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A LOW TEMPERATURE DEMONSTRATION GEOTHERMAL POWER PLANT IN THE RAFT RIVER VALLEY

J. F. Kunze
L. G. Miller
D. T. Neill
C. R. Nichols

Aerojet Nuclear Company

NATIONAL REACTOR TESTING STATION
Idaho Falls, Idaho — 83401

Date Published - April 1974

PREPARED FOR THE
U. S. ATOMIC ENERGY COMMISSION
IDAHO OPERATIONS OFFICE UNDER CONTRACT AT(10-1)-1375

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NOTICE CONCERNING PRELIMINARY STATUS

The contents of this report were originally submitted as a proposal to the U.S. Atomic Energy Commission by Aerojet Nuclear Company and Raft River Rural Electric Cooperative, Inc. Certain phases of the proposed program have been implemented in FY-74 as of the time of issue of this report. Other aspects of the proposal have not been implemented or officially neither sanctioned nor accepted by either the U.S. Atomic Energy Commission or other participants in the program. Nor have scoping or funding of the program beyond FY-74 been officially committed as of this date.

AEROJET NUCLEAR COMPANY

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ABSTRACT

The potential of geothermal energy in satisfying the nation's energy needs depends in part on the size and extent of hydrothermal reservoirs and on the economics of extracting energy from such reservoirs to be converted to electric power. The Raft River Project will study the techniques (by actual testing) of utilizing water at temperatures well below what is now considered the commercially viable range. Geochemical indicators show reservoir temperatures of less than 150°C (302°F). Environmental conditions will be a major consideration in this project, and will include the re-injection of all waste geothermal fluids without contaminating the abundant near-surface aquifer.

The first draft of this report was issued July 27, 1973, and made part of the testimony to the August 10, 1973, U.S. Senate Subcommittee Hearings on Water and Power, Committee of Interior and Insular Affairs. The report has subsequently received minor revisions as progress on the Raft River Project has developed.

Principal authors are:

J. F. Kunze and L. G. Miller of Aerojet Nuclear Company

D. T. Neill, a professor at Idaho State University who was temporarily employed by Aerojet Nuclear Company during the summer of 1973.

C. R. Nichols, a professor at Boise State University who was a consultant to Aerojet Nuclear Company in the summer of 1973.

Major contributions to the organization and development of this project were made by:

Edwin C. Schlender, Manager, Raft River Electric Cooperation

Jack A. Barnett, Geological Consultant to Raft River Electric Cooperative.

In addition, the authors wish to acknowledge the contributions to this work by R. M. Brugger and E. R. Christie of Aerojet Nuclear Company and R. E. Wood and J. L. Griffith of the U.S. Atomic Energy Commission, Idaho Operations Office. The Northwest Public Power Council (Vancouver, Washington) and the Snake River Power Association membership have also provided valuable support and ideas.

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1.0 INTRODUCTION AND SCOPE

The area of Southern Idaho is one of the most promising regions within the United States for near surface, economically recoverable geothermal energy. It is identified by geologists as the younger end of a major Volcanic Rift Province. The Raft River Valley is a faulted, north-south trending sedimentary basin intersecting the major volcanic rift known as the Snake River Plain. It is in the Raft River Basin that a number of wells, drilled for irrigation purposes, unexpectedly yielded warm to hot water. Two such wells bottoming at 400 and 540 ft yield boiling water under artesian flow. These wells are near the Malta, Idaho headquarters of the Raft River Rural Electrical Cooperative, Inc., an REA financed power company serving 10,000 sq miles of Southcentral Idaho, Northwestern Utah, and Northeastern Nevada. The National Reactor Testing Station, with its 5,000 man work force and extensive research and development facilities is located approximately 40 miles north of the Raft River Electric service area, with its headquarters (those of the Idaho Operations Office) located in Idaho Falls. Aerojet Nuclear Company is the principal and an exclusive contractor to the U.S. Atomic Energy Commission at the National Reactor Testing Station.

The occurrence of the boiling water in the Malta, Idaho area prompted the Raft River Rural Electric Cooperative to conduct preliminary geological investigations pertinent to the possibility of establishing a geothermal power plant in the area for the production of electricity. Simultaneously, the Coop management began securing geothermal leases on the private land owned by its members. Aerojet Nuclear Company entered into a preliminary engineering and feasibility study, including assistance in gathering additional geophysical information from the Raft River Valley.

The harnessing of geothermal energy for electric power production in the United States has occurred only in one area, the Geysers in Northern California. There, the geology provides a dry steam production area at 4,000 to 8,000 ft depth, where pressures are only 500 psi and temperatures are approximately 195°C (380°F). Unfortunately, this type of geothermal anamoly is rare, primarily because of high fluid content and hence high pressure (2,000 to 4,000 psi) at these depths. Most geothermal fields are therefore hot water fields. As would be expected, the lower the temperature of the water, the more of it occurs throughout the nation. Theoretically, a power plant can be operated on fluid of any temperature above the heat sink (condenser) temperature.

At low temperatures the most common working fluid, water, has extremely low density as a gas. Turbine machinery must therefore be extremely large to handle this gas. On the other hand, a heat exchanger on the "front and rear" of the turbine could transfer heat to a fluid having higher density (such as freon), allowing the turbine to be smaller than a steam turbine of the same output. The advantage of a smaller turbine is coupled with the disadvantage of needing the two heat exchangers. Theoretically, both systems can be considered as having the capability of approaching but never attaining the ideal Carnot cycle efficiency of

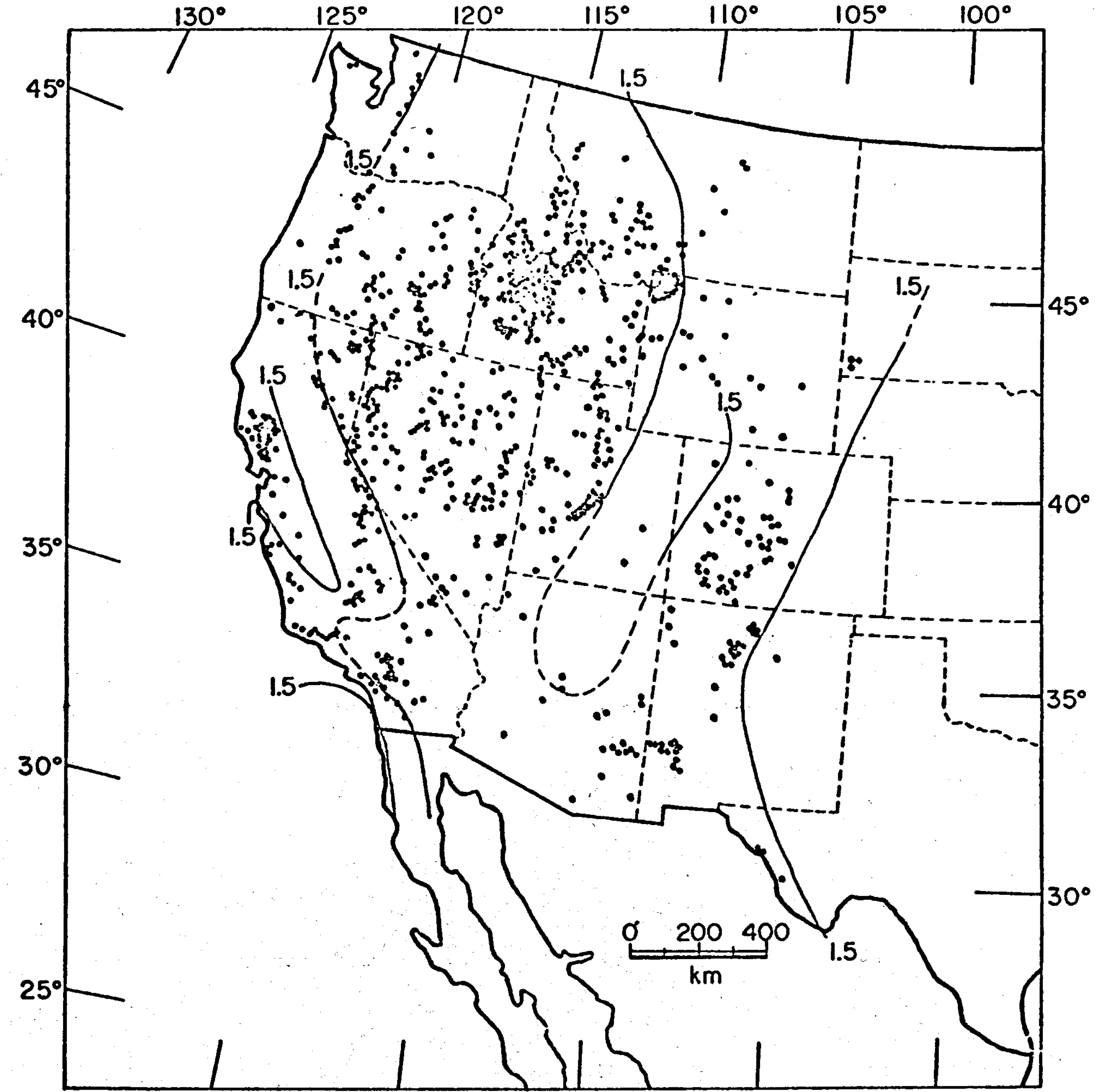
$$\text{Eff} = \frac{T_1 - T_2}{T_1}$$

T_1 is the hot source temperature (geothermal fluid) and T_2 is the condenser temperature, both on the absolute temperature scale.

In practice, few machines can attain this ideal efficiency. But also, in practice, work can be done with a machine for which the heat source (T_{hot}) is at a higher temperature than the heat sink (T_{cold}). As an example, the Russians are reportedly operating geothermal power plants in one case between 80°C (186°F) and 15°C (59°F) and in another case between 40°C (110°F) and 5°C (41°F). To be able to do so easily with competitive costs would make geothermal energy attractive almost any place in the world, but particularly so in the western United States with its abundant near surface hot water. Figure 1 shows the major hot spring areas, of which Idaho is the most prominent region. To demonstrate that electric power can be generated effectively and economically from hot water geothermal sources would make available to the nation (and the world) a very abundant, safe, and non-polluting form of energy.

The objective of this project is to construct a 20 MW(e) dual cycle (one steam, one binary) geothermal power plant operating from a relatively low temperature (approximately 150°C), highly convective geothermal area. This temperature is the indicated (minimum) geochemical thermometer value obtained from the Raft River hot wells. Also, 150°C (300°F) represents the typical indicated geothermal reservoir temperatures from most of the wells and hot springs in Southern Idaho. (Young and Mitchell, 1973).

