The total fixed cost of capital on the plant was taken as 17%, while the field cost of capital was assumed to be 25%. A comparison of these costs with the costs of alternative energy sources will yield the economic feasibility of this study.

Table 5. Price of Power (mill/kw-h)

	Average Well Flow Rate (lbm/hr)	
	200,000	400,000
Field System Capital Costs	83.6	49.0
Field O&M Costs	11.1	7.7
Plant Capital Costs	56.7	56.7
Plant O&M Costs	7.0	7.0
Transmission Line Costs	1.8	1.8
Well Replacement/Redrilling	15.5	8.6
Total	175.7	130.8

CHAPTER 4

AN ECONOMIC ANALYSIS OF ELECTRICAL POWER GENERATION AT BIG CREEK HOT SPRINGS, IDAHO

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Economic Analysis

Analysis of investment in geothermal facilities must basically answer two questions: first, can geothermal supply energy more cheaply than alternative fuel sources; and second, can geothermal compete with other types of investments.

For investment in a geothermal system the answer to both these questions must be positive. Even if geothermal supplies energy at a cost below that of alternative fuel sources it still needs to compete for scarce investment dollars and must earn a rate of return at least as high as alternative investments.

The analysis that follows takes as given the engineering design and costs developed for Noranda by INEL in "Preliminary Evaluation of an Advanced Binary Power Plant for Big Creek Hot Springs". That evaluation, based on 400,000 lb/hr flow rates and 149°C (300°F) water from a depth of 1830m (6000ft), predicts an electricity price of 130 mills per KWH from an 11MW binary plant operating at an 80% load factor.

A Conventional Comparison

Typical analysis of geothermal energy use centers around the cost of providing the geothermal and potential savings to be generated through reduced use of conventional energy sources. A geothermal system typically has large capital costs relative to conventional fuel sources, but these large front-end costs may be offset by low annual operating costs, mainly a relatively small allowance for operation and maintenance expense. For Noranda Mining a $51,796,919 investment in a well field, power plant, and transmission facilities would beget a geothermal electric power source with annual operating expenses of only $1,797,724. Any annual savings generated would be derived by subtracting this annual operating expense from the annual cost of buying electricity elsewhere. Thus the geothermal system would generate a stream of savings over its 30-year life. Evaluation of the worth of that stream of savings could be done in either of two ways. One could simply add the savings (in either nominal or present value terms) each year to discover how long it takes for the savings to "pay back" the original investment. Or, one can calculate the internal rate of return, that rate of discount which just equates the present value of the savings stream to the original investment cost.

Such a process has been carried out in Tables 1 and 2. Footnotes to the columns indicate data sources and actual calculations performed in making savings projections. As seen from the data in Table 1, the geothermal system in this case does generate some annual savings compared to the purchase of electricity at 45 mills (a price quoted to Noranda by an existing public utility for interruptible service). However, the saving is small (even smaller when evaluated in terms of present value) relative to the capital investment required. These savings pay off the original capital cost in 28 years if one ignores present value considerations. If one evaluates that stream of savings in present value terms the capital investment is never paid back. The internal rate of return calculated on the basis of the savings in column (3) of Table 1 is a meager 1.5%, far too low to attract outside investors.

An alternative calculation using the same basic power plant data is found in Table 2. In this new scenario explicit recognition was made of the fact that under future Idaho Public Utility Commission regulations Idaho utilities will be required to purchase electricity from small power producers at a price based on the utility's "avoided cost".

Since the projected binary cycle power plant is designed for an 11MW peak load and Noranda expects to use only 7MW, there is an anticipated surplus of 4MW. Selling this surplus to Idaho Power at an "avoided cost" of 4.5¢ per kwh (the figure currently estimated by Idaho Power in hearings before the Idaho Public Utilities Commission) generates revenues of $1,261,440. These revenues from selling excess power must be added to operational cost savings to generate total geothermal savings.

After addition of surplus power revenues to geothermal saving, recalculation of payback period and rate of return resulted in much more attractive results than in Table 1. The payback period has shortened to 15 years and the internal rate of return has risen to 8.6%. These figures are much better than the dismal ones calculated for Table 1; the payback period is halved and the rate of return is quadrupled. Consideration of surplus power sales brings the economics of this binary cycle plant into the realm of feasibility.