The first phase of this project will result in the construction and operation by winter 1975-76, of a demonstration geothermal power plant of approximately 10 MW capacity using a low temperature steam rankine cycle. The plant will be built in the Snake River Plain region within the service area of the Raft River Rural Electrical Cooperative. Phase II will result in expansion of the power plant size by the addition of another 10 MW unit operating on a binary fluid rankine cycle. Performance and efficiency of the two component plant will depend on the supply-recharge capabilities of the geothermal field, of the temperature of the supply fluid, of the plant performance, and of the requirements for demonstrating the performance of a binary fluid power system. The site to be chosen is expected to be a relatively low temperature, wet-convective geothermal area, with maximum temperatures in the range of 150°C (302°F). This program thus will demonstrate the capacity of harnessing the low temperature geothermal sources relatively near to the surface. The exact site for the power plant will be selected from geophysical studies to be performed initially in this program. The site in any case will be in or immediately contiguous to the service area of the REA company serving Southcentral Idaho, Northwestern Utah, and Northeastern Nevada. This company, the Raft River Rural Electrical Cooperative is publicly owned and serves 1,750 customers over a 10,000 square mile area. Figure 2 shows the Raft River service area and the NRTS geographic relationship. Its present peak winter load is 10 MW, and its summer irrigation season peak is 40 MW. All its power is currently purchase from the Bonneville Power Administration at approximately 3 mills/kW hr. The BPA is willing to make arrangements to "wheel" any excess power to neighboring public utilites which a geothermal plant in the area might develop. The need for geothermal power development in the area is of particular significance because currently all available hydroelectric energy is being utilized. Coal, gas, or oil supplies for any type of fossil plant must be shipped from a great distance. Expansion in irrigation pumping requirements have resulted in a steady 10% growth in electric power assumption in this area. The potential for large mineral extraction industires at the Great Salt Lake, in the southwest part of the Raft River Cooperative service area, is also of significance in regard to future power growth requirements.



THERMAL SPRINGS IN THE WESTERN U. S.
(Stearns et al., 1935)

Fig. 1

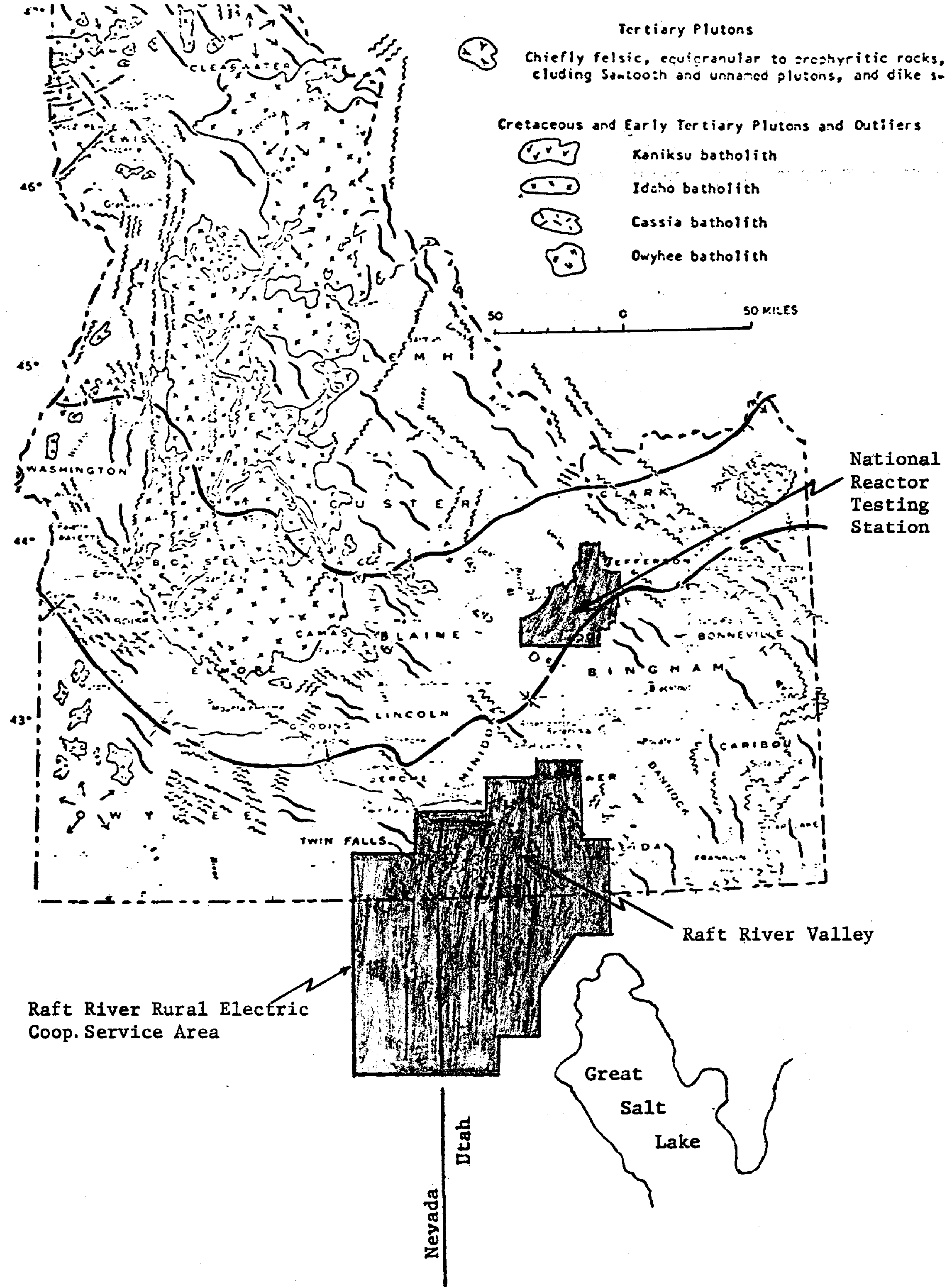


Fig. 2 Raft River Valley and Snake River Volcanic Rift Area of Idaho

The AEC and its contractor will design and install the geothermal plant. Raft River Rural Electric will arrange for leasing of the private-land geothermal rights on which it now has an option. The utility will also provide for the electrical connections and use of the power. The AEC will actively monitor and manage the geothermal field, which though highly convective exists in a region where ground water supplies have been shown to be quite sensitive to withdrawal rates. Reinjection of both geothermal and condenser cooling-water (from the cold-water aquifer) is considered a likely necessity. Once a nominally stable operation is achieved, the field operation will be turned over to the Raft River Electric or to its associated public power group, the Snake River Power Association.

The scope of this program includes two principal goals unlike other current geothermal projects:

1. The utilization of relatively low temperature geothermal fluid (150°C), involving comparison studies of both the steam and binary (organic fluid) rankine cycles. Cost comparisons for subsequent commercial applications will be made.

2. The managing of the field by re-injection of both thermal and condenser cooling waters to minimize environmental impact and to achieve long field life.

These above goals will involve the harnessing of energy from a typical tectonic valley structure for the Western U.S., with adequate wet-convective energy to run a 100 MW(e) plant for several hundred years. Thus, technology transfer to other areas in the Western U.S. should be expedited.

The Raft River area is ideal for demonstrating the harnessing of the power producing potential in warm, not hot, water. With only 150°C water anticipated, conventional steam turbine systems appear only marginal for normal applications. But, the Raft River Valley's near surface aquifer is quite cold, approximately 10°C (50°F). With such a cold temperature heat sink, 150°C water becomes quite attractive. Approximately 15% of the sensible heat (relative to 0°C or 32°F) can be withdrawn from this water and converted to mechanical energy by using the 10°C sink. Since the heat is free in a sense, a cycle efficiency by the normal definition cannot be given. But stated relative to the heat stored in the geothermal water, a 15% efficiency can be defined.

The choice of 10 MW(e) as the size of the demonstration plant modules is based, at least partially, on specific considerations relating to convenience. The full output of the first 10 MW power plant output could easily be absorbed by the Raft River Rural Electric Coop., except perhaps during off-peak conditions on warm winter days. The second 10 MW output could be absorbed easily during irrigation season and could, at other times, be transmitted to adjacent utilities of the Snake River Power Association. A further consideration for the steam plant is the fact that there exist "off-the-shelf" turbine generator units capable of operating on 150°C saturated steam and delivering nearly 10 MW(e) output. The binary (organic fluid) cycle to be added for the second 10 MW unit will probably be somewhat undersized compared to the total amount of extractable heat that can be obtained from the geothermal fluid used to drive the first steam plant. (See Section 3.4) However, until the first well is dug and the bottom hole pressures and temperatures are determined, the appropriate design size for the binary plant cannot be determined.

Small geothermal power plants in the 10 to 20 MW(e) also have particulat significance to this region of the nation. With the sparse population, electric utility load centers are largely of the magnitude range 10 to 50 MW, with 50 to 100 miles separating load centers of this type. Currently, most of the power consumed by the consumer-owned utilities in Southern Idaho is generated by the hydroelectric facilities in the Columbia River Basin, 300 to 700 miles away. Transmission loses are large, the order of 15%, and the building of new transmission lines when needed will be expensive (typically $150,000/mile). Therefore, construction of small-sized generating facilities at these many small, isolated load centers not only provides a secure generating base for the center but helps to buoy-up the entire transmission system within the northwest power grid. Despite the insignificance of 10 to 20 MW(e) to the total power needs of the nation, plants of this size placed as discussed are of great advantage in this region of the country.

Plant sizes in the range of 20 to 200 MW(e) are probably of optimum size economically for application of geothermal energy, because of its relatively diffuse nature. A single well can probably produce fluid sufficient to generate between 3 and 10 MW(e), depending on the exact conditions. Wells must be spaced sufficiently far apart (i.e., one per 40 acres) so as to have insignificant interaction. And, the fluid cannot be piped over too long a distance to the generator without excessive expense and loss of fluid enthalpy. Therefore, it would appear that 10 to 20 wells is the maximum number that could serve one power plant module. For this reason, it seems that 200 MW(e) may be the maximum practical turbine size to consider for even the best of geothermal fields.

The purposes of the Raft River Project are to perform the necessary research and development to attain the major principal objectives listed above. Hopefully, performance and cost data from the experience on this project will show that the commercial construction of geothermal power plants operating on medium temperature water can be competitive with other forms of energy. If indeed this can be demonstrated, then subsequent expansion of the Raft River plant and construction of plants elsewhere can be undertaken without government funding.*

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* It is neither the charter nor the intention of the Aerojet Nuclear Company, a prime, wholly integrated contractor to the U. S. Atomic Energy Commission, to produce electric power for commercial markets. The Raft River Rural Electric Coop., Inc., is participating in this program for two principal reasons: 1) to encourage and support the necessary research and development to make medium temperature geothermal fields of value to the nation's energy requirements, and 2) to assure that the power developed in such a research effort is not wasted but is indeed utilized within the northwest power grid.

2.0 THE GEOLOGICAL SETTING AND PRE-CONSTRUCTION INVESTIGATIONS

The presence of two wells which produce water at or near the boiling point has attracted considerable geologic attention to the Raft River Valley. (Fig. 2) Though Idaho is a state with abundant hot spring activity, the Raft River Valley wells and one spring near Salmon produce the only surface water at or near the boiling point (Ross, 1970).

The Raft River Valley appears to be ideally situated for a geothermal demonstration project in terms of its geologic setting. Two alternative explanations for the occurrence of hot water in the Raft River wells are possible on the basis of available data.

1. The hot water occurs within a down faulted valley which is typical in many respects of hundreds of similar valleys in the Basin and Range Province of Utah, Nevada, and Idaho. The thermal water may reflect simply the result of deep convective circulation of ground water to depths of about 6,000 ft in an area of regionally high heat flow.
2. The thermal waters at Raft River may result from heating by a cooling intrusive mass emplaced at relatively shallow depths beneath or adjacent to the valley.

If the first explanation is the correct one, the results of the study would be directly applicable to the numerous other faulted valley situations throughout the entire Basin and Range province of the western United States. The 145°C minimum temperatures geochemically predicted for the Raft River wells are typical of the geothermal systems throughout the western United States.

If, however, a local intense heat source is encountered within the valley, the chances of a higher temperature, more efficient power generation facility would be enhanced. In either instance an effective demonstration project appears geologically feasible.

2.1 Geothermal Evidence

Initial interest was drawn to the Raft River Valley because of two wells drilled many years ago for irrigation, wells that turned out to be artesian hot water wells with temperatures near the boiling point. One well was abandoned, but the other has subsequently been utilized for heating a greenhouse. Several other wells throughout the Raft River Valley were drilled for cold water source and found to yield warm water, 10 to 25 degrees C above the average near surface aquifer temperature. It appears that after passing through a shallow cold water aquifer these wells reach high temperature water at depths of 350 to 450 feet.

The Raft River Valley is an irrigated farming and livestock raising area. Most of it is irrigated from underground water. There are about 1,000 wells varying in depth from 50 to 1300 feet. A number of these have been abandoned because unexpected high water temperature has destroyed the crops. Most of the wells, though, are fed by cold and warm aquifers so that water is useable for irrigation.

Temperature logs on numerous wells throughout the valley indicate cold water aquifers are down to depths of 300 feet at the upper valley and 500 feet in the lower valley with a warm or hot water aquifer below these levels. The water table also drops about 200 feet from the upper to lower valley. The warm or hot water aquifer appears to be a near continuous aquifer with the higher temperatures generally along the western side of the valley. A known fault also runs along this side of the valley and most artesian wells are located along this same side of the valley.

These characteristics seem to indicate some major heat source south of Malta which is influencing a major part of the valley. Since the heat can move laterally more easily than vertically through the valley fill, heat is being supplied from below the hot aquifer over parts of the valley, with hot water under pressure being forced up the fault line to produce the hot artesian wells.

As added evidence for the above model, a nose of a magnetic high pushes into the area just north of the hottest water well and an anomalous high gravity measurement covers this same region. Both of these would possibly indicate some buried stock or intrusive mass at not to great a depth. However, its age and intrinsic heat cannot be inferred from the existing information.

2.2 Previous Investigations

Previous geologic investigations of the region include a comprehensive study by Anderson (1931) and more recent investigations emphasizing hydrologic aspects of the area by Nace et al., (1961), Armstrong (1966), Comptor (1966), Damond (1966), and Walker et al., (1970). Gravity and magnetic mapping on a regional scale which include this area have been accomplished by Don Mabey of the Regional Geologic Branch, Denver Region, United States Geologic Survey. This information is available on an open file basis at the Denver Survey Office.

Approximately a year of geothermally oriented geologic work has been accomplished by Mr. Jack Barnett, Consulting Geologist for the Raft River Rural Electric Cooperative. This investigation has included detailed well water temperature and chemistry surveys in the Raft River Basin, application of the SiO_2 geothermometer technique, self-potential surveys and temperature measurements in shallow drill holes.

2.3 Geologic Setting

The Raft River Valley is a Basin and Range type north-south trending structural depression which has as its northern limit the Snake River Plain. Stone (1969) has suggested that recent basaltic volcanism at the north end of the valley marks the intersection of three major tectonic features, the rift zones of the eastern and western Snake River Plains, and the major north-south trending faulting of the Raft River Valley. These faults separate the valley from the Cottrell Range to the west and the Sublett and Black Pine Ranges on the east. The floor of the Raft River Valley is a westward-tilted, down faulted block, whereas the Cottrell range is an upfaulted block which also has a westward dip (Anderson 1931).

The south end of the valley is terminated by the east-west trending Raft River Range. A west-trending fault zone is suggested by topographic considerations in the vicinity of "The Narrows" at the southern terminus of the Cottrell Range and the Raft River Valley near the vicinity of the hot wells and the Frazier KGRA. (Known Geothermal Resource Area, Figure 7).

The Raft Formation of Quaternary Age and the Salt Lake Formation of Tertiary Age occurs within the structural depression or graben of the Raft River Valley. Open file USGS gravity data indicates a total thickness of 6000 feet of sedimentary and volcanic fill within deeper portions of the valley. The Salt Lake formation consists of sandstones, silty sandstone, tuffs and welded tuffs with a maximum aggregate exposed thickness of 2,500 feet (Walker et al., 1970).

The Raft Formation consists of an exposed thickness of 1,000 feet of alluvial, fluivioglacial and lucastrine sands and gravels. The percentage of coarse-grained material in the Raft Formation in the valley increases markedly toward the south. Both the Raft Formation and Salt Lake Formation serve as aquifers in the valley. The median yield of 18 wells completed in the upper unit of the Salt Lake Formation is about 1,600 gpm (Ibib, p 25).

2.4 Geologic Objective and Research Plan

The geologic phase of the proposed research would have as its primary objective the location of specific drilling sites within the Raft River area which possess the optimum potential for producing high temperature and high volume thermal fluids. In order to accomplish this goal a combination of geologic, geochemical and geophysical techniques would be utilized to expand the present understanding of the geothermal system within the Raft River Valley. Techniques to be employed in an approximate chronological order could be:

1. Detailed geologic mapping assisted by both "black and white" and "false-color" infra-red stereo aerial photography.
2. A detailed interpretation of available aero-magnetic and gravity data for the Raft River Valley.

3. Microseismic and ground noise monitoring.
4. Dipole-Dipole resisitivity mapping of suspected thermal zones.
5. Thermal gradient measurements in intermediate-depth bore holes and heat flow calculations.
6. Refraction seismic techniques applied to suspected fault zones.
7. Analysis of data and selection of an initial test site.
8. Geologic, geochemical, and geophysical monitoring of test drilling.

1. Detailed Geologic Mapping

A detailed knowledge of the structural and stratigraphic framework of a geothermal zone is an absolute requirement for optimum well siting and completion. The predrilling geologic investigation and particularly the detailed geologic mapping is the base on which all other data is accumulated. The primary objective of this phase of the work is the delineation of the structural and stratigraphic controls on hot water occurrences at the demonstration site. Geologic mapping by previous investigators will be utilized as the starting point for more detailed investigations of the fault distributions.

Available stereo, black and white aerial photography from the Geologic Survey will be supplemented by "false-color" infra-red photography work. It is anticipated that the moisture sensitive infra-red photography will potentially aid in the detection of the fluid bearing, covered fault zones. The faults bordering the Raft River Valley are only suggested in conventional photography by subtle linear trends.

In addition to detailed geologic mapping, samples of the Raft and Salt Lake Formations will be collected in order to obtain laboratory measurements of this density. These in turn will be utilized in the detailed analysis of the gravity data already available. The geologic mapping will be continuously refined in terms of newly acquired geophysical data as the program progressed.

2. Detailed Analysis of Available Geophysical Data

Aeromagnetic and gravity data are available for the Raft River Valley as the result of continuing regional investigations by geophysicis and geologists of the Geology Branch, Denver Region, USGS. A preliminary analysis of this data has suggested the possible presence of a buried intrusion in the vicinity of the hot wells, whose surface manifestations may be a small impediment. Detailed analysis of the gravity and aeromagnetic anamoly maps will be undertaken in order to more accurately estimate the depths of valley fill and clarify the possible presence of intrusive rock.

3. Microseismic and Ground Noise Investigation

The close spatial relationship between micro-earthquakes (Magnitude - 2 to 4 on the Richter scale) and geothermal zones has been noted by Ward (1972), Hamilton and Muffler (1972), Palmason (1971), Rinehart (1968), and Ward, Palmason and Drake (1969). Intense micro-earthquake swarm activity in southeast Idaho has been reported by Weslphal and Lange (1966), Sbar et al., (1972), and Smith and Sbar (1973, in press).

Micro-earthquake monitoring in the Raft River Valley would be utilized both as an exploration tool for the obtaining of fault plane solutions and accurate fault plane locations and as a monitoring system during subsequent production.

A related technique involves the monitoring of low frequency "ground noise" as an indication of local geothermal zone development. Ground noise techniques as described by Clacey (1969), Ward and Jacob (1970)and Iyer (1971), seem less conclusive and more difficult to interpret than do micro-earthquakes but the relationship between ground noise and active geothermal systems seems real. The proposed study would include the monitoring of ground noise in addition to micro-earthquake detection.

4. Dipole-Dipole Resistivity Mapping

An induced electric field dipole survey will be made in areas of interest. To implement a dipole survey, a grounded wire source is located somewhat outside the prospect area in order to achieve sufficient penetration in the prospect area. The signal transmitted by the source is a square wave of period 30 seconds and of amplitude up to several hundred ampere. The flow of current in the ground generates an electrical field which is detected by two orthogonal electric dipoles oriented parallel and perpendicular to the source so that the field components in these directions can be added vectorially to find the total field. Interpretation of the data will be made using computer techniques. The generator may be a modified government surplus device and the detection equipment and expertise is available at the NRTS.

5. Thermal Gradient Measurements in Intermediate Depth Bore Holes and Heat Flow Calculations

Several intermediate depth test holes (300 to 400 ft) will be drilled into the Salt Lake Formation near the Cottrell Range in order to evaluate the heat flow situation existing within the Raft River Basin. These wells will provide gradient information which will be extrapolated to the probable depth of the valley fill (6,000 ft) in order to provide an estimate of maximum temperatures. These data would be compared with measurements of temperature gradients in all available irrigation wells in the area and unpublished regional heat flow data recently made available. Hopefully the nature of the thermal anamoly (local intense heat source vs deep circulation in a basin within a region of high heat flow area) could thus be determined.

6. Refraction Seismic Techniques

The difficulty in interpreting active seismic data in the complex geothermal environment is well documented (Hayakawa, 1970). Of the active seismic techniques, the refraction method has been applied with more success in geothermal exploration. Hochstein and Hunt (1970) for example have discussed the application of refraction and reflection techniques in New Zealand, concluding that the refraction technique is of greater value. The present investigation proposes the limited application of refraction techniques in the definition of the structural framework of the Raft River Valley. Refraction techniques may be of great value if the eventual drilling target is determined to be a fault controlled thermal fluid distribution pattern. The refraction data will also be utilized in determinations of volcanic interfaces.