A Premium for Uncertainty

The analysis in Tables 1 and 2 ignore the interruptible nature of the 45 mill per KWH for electricity from a utility. One way to treat the possibility of interruption is to add a premium to the cost of power to reflect the cost of interruption.

Data in Table 1 was recalculated with two premiums, one of 50% and one of 100 %. If the cost of power is raised to 67.5 mills the annual cost of purchased electricity starts at $3,315,000 rather than $2,210,000. The internal rate of return rises to 7.6% with the 50% premium and the payback period falls to 17 years. If the premium for interruptible power rises to 100%, 90 mills per KWH, the internal rate of return rises further, to 11.4%, and the payback period falls further, to 13 years.

With the 100% premium added to compensate for the interruptible nature of power supply the investment in a binary power plant looks just competitive in terms of rate of return and payback period. What this means is that electricity power purchased from the outside at about 90 mills is roughly competitive with power at 130 mills from an owned power plant. Such competitiveness comes from the fact that over the 30 year life of the plant geothermal power will increase in cost at a rate much slower than power purchased from outside since the only source of such increases for geothermal power is operations and maintenance, a relatively small annual expense. This analysis would become even more positive if the revenue from selling 4MW is considered.

Looking to the Future

The projected price of 130 mills per KWH is astronomical with respect to present prices of any alternative way of producing electricity. However, today's electric rates, whether for coal, nuclear, diesel, or hydropower, are blended rates whose low level reflects the fact that most utility overhead costs are from a bygone era. Today's sales are still relatively cheap because the plants that produce that electricity were built long ago when they, too, were cheap.

The only fair way to compare geothermal to other ways of producing electric power today is in terms of costs to be undergone now and in the future. The comparison is not between geothermal electricity at 130 mills and the cost of a coal or nuclear or hydro power at 2 mills but between geothermal at 130 mills and the cost of a coal or nuclear or hydro plant to be built at today's costs. While these costs are a matter of some dispute, especially since today's utilities will evidently be forced to buy excess power from cogenerators and small power producers at "avoided" cost and thus utilities want to keep their estimates of "avoided" costs as low as possible, there is a general range of costs to be discovered. Hydro facilities built today may supply electricity at a cost somewhere between 40 and 65 mills depending on the site and, of course, the actual load factor. Idaho utilities estimate a modern coal-fired plant will produce power somewhere around 50 mills per KWH. The various delays associated with public hostility to nuclear plants have raised many estimates of nuclear power to near 80 mills per KWH.

Conclusion

From the foregoing analysis, it appears that electrical power generation at Big Creek Hot Springs is presently economically feasible if 11MW can be generated and if 4MW are sold to Idaho Power at an "avoided cost" of 4.5¢ per kwh. The payback period for such an installation would be 15 years, with an internal rate of return of 8.6%. This possibility becomes increasingly attractive when the future cost of electricity supplied by conventional means is considered. These costs will undoubtedly rise, whenever the cost of geothermal electrical power generation will remain constant. Moreover, a geothermal electrical power source is a guaranteed power source in contrast to the interruptible power service currently offered by Idaho Power. As future growth places higher demands upon the Idaho Power company service grid, the prospect of periods of interrupted electrical power at the Blackbird Cobalt Mine becomes an increasingly likely possiblility. In light of these considerations, the investment in a geothermal power source may be very attractive.