7. Analysis of Data and Selection of a Deep Test Site

At this point in the project a decision would be made concerning the feasibility of deep test drilling. If the geologic, geochemical and geophysical data accumulated at that time indicates the probable presence of sufficient volume of 150°C fluid to operate the demonstration plant, an initial drilling site would be selected.

8. Geologic, Geochemical, and Geophysical Monitoring of the Deep Test Drilling

Geologic monitoring of the drilling will be provided continuously during the well drilling operation. Mineralogic and petrographic analysis of cuttings and cores by standard optical and X-ray diffraction techniques will be performed. Corings will be made as deemed appropriate for useful scientific information. Fluids encountered during the drilling operation will be chemically analyzed and monitored for possible waste water disposal problems. The SiO_2 and Na/K/Ca geothermometer will be applied to thermal fluids. Standard electric, radioactivity, drilling time, and temperature logging will be contracted through established commercial firms. Data acquisition during the drilling phase will be given a high priority.

9. Recent Deep Drilling in the Area

In the fall of 1973, two deep oil- and gas-exploratory wells were drilled by a private company (Standard American) within approximately 15 miles of the older, 400 to 500 ft deep boiling wells. These oil and gas wells were sunk nominally to the Paleozoic age, limestone, and dolomite rock at approximately 6,000 ft. Above this depth, the material is mostly volcanic tuffs, siltstone, shale, and sandstone. Neither well yielded commercial quantities of gas or oil. Nor did either well yield hot water initially. The one well, however, began to spout hot water (80°C) approximately three weeks after being abandoned. The slow percolation of the hot water through drilling mud probably was the cause of the time delay. This well was not cased below 600 ft, and mixing of thermal waters from deep with cooler waters from above is a possibility, making it difficult to assess a reservoir temperature for that area. Drilling mud contamination also made geochemical work virtually impractical.

3.0 POWER PLANT DESIGN CONSIDERATIONS

The production of electrical power using steam obtained directly from geothermal sources has been practiced for a number of years. Most of the existing systems were designed to utilize the relatively high temperature geothermal sources which have been exploited to date.

The Raft River area geothermal sources may have temperatures only as high as 302°F (150°C) while cooling water is available at about 50°F (10°C). These conditions are considerably different from those available at the developed geothermal fields, yet they are characteristics of conditions which may be available over large areas while the high temperature sources are available at only a few, special locations.

The two major possibilities for producing electrical power from geothermal sources such as the Raft River area are direct low pressure steam or an organic type fluid (pentane, freon, etc.). In order to provide some idea of the conditions and parameters which would be typical of such power plants, calculations have been made for each type of plant.

3.1 Steam Cycle

The Raft River area may provide saturated steam at 300°F or saturated water at 300°F so calculations were made for a steam obtained by flashing from 69 psia down to 60 psia and down to 35 psia. Figure 1 is a flow diagram for such a system. Table I is a description of each line indicated by the circled numbers on Figure 3. Table II presents the flow rates temperatures and pressures in each line for each geothermal supply condition.

The following assumptions were common to each calculation:

1. The power generation equaled 10 MW(e)
2. The generator efficiency is 90% and the turbine efficiency is 75%.
3. The condensers are all direct contact type.

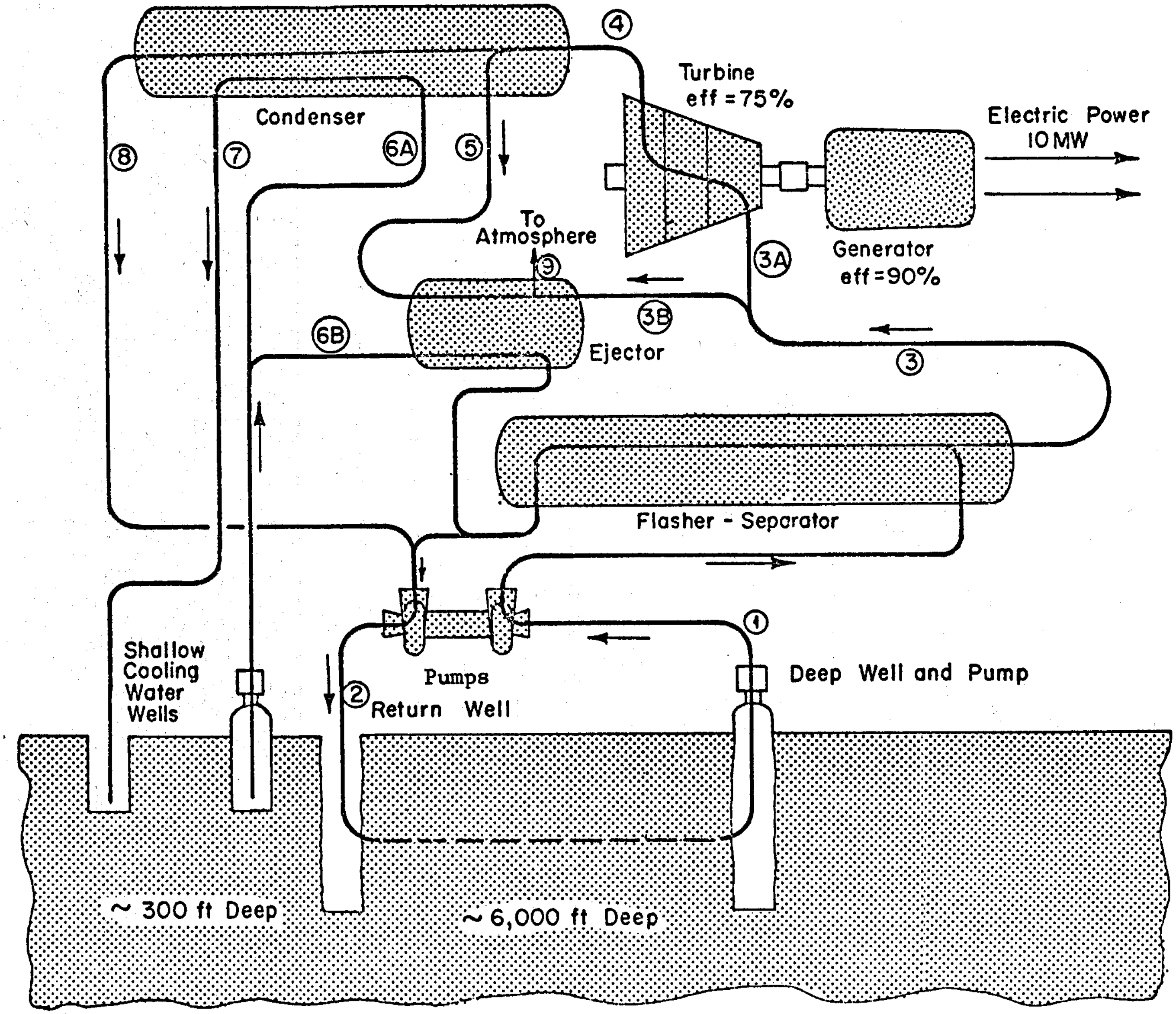


Figure 3 GEOTHERMAL STEAM CYCLE

ANC-A-1595

Table I

Line Identification Key
(for Figure 3)

1	Geothermal water or steam from production wells
2	Geothermal water to re-injection wells
3	Steam from the moisture separator
3A	Steam flow to the turbine
3B	Steam flow to the ejectors
4	Steam from the turbine discharge
5	Non-condensable gases and entrained moisture (50/50 mixture by weight)
6	Cooling water supply
6A	Cooling water to the turbine condenser
6B	Cooling water to the ejector condensers
7	Turbine condenser outlet with 3% geothermal condensate
8	Ejector condenser outlet with 15% geothermal condensate
9	Non-condensable gases vented to the atmosphere.

Table II

Comparison Table
10 MW(e) Steam Rankine Cycle Geothermal Plants

System Cases / Line Designations	Steam From the Field	Geothermal Water From the Field Flashed to 60 psia	Geothermal Water From the Field Flashed to 35 psia
1	Steam 0.184×10^6 lb/hr 300°F 69 psia	Water 19.3×10^6 lb/hr (38,700 gpm) 300°F 69 psia	Water 5.0×10^6 lb/hr (10,000 gpm) 300°F 69 psia
2	Water Negligible Flow 300°F 69 psia	Water 19.1×10^6 lb/hr (38,300 gpm) 293°F 60 psia	Water 4.76×10^6 lb/hr (9,540 gpm) 259°F 35 psia
3	Steam 0.184×10^6 lb/hr 300°F 69 psia	Steam 0.195×10^6 lb/hr 293°F 60 psia	Steam 0.235×10^6 lb/hr 259°F 35 psia
3A	0.166×10^6 lb/hr	0.172×10^6 lb/hr	0.195×10^6 lb/hr
3B	1.8×10^4 lb/hr	2.3×10^4 lb/hr	4.0×10^4 lb/hr
4	Steam with 14% Moisture 0.17×10^6 lb/hr 79°F 1 in HgA	Steam with 13.8% Moisture 0.19×10^6 lb/hr 79°F 1 in HgA	Steam with 12.5% Moisture 0.23×10^6 lb/hr 79°F 1 in HgA
5	Gas with Moisture Entrained 1.66×10^3 lb/hr (gas) 1.66×10^3 lb/hr (water) 79°F 1 in HgA	Gas with Moisture Entrained 1.92×10^3 lb/hr (gas) 1.92×10^3 lb/hr (water) 79°F 1 in HgA	Gas with Moisture Entrained 2.85×10^3 lb/hr (gas) 2.85×10^3 lb/hr (water) 79°F 1 in HgA
6	Water 5.66×10^6 lb/hr (11,320 gpm) 52°F 1 atm	Water 5.85×10^6 lb/hr (11,700 gpm) 52°F 1 atm	Water 6.93×10^6 lb/hr (13,900 gpm) 52°F 1 atm

Table II (continued)

System Cases / Line Designations	Steam From the Field	Geothermal Water From the Field Flashed to 60 psia	Geothermal Water From the Field Flashed to 35 psia
6A	5.55×10^6 lb/hr	5.79×10^6 lb/hr	6.69×10^6 lb/hr
6B	1.15×10^5 lb/hr	1.46×10^5 lb/hr	2.45×10^5 lb/hr
7	Water 5.72×10^6 lb/hr (11,500 gpm) 79°F 1 atm	Water 5.95×10^6 lb/hr (11,800 gpm) 79°F 1 atm	Water 6.93×10^6 lb/hr (13,900 gpm) 79°F 1 atm
8	Water 1.35×10^5 lb/hr (270 gpm) 200°F 1 atm	Water 1.68×10^5 lb/hr (335 gpm) 200°F 1 atm	Water 2.85×10^5 lb/hr (570 gpm) 200°F 1 atm
9	Gas 1.65×10^3 lb/hr (240 scfm) 200°F 1 atm	Gas 1.92×10^3 lb/hr (280 scfm) 200°F 1 atm	Gas 2.85×10^3 lb/hr (420 scfm) 200°F 1 atm

All liquid volume flow rates based on water at 70°F.

All gas volume flow rates based on CO_2 at 70°F, 1 atm.

5. The entraned gas is 1% by weight in the 300°F, 69 psia steam, 1.13 w/o in the 60 psia steam and 1.5 w/o in the 35 psia steam.
6. The ejector capacity was assumed to follow those values given by Perry's Ch. Engr. Handbook, p. 1454.
7. The hot water expanded at constant enthalpy to produce the low pressure steam.

It is rather apparent that a lot of 300°F geothermal water must be brought to the surface to produce the necessary steam by flashing and that a lot of usable heat remains in the saturated water from the flasher. One way to utilize that heat is to install an organic or binary cycle.

3.2 Binary Cycle

Three different working fluids were considered for the binary cycle, Freon-11, Freon-12, and Freon-21. The heat source was assumed to be 300°F water for each case. Figure 4 is a flow diagram of the binary cycle. The resulting flow rates, temperature and pressure for each numbered line and working fluid are listed in Table III.

The same electrical power generation and generator efficiency were used as for the steam cycle but the turbine efficiency was set at 85% to be more representative of organic fluid turbines. The other major assumption was that minimum pinch-points of 10°F were set on all heat exchangers and boilers.

The major difference between the working fluids is that Freon-12 is a supercritical fluid through the heater so it does not boil. Consequently, the geothermal water temperature can be lowered some 90°F and the maximum use is made of the heat available in each pound of geothermal water. The Freon-11 and Freon-21 both were assumed to boil at 250°F. This boiling means that the 10°F pinch point temperature difference restricts the amount of heat which can be extracted from the geothermal water. Therefore, larger amounts of geothermal water must be supplied to the system. As shown in Table III the temperature of the geothermal return water would be about 235°F for either Freon-11 or Freon-21.

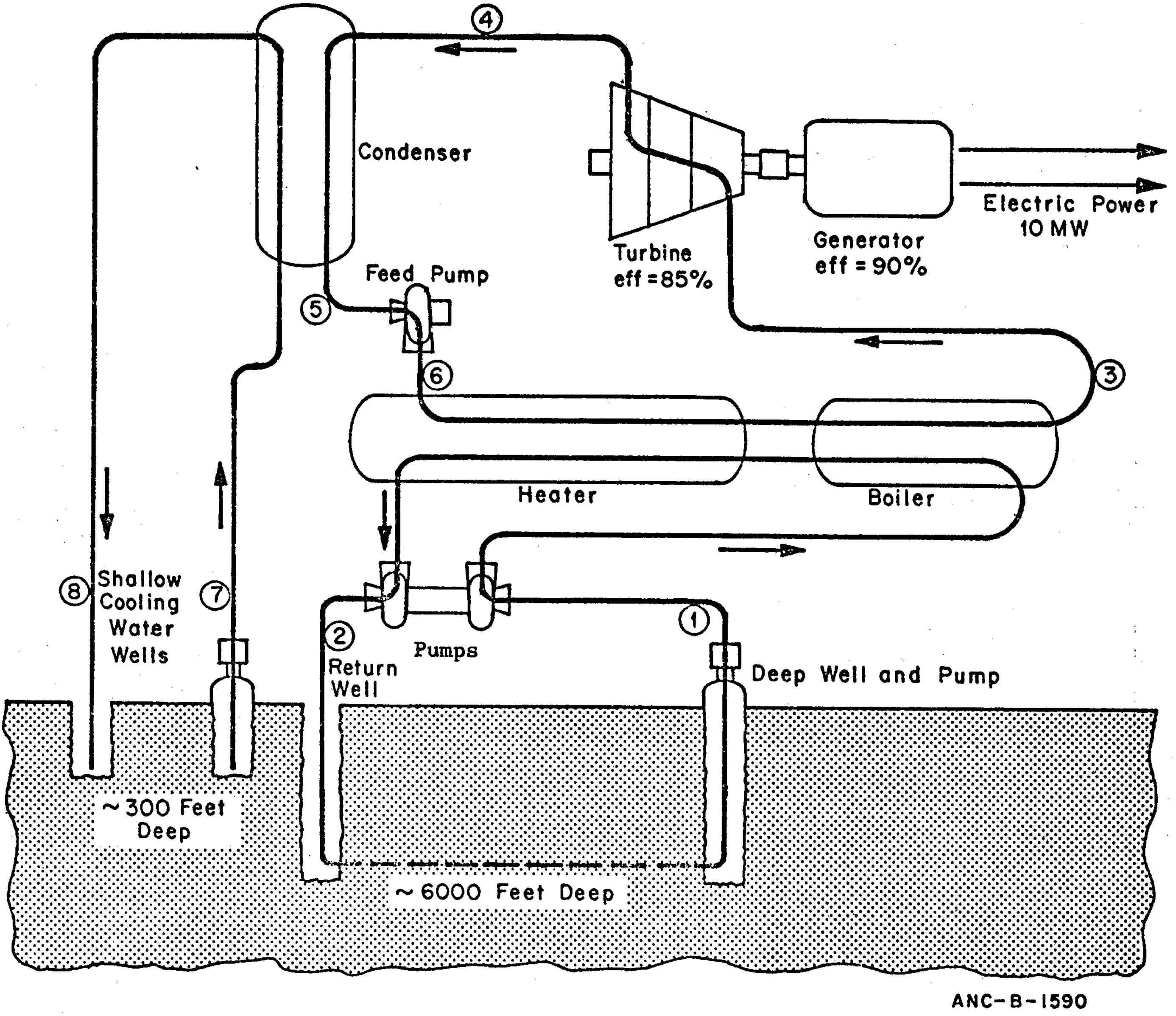


Figure 4 GEOTHERMAL BINARY CYCLE

Table III

Comparison Table
Organic Fluid "Binary" Cycle
10 MW(e) Output

System Cases Line Designations	Geothermal Water from Field to Freon-11	Geothermal Water from Field to Freon-12	Geothermal Water from Field to Freon-21
1	Water 3.01×10^6 lb/hr (6,050 gpm) 300°F >69 psia	Water 1.05×10^6 lb/hr (2,110 gpm) 300°F >69 psia	Water 3.35×10^6 lb/hr (6,750 gpm) 300°F >69 psia
2	Water 3.01×10^6 lb/hr 234°F	Water 1.05×10^6 lb/hr 90°F	Water 3.35×10^6 lb/hr 237°F
3	Freon-11 Sat. Vapor 2.06×10^6 lb/hr 250°F 180 psia	Freon-12 Super Critical 2.92×10^6 lb/hr 290°F 700 psia	Freon-21 Super Heated 1.72×10^6 lb/hr 290°F 300 psia
4	Freon-11 Sat. Vapor 2.06×10^6 lb/hr 80°F 16 psia	Freon-12 Sat. Vapor 2.92×10^6 lb/hr 117°F 99 psia	Freon-21 Sat. Vapor 1.72×10^6 lb/hr 80°F 28 psia
5	Freon-11 Sat. Liquid 2.06×10^6 lb/hr 80°F 16 psia	Freon-12 Sat. Liquid 2.92×10^6 lb/hr 80°F 99 psia	Freon-21 Sat. Liquid 1.72×10^6 lb/hr 80°F 28 psia
6	Freon-11 Comp. Liquid 2.06×10^6 lb/hr 82°F 180 psia	Freon-12 Comp. Liquid 2.92×10^6 lb/hr 88°F 700 psia	Freon-21 Comp. Liquid 1.72×10^6 lb/hr 83°F 300 psia
7	Water 8.1×10^6 lb/hr (16,300 gpm) 50°F	Water 9.4×10^6 lb/hr (19,900 gpm) 50°F	Water 8.7×10^6 lb/hr (17,400 gpm) 50°F
8	Water 8.1×10^6 lb/hr 70°F	Water 9.4×10^6 lb/hr 70°F	Water 8.7×10^6 lb/hr 70°F

Table IV

Operating Parameters
Combined True Binary System

Line Number	Conditions
1	Geothermal water and steam 2.23×10^6 lb/hr, 300°F
2	Geothermal water 2.03×10^6 lb/hr, 300°F, 69 psia
2A	1.05×10^6 lb/hr, 300°F
2B	0.98×10^6 lb/hr, 300°F
3	Saturated steam, 0.203×10^6 lb/hr, 300°F, 69 psia
3A	0.188×10^6 lb/hr
3B	0.015×10^6 lb/hr
4	Steam with 13% moisture, 102°F, 2 in HgA
5	Non-condensate gas with entrained moisture, 0.188×10^4 lb/hr (gas, 0.188×10^4 lb/hr (moisture), 102°F, 2 in HgA
6	Cooling water, 9.4×10^6 lb/hr, (18,800 gpm), 50°F
6A	3.4×10^6 lb/hr, 70°F
6B	5.9×10^6 lb/hr, 70°F
6C	0.11×10^6 lb/hr, 70°F Water
7	Water condensate, 6.1×10^6 lb/hr (12,200 gpm), 102°F
8	Water condensate, 0.11×10^6 lb/hr, (220 gpm), 200°F
9	Cooling water and condensate, 9.61×10^6 lb/hr (19,200 gpm) 92°F
10	Geothermal water, 1.05×10^6 lb/hr, 90°F
11	Geothermal water, 2.03×10^6 lb/hr, 192°F
12	Non-condensable gas, 0.188×10^4 lb/hr, (275 scfm), 200°F
13	Freon-12, Super-heated vapor, 2.92×10^6 lb/hr, 290°F
14	Freon-12, Superheated vapor, 2.92×10^6 lb/hr, 117°F, 99 psia
15	Freon-12, Saturated Liquid, 2.92×10^6 lb/hr, 80°F, 99 psia

This pinch-point limit can be offset somewhat by splitting the heat exchanger and boiler into separate units and supplying each with 300°F water or by utilizing reheat at lower stages of the turbine. Both solutions would require significant capital cost over that required by the Freon-12 system.

It is impossible at this time to make any final selection on such matters as the type of organic fluid; especially since the Freon-12 system operates at significantly higher pressures than either the Freon-11 or Freon-21 systems.

Also, the hot water from the flasher of the geothermal steam system could be used for reheating at the lower steam turbine stages. However, the complete utilization of the heat in the geothermal water by an organic cycle should be more attractive—at least for the demonstration plant.