TABLE 1

30-YEAR PROJECTION OF OPERATING COST SAVINGS
WITHOUT THE SALE OF 4MW TO IDAHO POWER

(1) Conventional Fuel Cost	(2) Operation and Maintenance	(3) Geothermal Saving	(4) (10%) Present Value
2,210,000	1,797,724	412,276	374,796
2,397,850	1,941,542	456,308	377,114
2,601,667	2,096,865	504,802	379,265
2,822,809	2,264,615	558,194	381,254
3,062,748	2,445,784	616,964	383,086
3,323,081	2,641,446	681,635	385,765
3,605,543	2,852,762	752,781	386,296
3,912,014	3,080,983	831,031	387,682
4,244,536	3,327,462	917,074	388,929
4,605,321	3,593,659	1,011,622	390,039
4,996,773	3,881,151	1,115,622	391,019
5,421,499	4,191,643	1,229,856	391,870
5,882,327	4,526,975	1,355,352	392,597
6,382,324	4,889,133	1,493,191	393,204
6,924,822	5,280,263	1,644,559	393,694
7,513,432	5,702,685	1,810,747	394,071
8,152,073	6,158,899	1,993,174	394,339
8,884,500	6,651,611	2,193,389	394,500
9,596,825	7,183,740	2,413,086	394,559
10,412,555	7,758,439	2,654,116	394,517
11,297,622	8,379,115	2,918,507	394,380
12,257,920	9,049,444	3,208,476	394,148
13,299,843	9,773,399	3,526,444	393,827
14,430,330	10,555,271	3,875,059	393,418
15,656,908	11,399,693	4,257,215	392,924
16,987,745	12,311,668	4,676,077	392,348
18,431,703	13,296,602	5,135,101	391,694
19,998,398	14,360,330	5,638,068	390,963
21,698,262	15,509,156	6,189,106	390,158
23,542,614	16,749,889	6,792,725	389,281

(1) 7MW peak load and 80% load factor as estimated by W. Moens, Noranda Mining requires an average yearly usage of 4.91 x 10^7 KWH. A purchase price of 45 mills per KWH generates a yearly electricity bill of $2,210,000. This figure is escalated at the very conservative rate of 8.5% per year suggested by Dames & Moore, Consultants to the Idaho Public Utilities Commission.

(2) Estimated in INEL Preliminary Evaluation of an advanced Binary Power Plant for Big Creek Hot Springs. Escalated at 8% per year.

(3) Saving is equal to the difference between conventional fuel cost and geothermal operation cost -- column (1) minus column (2).

(4) Savings in column (3) discounted to present value at rate of 10%.

TABLE 2

30-YEAR PROJECTION OF OPERATING COST SAVINGS
WITH THE SALE OF 4MW TO IDAHO POWER

(1) Conventional Fuel Cost	(2) Operation and Maintenance	(3) Revenue	(4) Geothermal Saving	(5) Present Value (10%)
2,210,000	1,797,724	1,261,440	1,673,716	1,521,560
2,397,850	1,941,542	1,368,662	1,824,970	1,508,240
2,601,667	2,096,865	1,484,999	1,989,801	1,494,967
2,822,809	2,264,615	1,611,224	2,169,418	1,481,742
3,062,748	2,445,784	1,748,178	2,365,142	1,468,567
3,323,081	2,641,446	1,896,773	2,578,408	1,455,444
3,605,543	2,852,762	2,057,998	2,810,779	1,442,374
3,912,014	3,080,983	2,232,928	3,063,959	1,429,359
4,244,536	3,327,462	2,422,727	3,339,801	1,416,402
4,605,321	3,593,659	2,628,659	3,640,321	1,403,501
4,996,773	3,881,151	2,852,095	3,967,717	1,390,661
5,421,499	4,191,643	3,094,523	4,324,379	1,377,880
5,882,327	4,526,975	3,357,557	4,712,909	1,365,162
6,382,324	4,889,133	3,642,950	5,136,141	1,352,506
6,924,822	5,280,263	3,952,601	5,597,160	1,339,916
7,513,432	5,702,685	4,288,572	6,099,319	1,327,390
8,152,073	6,158,899	4,653,100	6,646,274	1,314,930
8,884,500	6,651,611	5,048,614	7,242,003	1,302,538
9,596,825	7,183,740	5,477,746	7,890,832	1,290,214
10,412,555	7,758,439	5,943,354	8,597,470	1,277,959
11,297,622	8,379,115	6,448,539	9,367,046	1,265,774
12,257,920	9,049,444	6,996,665	10,205,144	1,253,661
13,299,843	9,773,399	7,591,382	11,117,826	1,241,618
14,430,330	10,555,271	8,236,649	12,111,708	1,229,648
15,656,908	11,399,693	8,936,765	13,193,980	1,217,752
16,987,745	12,311,668	9,696,390	14,372,467	1,205,928
18,431,703	13,296,602	10,520,583	15,655,684	1,194,179
19,998,398	14,360,330	11,414,832	17,052,900	1,182,505
21,698,262	16,509,156	12,385,093	18,574,199	1,170,907
23,542,614	16,749,889	13,437,826	20,230,551	1,159,384

(1) 7MW peak load and 80% load factor as estimated by W. Moens, Noranda Mining requires an average yearly usage of 4.91×10^7 KWH. A purchase price of 45 mills per KWH generates a yearly electricity bill of $2,210,000. This figure is escalated at the very conservative rate of 8.5% per year suggested by Dames & Moore, Consultants to the Idaho Public Utilities Commission.