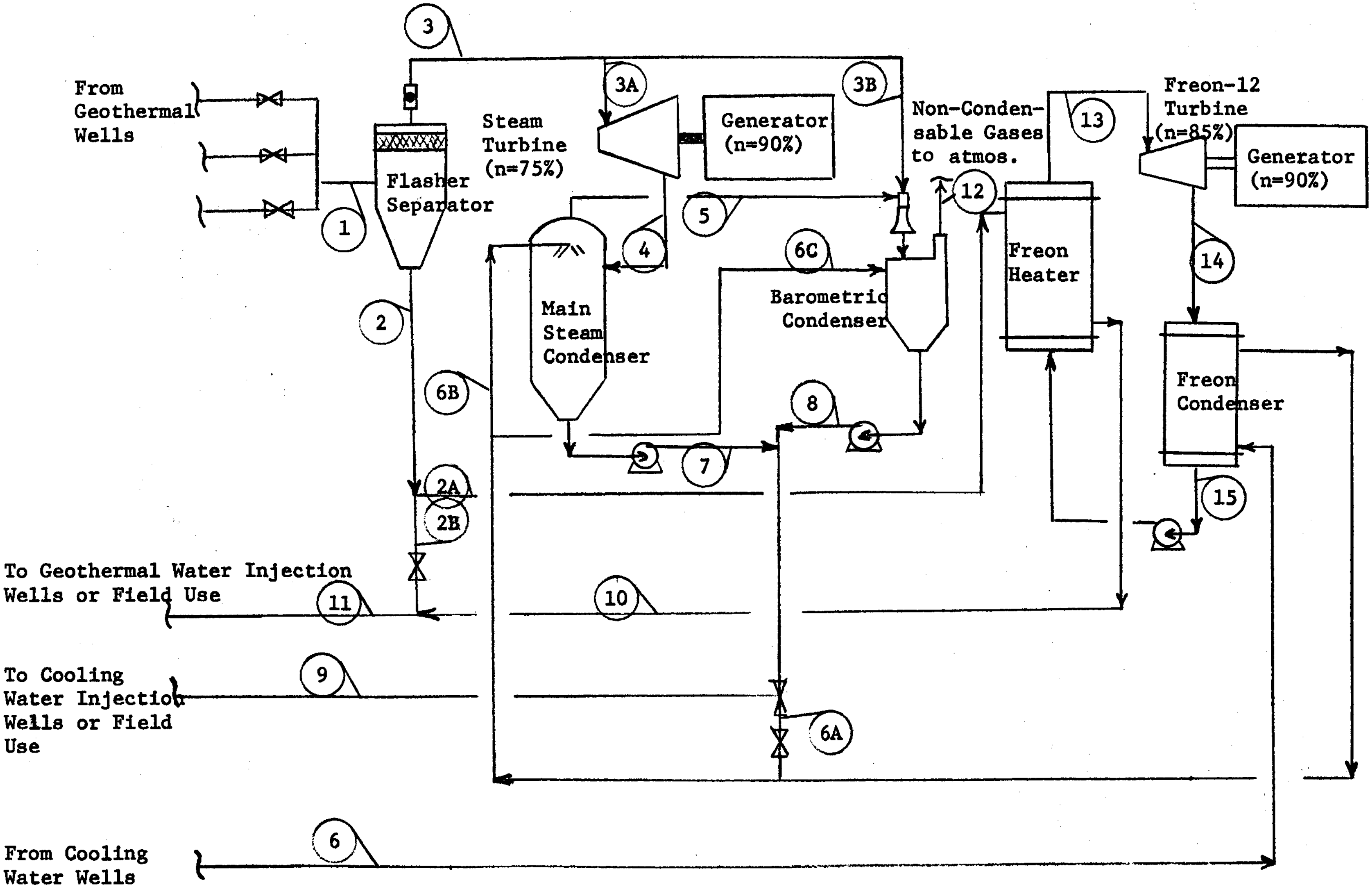
3.3 Combined System

Figure 5 is the flow diagram for a combined, true binary system. Steam is separated at 300°F and sent to the steam turbine and associated condensers, ejectors, etc. Table IV presents operating parameters for the combined system. The hot water from the separator is used to heat Freon-12 before being returned to the geothermal aquifer. During the summer months when the demand for irrigation water is high, the spent geothermal water can probably be used by the area farmers. During the irrigation off-season the spent geothermal water would be returned to the geothermal aquifer. If needed, the regular irrigation wells could be used to recharge the geothermal aquifer during the off-season. Such trading would serve to smooth the power and water demands for everyone.

The amount of geothermal water which will be produced per pound of steam will depend on the aggregate conditions of all the geothermal wells which supply the flashing unit. For the purposes of this design, we assumed that 90% of the geothermal well flow would be water and 10% steam. We also assumed that the steam would contain 1 w/o non-condensable gases.

The size of the Freon-12 system was set at 10 MW(e) so it utilizes only about half of the geothermal water that is available from the flasher

Fig. 5 Combined Steam-Freon Cycle



separator. Trying to optimize the size of the Freon-12 system to the available geothermal water is unwarranted until we have more data on what the geothermal wells produce.

Cooling the geothermal water to 90°F in the Freon-12 system may be impractical due to the precipitation of solids. Such a limitation may well restrict the lower geothermal water temperature to say 150°F; which will mean that more geothermal water is required for the Freon-12 system.

Regeneration has not been incorporated into these designs because it has no economic merit on geothermal power cycles. Regeneration does indeed raise the heat efficiency of power cycles but since geothermal power does not have to purchase any fuel such efficiencies are not good indicators of merit. The only true economic indicator is the total cost per kW-hr which includes fuel costs, operating and maintenance costs, and amortization of the capital investment. The cost of geothermal power will be dominated by the last two factors.

3.4 Two Stage Steam Flash System

Discarding of 95% of the geothermal water after a single flash to 260°F is obviously undesirable. This water could be flashed in a second stage to atmospheric conditions (210°F) and fed to a larger, low pressure turbine tied to the shaft of the high pressure turbine. By flashing at no lower than atmospheric pressure, leakage problems for the flashing unit are minimized. Figure 5a shows such a cycle, and Table IVa gives the flow rates, temperatures and pressures for each numbered line on the figure. This two stage flash system discards 90% of the original water. However, 45% of the enthalpy has been removed (relative to condenser conditions) before the water is discharged. The low pressure turbine will have approximately the same steam mass flow as the high pressure turbine, and the inlet steam density will be only about 1/2 that of the high pressure stage. For this example, both turbines will be operated at a 1 in. Hg back-pressure. The low pressure turbine will need to be much larger (nominally 1.5 times the diameter) than the high pressure turbine. This additional turbine size and cost needs to be contrasted with the heat exchanger and organic fluid turbine for the binary cycle.

Ultimately, unknown technical factors such as the precipitation and fueling by dissolved solids and the amount of non-condensables in the geothermal fluid, will be major deciding factors in determining the most economical geothermal power system.

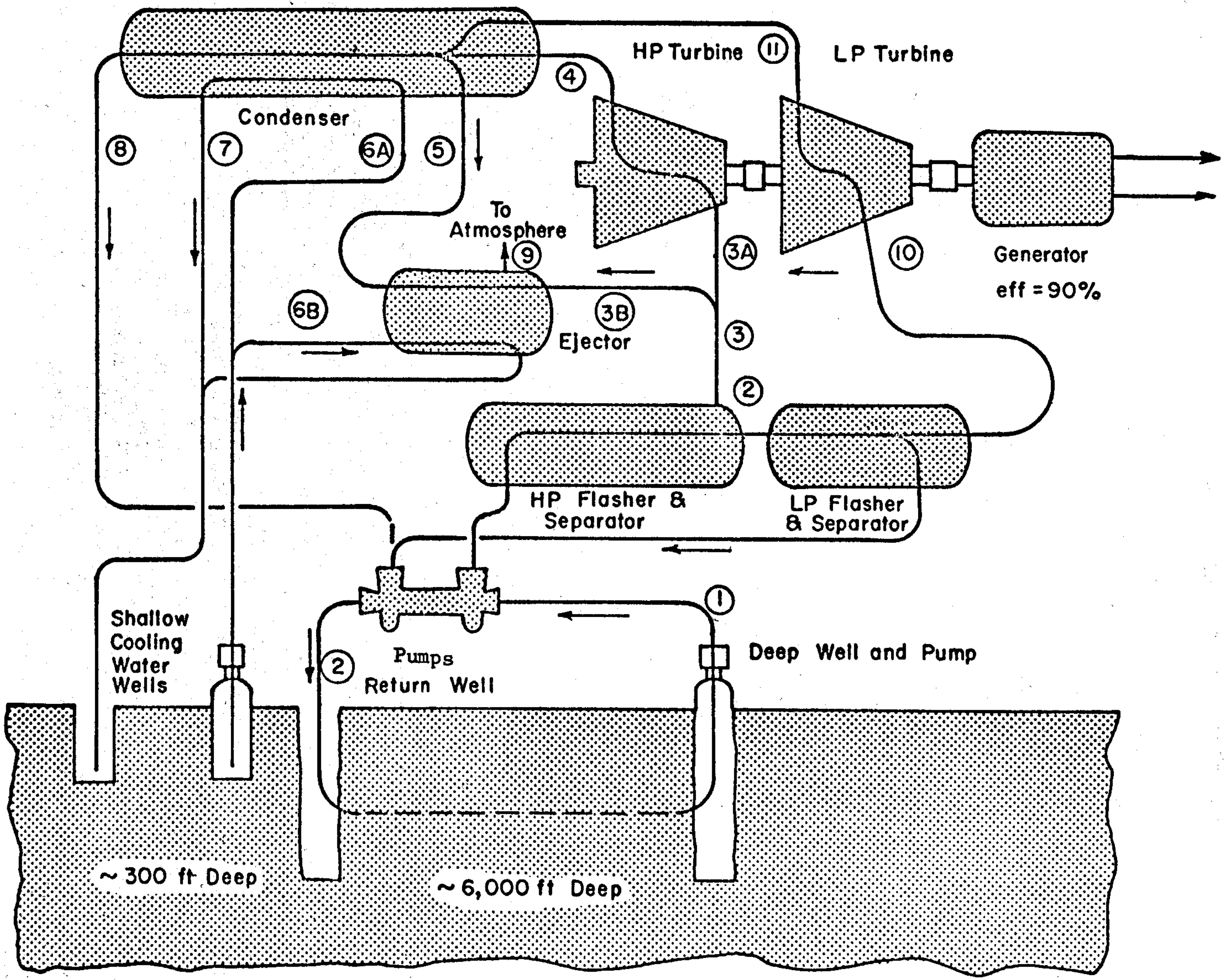


Fig. 5a Geothermal Two Stage Steam Cycle

Table V

Two Stage Steam Flash

	First Stage	Second Stage	Condenser Stage
1	Water 5×10^6 lb/hr (10,000 gpm) 302°F 69 psia		
2	Water 4.8×10^6 lb/hr (9,540 gpm) 260°F 35 psia		
3	Steam 0.24×10^6 lb/hr 260°F 35 psia		
3A	0.20×10^6 lb/hr		
3B	4.0×10^4 lb/hr		
4	Steam with 13% moisture entrained 0.23×10^6 lb/hr 79°F, 1 in. Hg A		
5	Gas with moisture entrained 3×10^4 lb/hr (gas) 5×10^3 lb/hr (water) 79°F, 1 in. Hg A		
6			Water 12.2×10^6 lb/hr (21,400 gpm) 52°F 1 atm
6A			11.7×10^6 lb/hr
6B			5×10^5 lb/hr
7			Water 12.2×10^6 lb/hr 21,500 gpm 79°F, 1 atm
8			Water 6×10^5 lb/hr (1200 gpm) 200°F, 1 atm
9			Gas 6×10^3 lb/hr 900 scfm 200°F, 1 atm
10		Steam 0.24×10^6 lb/hr 210°F 14.1 psia	
11		Steam with 11% moisture 0.24×10^6 lb/hr 79°F, 1 in. HgA	
Power Output with 75% turbine and 90% generator efficiency	10 MW(e)	10 MW(e)	

All liquid volumes based on water at 70°F
All gas volumes based on CO_2 at 70°F, 1 atm

3.5 Geothermal Well Flow

The artesian flow from a geothermal well is governed by numerous variables—the permeability and porosity of the strata in the barefoot section, the fluid resupply to such, the down hole pressure, and the geothermal field temperature. When dealing with low or medium temperature geothermal fluid, the question arises of how well artesian pumping occurs from assumed hydrostatic head differences. The following analysis directs itself to that portion of the total problem of well flow. Assuming adequate supply of geothermal fluid to the bottom of the well bore, what are the maximum pumping rates that can be expected.

Figure 6 is a graph of calculated well flow velocities from different depth wells. The hydrostatic pressure difference due to the density difference between hot and cold legs was used as the available head for producing flow. The cold leg is essentially water-logged soil or a cold water injection well. The assumed 20°C constant cold leg temperature is probably not too realistic, but it is a good working assumption in the absence of detailed information. The hot leg is the geothermal water flowing up the pipe casing in the well. The geothermal water temperature probably wouldn't remain constant, nor would steel pipe casing extend the whole depth of the well; but again those are good working assumptions.

The value of L_m shown for each temperature on Figure 6 is the well depth required to produce a well top pressure equal to the hot leg saturation pressure by the hydrostatic pressure difference between the hot and cold legs. As the well depth is increased beyond L_m, the well flow velocity from Figure 6 is that that could be attained with a well top pressure equal to the saturation pressure. The geothermal water should not boil as it rises to the surface. The two-phase flow which results from boiling will surely increase the friction losses and result in less total flow from a given pipe size. In addition, the friction losses in the above ground piping network between the wells and the power plant proper can be easily and inexpensively overcome by pumping if the fluid is a liquid. But only a thorough study of a given system would reveal the most economical method of bringing the geothermal heat to the surface in a usable vehicle.

The above set of assumptions addresses only the ideal situation of flow with the postulated hydrostatic pumping force. The producing zone permeability has been ignored. If it is inadequate to supply the flows that the hydrostatic head differences can pump, then of course yields will be reduced. Furthermore, the effective depth of the well might be much greater than the actual bore depth, if adequate permeability exists between the bottom of the well and the reservoir.

The results presented in Figure 6 are rather thorough calculations on the simple flow model assumed. The flowing friction factor was calculated from the following equation given in Perry's Chem. Engr. Handbook, 3rd edition, page 282: *

$$f = 0.0014 + 0.090(\mathrm{Re})^{-0.23}$$

The entrance and acceleration losses were assumed to be $1.5\ V^2/2g_c$ in all cases. Table V presents some values which were used in the calculations and which can be used to adjust results on Figure 6 to other situations.

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* Note, this equation should not be used for excessively high ($>10^5$) Reynolds numbers.

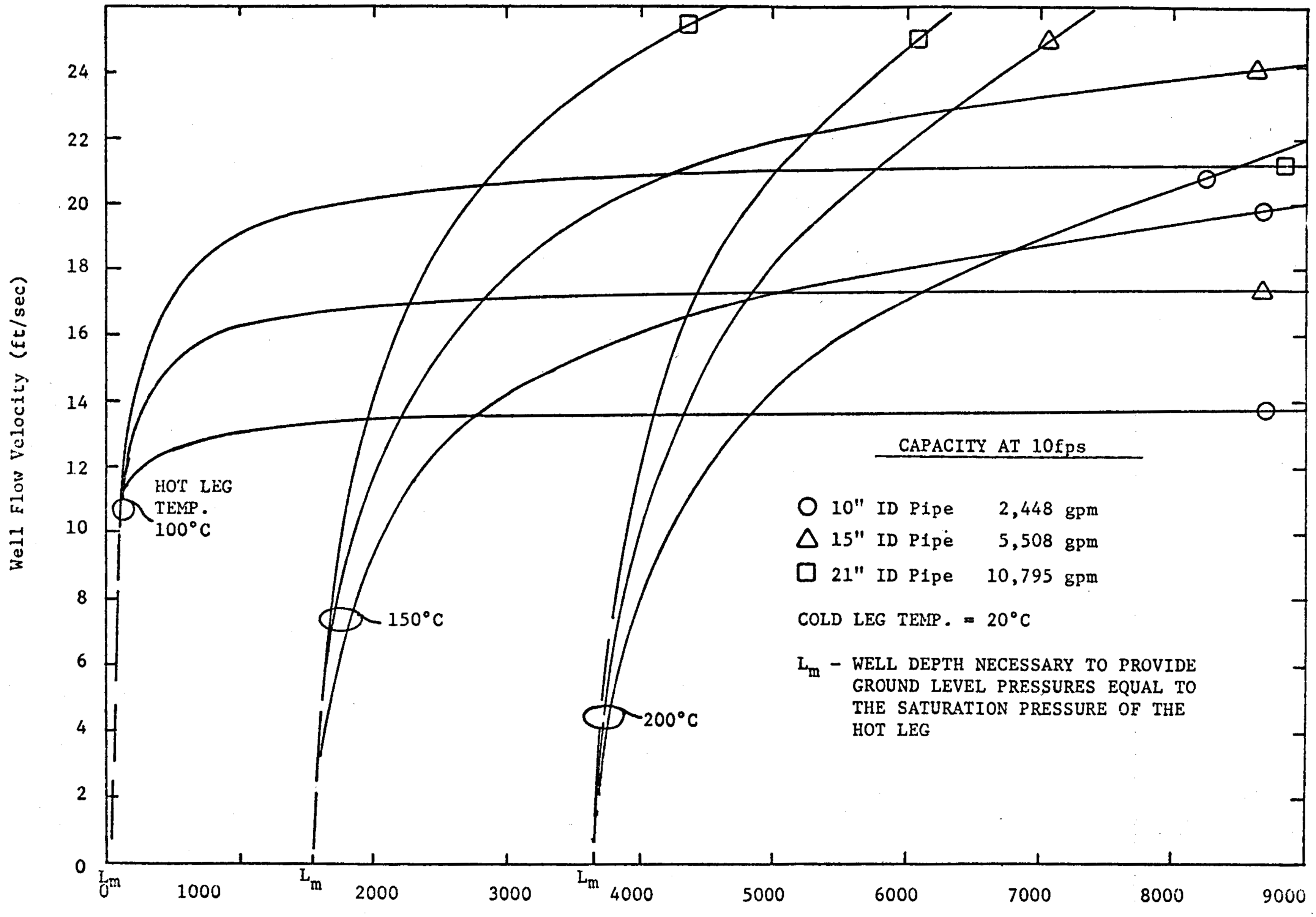

Figure 6 - CALCULATED FLOWS DUE TO HYDROSTATIC HEAD

TABLE VI

Hydrostatic Pressures (Cold leg temp. = 20°C)

Hot Leg Temp. (°C)	Density Difference (lb_m/ft^3)	Hydrostatic pressure per 100 ft. due to the density difference. (psf)	(psi)	Liquid head at 20°C(ft)
100	2.496	249.6	1.73	4.0
150	5.064	506.4	3.52	8.1
200	8.339	833.9	5.79	13.4

For example: say a 15 inch diameter well is drilled to 5000 ft and encounters 150°C water at 80 psig. Using the data in Table V we can determine hot leg/cold leg well depth equivalent to 80 psig:

$$\text{Equivalent well depth} = \frac{80 \text{ psig}}{3.52 \text{ psi/100 ft depth}}$$

$$\text{Equivalent well depth} = 2270 \text{ ft } *$$

From Figure 6, the flow velocity from 2270 ft well would be 14 ft/sec. However, since the actual well contains 5000 ft. of pipe, the square of the flow velocities should be reduced by the inverse ratio of the well depths

$$\frac{(V_{act})^2}{(V_{Fig.\ 6})^2} = \frac{L_{Fig.\ 6}}{L_{act}}$$

$$(V_{act})^2 = (14)^2 \left(\frac{2270}{5000}\right)$$

$$V_{act} = \sqrt{89}$$

$$V_{act} \approx 9.5 \text{ fps}$$

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* In this particular example, the 80 psig at the well bottom at 5,000 ft is less than that obtained from the hot-leg/cold-leg density difference model, which gives 2270 ft for 80 psig.

This estimating technique neglects the difference between the entrance and acceleration losses and between the friction coefficients for the two velocities; however, that error should be quite small compared to other uncertainties such as the variation in the well water temperature, the effects of strata permeability, etc.

From the capacity table on Figure 6, we see that the well would produce about 5,250 gpm. If we assume the geothermal plant requires some 5 x 10^6 lb/hr (10,000 gpm at STP), then eight geothermal wells would be required to produce the water required by a 10 MW(e) plant which flashes only 5% of the geothermal water to steam for the turbines. Such high producing wells have seldom been encountered anywhere in the world, and production rates of 1500 to 2000 gpm are considered likely for planning purposes. Thus, 5 to 6 producing wells would be needed.

3.6 Flow From the Well to the Power Plant

Assume that the geothermal water from the scattered wells are collected into headers, say two wells per header, and pumped one mile through a pipe to the power plant. Each pipeline will have to carry approximately 5 x 10^6 lb/hr (10,000 gpm at 70°F). Assuming an economic pipe velocity of 10 fps the required pipe diameter is 21 in., the pressure drop is 26 psi, and the pumping power is 123 kW. The total system would require nearly 500 kW for pumping. The 10 fps velocity is somewhat higher than the usual economic velocity in a pipeline, however, the necessity of insulating the pipeline will encourage a faster flow. After the geothermal water has been passed through the power plant, it will have to be "returned" a like distance before it is injected back into the aquifer and this will require another 500 kW of pumping power. The total pumping power would be 1000 kW for this system.

As mentioned above, if approximately 5% of the geothermal water is to be flashed to steam, 10,000 gpm will produce 10 MW with 260°F steam. If a higher percentage is flashed, the result will be lower steam pressure and temperature conditions requiring a much larger turbine. The remaining water contains a tremendous amount of heat which can be used to generate power through a binary cycle. This proposal calls for using approixmately 1.0 x 10^6 lb/hr of 125°C water (or its equivalent from the bottom of the flasher/separator unit) and using Freon-12 as a working fluid to produce an additional 10 MW (e) to 15 MW, depending on heat exchanger performance.

Even with both power producing systems in operation some 94% of the geothermal water will still contain a tremendous amount (over 90%) of heat which could be used for other things such as space heating, chemical production, etc. At this point that heat is cheap; however, the capital cost of the equipment to utilize the heat is not.