(2) Estimated in INEL Preliminary Evaluation of an advanced Binary Power Plant for Big Creek Hot Springs. Escalated at 8% per year.

(3) Revenue from selling 4MW (difference between 11MW capacity and 7MW usage) excess power at "avoided cost" of 4.5¢ per KWH. Escalated at 8.5% per year as in note (1).

(4) Saving is equal to the difference between conventional fuel cost and geothermal operation cost -- column (1) minus column (2) -- plus revenue from selling 4MW excess power at "avoided cost" of 4.5¢ per KWH -- column (3).

(5) Savings in column (3) discounted to present value at a rate of 10%.

Payback period - 15 years
Internal rate of return - 8.6 %
(Evaluation of savings in column (4) generated by $51 million investment)

CHAPTER 5

AN INSTITUTIONAL ANALYSIS OF DEVELOPMENT AT BIG CREEK HOT SPRINGS

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September 1980

Institutional Development Process

The development of geothermal energy at Big Creek Hot Springs will require close cooperation between Republic Geothermal, Inc., Noranda Mining, Inc., Salmon National Forest officials, and the Bureau of Land Management. The impacts of developing a binary cycle power plant must include the potential effects of plant construction, electric power transmission, and disposal of the thermal water.

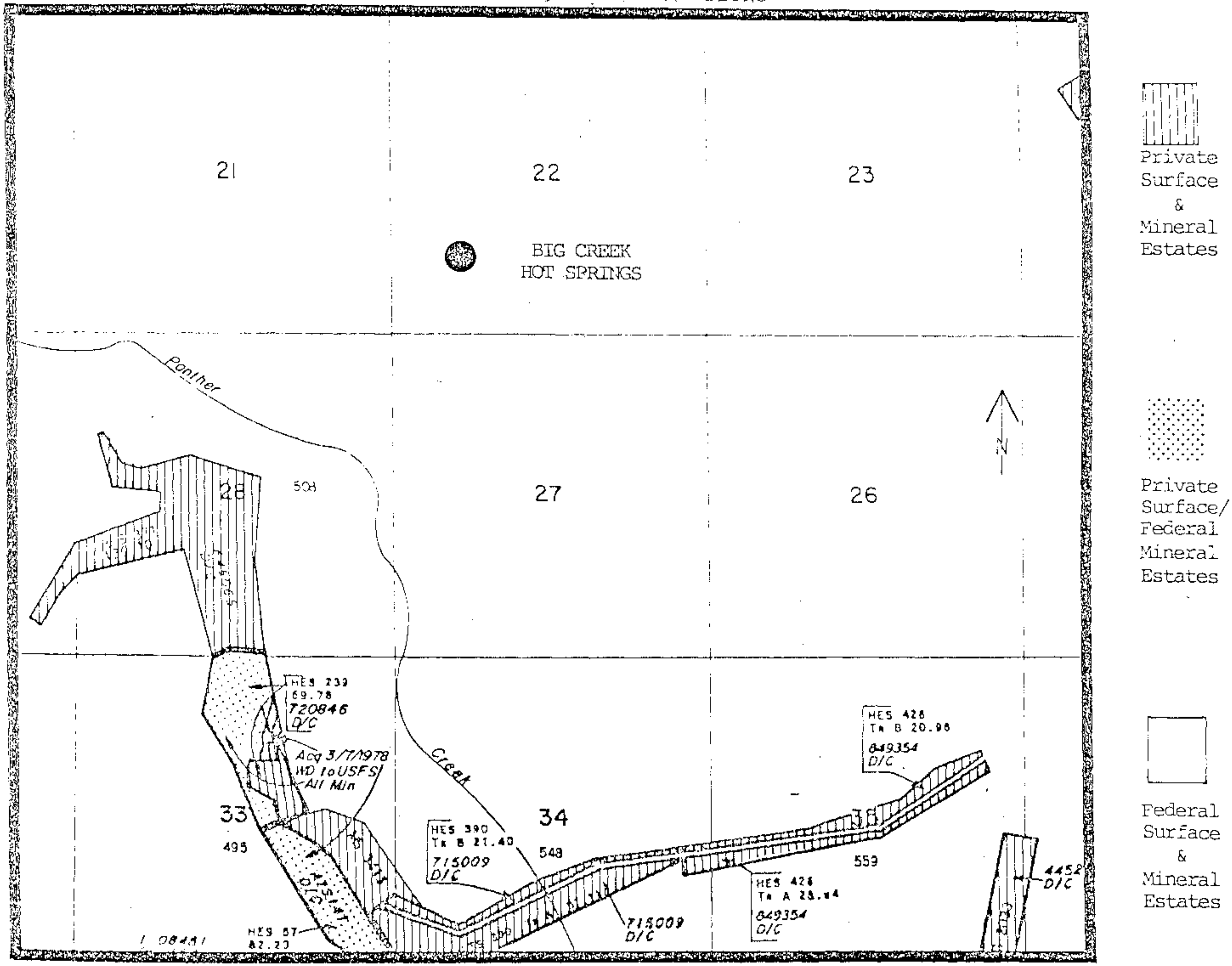
Resource Ownership

The land containing Big Creek Hot Springs is part of the Salmon National Forest. Much of the area is unsurveyed and remote, although not roadless. Figure 1 shows that portion of the Master Title Plat for T. 23 N., R. 18 E., containing Big Creek Hot Springs. This figure shows the location of federal and private interests; there are no state interests in the area. Exploration on any parcel of land which has federal ownership or a federal geothermal reservation will require a geothermal lease from the Bureau of Land Management. Because the area has not been classified by the U.S. Geological Survey as a Known Geothermal Resource Area (KGRA), federal geothermal resources can be leased to the first qualified applicant applying for a lease. Exploration drilling on any parcels under state ownership or parcels under private or municipal lands within the area requires permission from the landowner and the appropriate permits from the State of Idaho.

The probable drilling site outlined in the EG&G preliminary engineering study is located on Salmon National Forest land. Republic Geothermal, Inc., has lease applications covering the Big Creek area. These are shown below.

FIGURE 1

MINERAL OWNERSHIP AND RESERVATIONS



development and mining of cobalt and associated (in the same ore body) minerals. The intent of this provision of the bill is to allow any activities necessary for the development of cobalt. If the development of areas within the Special Mining Management Zone are necessary for the geothermal project (for transmission lines, power plant sites, etc.), then the generation of geothermal power at Big Creek must be defined as critical to the development of the Blackbird Cobalt Mine.

#	Order of Processing	Legal Descripton	Acreage
I-15975	8-30-79	T23N, R18E Sec. 14,15,22,23	2560
I-15976	8-30-79	T23N, R18E Sec. 21,27,28	1788
I-15977	8-30-79	T23N, R18E Sec. 16,26	1280

I-15975 covers the section containing the springs.

As of September 1, 1980, the Bureau of Land Management (BLM) had not acted to pre-adjudicate these lease applications.

The probable binary power plant site outlined in the preliminary EG&G study is also located on federal forest land. As such, the proposed plant would be subject to the Power Plant Siting Regulations administered by the BLM.

The proposed transmission lines would run thirteen (13) miles along Panther Creek where they would tie-in to the existing Idaho Power grid serving Blackbird mine and the town of Cobalt. Due to the pattern of land ownership along Panther Creek, transmission system development would utilize normal right-of-way procedures on federal lands, and easement acquisition techniques on private land.

Wilderness Status of Big Creek Hot Springs

Big Creek Hot Springs is outside of the wilderness boundary established by the River of No Return Wilderness Bill. As such, Forest Service multiple-use regulations apply to the site. However, the area between Big Creek Hot Springs and the Blackbird Cobalt Mine is included as part of the Clear Creek Special Mining Management Zone defined by the Wilderness Bill. Acceptable activities in the special management zone include exploration,