Rather than transporting all the geothermal water to and from the power plant, it could be flashed at the well and only the required steam and water pumped to the power plant. The water and steam could be transported in separate lines or they could be transported as a mixture.

Assume the geothermal water is flashed to produce enough steam (0.24 x 10^6 lb/hr) to generate 10 MW(e) through the steam turbine and enough hot water to generate another 10 MW through a Freon-12 binary cycle. The steam could be transported one mile with a pressure loss of about 13 psi. The water could be

TABLE VII

Flow Between The Wells and the Power Plant

Case	Fluid	Mas flow Rate (lb/hr)	Pipeline Diameter (in)	Velocity (ft/sec)	ΔP for 1 mile (psi)	Pumping Power (kW)
I	300°F water	20×10^6	21	10	26	123
II	300°F water	1.0×10^6	10.6	10	26	24.6
II	300°F steam	0.2×10^6	28.3	145	13	910
III	300°F steam-water mixture	1.2×10^6	23.7	—	55	3,900

Case Descriptions:

I - One percent of the water is flashed to steam for production of 10 $MW_{(e)}$. The remaining water is available to heat a binary cycle for power generation or to do other things.

II - Only the steam to generate 10 $MW_{(e)}$ and water to generate 10 $MW_{(e)}$ through a binary cycle are transported to the power plant in separate pipelines.

III - The steam and water for Case II are tranported in a single pipeline as a two-phase mixture.

transported at a pressure loss of 26 psi as previously developed. And the steam-water mixture could be transported in a single line with a pressure loss of 55 psi. The necessary pipe line sizes, pumping power, etc. are summarized in Table VI. These results are very interesting; particularly the large pumping power required to recover the pressure drop losses.

Transporting the steam and water as a mixture seems too impractical for further consideration.

The seperate steam and water pipelines would require some 935 KW of pumping power between the production well site and the power plant. However, the water out of the power plant would have to be pumped to the injection well site through a mile long 10-inch diameter pipeline. The water from the separators at the production wells would also have to be pumped to the injection well site and should require four 21-inch diameter pipelines. For essentially the same geographical layout, this system would require an estimated 1800 KW of pumping power.

These steam and two phase flow pressure loss results are not based on simple handbook calculations, but on combined experimental and calculated results of Y. Takahashi, et. al. as reported at the Pisa Geothermics Symposium. ("An Experiment on Pipeline Transportation of Steam-Water Mixtrues at the Otake Geothermal Field", Proceedings of the Pisa Symposium, Vol. II, pp 882-891). They obtained good agreement between experimental results and calculations by the Lockhart-Martinelli method. Since their experimental conditions were close to the conditions expected in the Raft River area, their results were simply adjusted to the required mass flowrates.

Some additional estimates based on the Takahashi article are:

1) Pressure losses at the well-head Christmas tree ≈ 2 psi
2) Pressure losses across the flasher/separator ≈ 3 psi
3) Pressure losses through the turbine inlet header ≈ 5 psi

There is little we can do about the losses under items (2) and (3) without compressing the steam so the necessity of conserving the pressure from the well to the power plant is again emphasized.

Since we do not expect to have much pressure to spare from the wells, our contention that boiling or flashing should be avoided until the last step before the turbine would appear to be justified.

3.7 Summary of Power Plant Design Considerations

The design of a geothermal power plant must be done from a systems approach because of the interlocking effects of so many decisions. The actual economics of the trade-offs between size, number of wells, number of pipelines, equipment costs, power costs, etc. are unknown. Obviously, the evaluation of these choices will require a major engineering effort to achieve an economic design. Also, the trade-off between the economics of a power plant and flexibility of purpose for a demonstration plant must be considered in any final decisions. For instance, as a result of this study, the choice has been made to pump all the geothermal water to and from the power plant. Such a plant will require at least four 15-in. dia. wells to produce 5×10^6 lb/hr of 150°C water from a 5,000 ft depth with a bottom hole pressure of 80 psig and 55 psig at the surface. This is sufficient to run a 10 MW(e) steam plant by flashing only 5% of the water (extracting 25% of the enthalpy). The ultimate capability of this total flow with an organic fluid turbine (binary cycle) is approximately 40 MW(e) if heat down to 36°C is extracted from the geothermal water. Thus the proposed combination of a 10 MW(e) steam and 10 MW(e) organic fluid power plant will either not utilize the full capability of the binary system to extract heat from the fluid, or will result in a steam plant which will not deliver 10 MW(e). Four wells may not be able to deliver 10 MW(e) with single stage steam flash, but their total capability with two stages of steam flash. Utilizing a binary cycle with low pinch point temperature difference capability in a heat exchanger greater than 30 MW(e) might be achieved.

Transporting all the geothermal water to and from the power plant will require four 21-inch diameter pipelines and consume almost 1000 kW of pumping power over the 2 mile distance. This is 10% (or more) of the steam plant output; 5% of the total proposed plant output.

4.0 OPERATION AND RESEARCH INVESTIGATIONS WITH THE PLANT

The documentation power plant will consist, initially, of a 10 MW(e) steam turbine driven generator. This will be followed, approximately a year later, by a binary (organic) fluid system. The binary fluid will probably be Freon-12 although a detailed study is needed before a final choice can be made. The Freon-12 system will be placed adjacent to the steam plant since the hot water to heat the Freon will come from the bottom of the steam flasher/separator unit. The two methods of converting geothermal heat into electricity can be directly compared. The maintenance and operating problems of the wells, pipelines, heat exchanger, turbines, pumps, etc. can be evaluated and new techniques to solve such problems tested.

As pointed out in Section 3.5, there will be a lot of heat available for studying other ways to utilize geothermal energy. For example: space heating, agricultural heating, production of fuel gas from agricultural wastes, chemical production, absorption refrigeration, heat pump augmentation and solar heat augmentation. Even with such diverse activities and investigations there should be plenty of heat to produce much more than 20 MW(e) electrical power by using the organic fluid cycles.

The prolonged performance of these wells is a critical factor in determining the economics of the power plant operation. A new well, if required, will cost two to three times the annual routine operating expenses of the power plant. Thus, the performance of the underground geothermal field in continuing to supply the wells, needs to be studied closely and be well understood before this research and development effort can be replaced by a routine operation.

The geothermal potential of the Raft River Basin can be estimated. It appears that the basin might be a standard Basin and Range type. The valley fill has sufficiently low thermal conductivity so that at a depth of approximately 5000 ft, uniform 150°C temperatures can be expected. The valley has an area of approximately 300 square miles. If one considers extracting 20°F of the heat from a 500 ft layer of rock and water (from 4500 to 5000 ft depth) with a net "efficiency" of only 10% (i.e., only 10% of sensible heat is converted to electricity), then the valley could run a 100 MW(e) plant for more than 250 years.

Note, heat flow (conduction) upwards from the basement rock is too small to be of interest, on the average, being able to supply only 10 MW(e) over the entire valley with heat flow of 3×10^{-6} cal/cm^2 sec. This assumes no near surface, hot, intrusive igneous body. However, if a hot intrusive body is present, then heat flow alone can contribute substantially more than this amount of power.

The geothermal waters in the Raft River Valley contain several thousand parts-per-million (ppm) of dissolved solids. (Present indications are 3000 ppm.) Though this could be considered "pure" water to geothermal standards, it is highly erosive to most conventional turbine materials. In addition, deposition is a problem on well casings, piping, and turbine blades. Methods of reducing such deposition are essential if re-drilling and maintenance costs are to be minimized. Various methods will be studied during plant operation phases.

4.1 Environmental Considerations

The proposed power plant will be located in a relatively isolated portion of the state. The general terrain consists of sagebrush-covered rolling landscape with a sprinkler-irrigated region encompassing the more flat river valley area. The power plant will be located most likely on federal (BLM) land with hot water wells and condenser cooling water wells on both private* agricultural, federal land and state land. (See Figure 7).

Most of this federal and state land has no present recreational developments since it contains no surface water or trees. It's agricultural value is marginal because of the lack of irrigation water and quality of the soil. Industrial value is low for this region because of the sparse population and present limited electric power. A power plant requires few operating

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* The Raft River Electric Co. has acquired 5 year leases on over 100,000 acres of private land in the area of interest. As a research and development project, it is assumed that the needed federal and state land will be reserved.

personnel and can be made to be esthetically pleasing to minimize visual pollution to the surrounding area. The proposed power plant will not release steam to the atmosphere from unused hot wells or cooling towers as is done in steam fields. Cooling water will be pumped from the cold water aquifer and returned to either the cold water or hot water aquifer. All cold water lines will be buried underground. Insulated hot water lines will probably be placed above ground because of considerations of temperature expansion and maintenance, but will be made to blend with landscape.

One power substation will be required with a high voltage power line connecting the substation to the main north-south power grid several miles away. Roads will be paved from the power station to the Raft River highway and existing roads will be utilized as much as possible.

4.2 Testing Program to Achieve Objectives

The testing program will be aimed at establishing the information needed to achieve the two principal goals: 1) economical power production from medium temperature geothermal water, and 2) minimum environmental impact in which all brackish geothermal fluids are re-injected without contaminating domestic and irrigation aquifers. Among the specific items which the testing program will address are the following:

Turbines	Steam turbine sizes will be larger, with unusually low pressure operation. Organic fluid turbines, though smaller, will be subject to possible corrosive attack from minor decomposition rates in what is otherwise an innocuous working fluid.
Condenser	Performance, both steam and organic, utilizing the maximum extent of the low temperature heat rejection reservoir.
Well Casing & Piping	Study and prevention of corrosion and deposition.
Heat Exchangers	For organic fluids, the deposition on the geothermal water side and the resulting degradation of heat exchanger performance must be studied and minimized.

Re-injection Capability	Both of the geothermal fluids, and the condenser coolant if aquifer water is to be used.
Field Performance	Maintenance of geothermal fluid reservoir content, and production capability of wells through re-injection and other means. Monitoring of micro-seismic activity. Also, fluid composition will not only affect power plant material performance, but the information may lead to methods of determining characteristic changes in the reservoir. Table VII gives the composition and characteristics of the water now flowing from the two boiling wells in the Raft River Valley.

Table VIII

Chemical Content and Other Characteristics of Boiling Raft River Wells

	Bridge (BLM) Well	Crank Greenhouse Well
Report Depth (ft)	414	540
Discharge Rate (gpm)	58	60
Discharge Temperature (°C)	93	>90
Silica (ppm Si)	90	97
Ca (ppm for following)	53	130
Mg	0.4	0.4
Na	560	1110
K	22	55
HNO_3	55	36
CO_3	0	0
SO_4	57	61
P	0	0.01
Cl	900	1900
F	5.7	14
NO_3	0.54	0.57
Total Dissolved Solids	1720	3360
Hardness as $CaCO_3$	130	330
Specific Conductance (mhos)	3050	6090
pH	7.4	7.7
Silica deduced reservoir temperature	135°C	135°C
Na/K/Ca deduced reservoir temperature	145°C	140°C

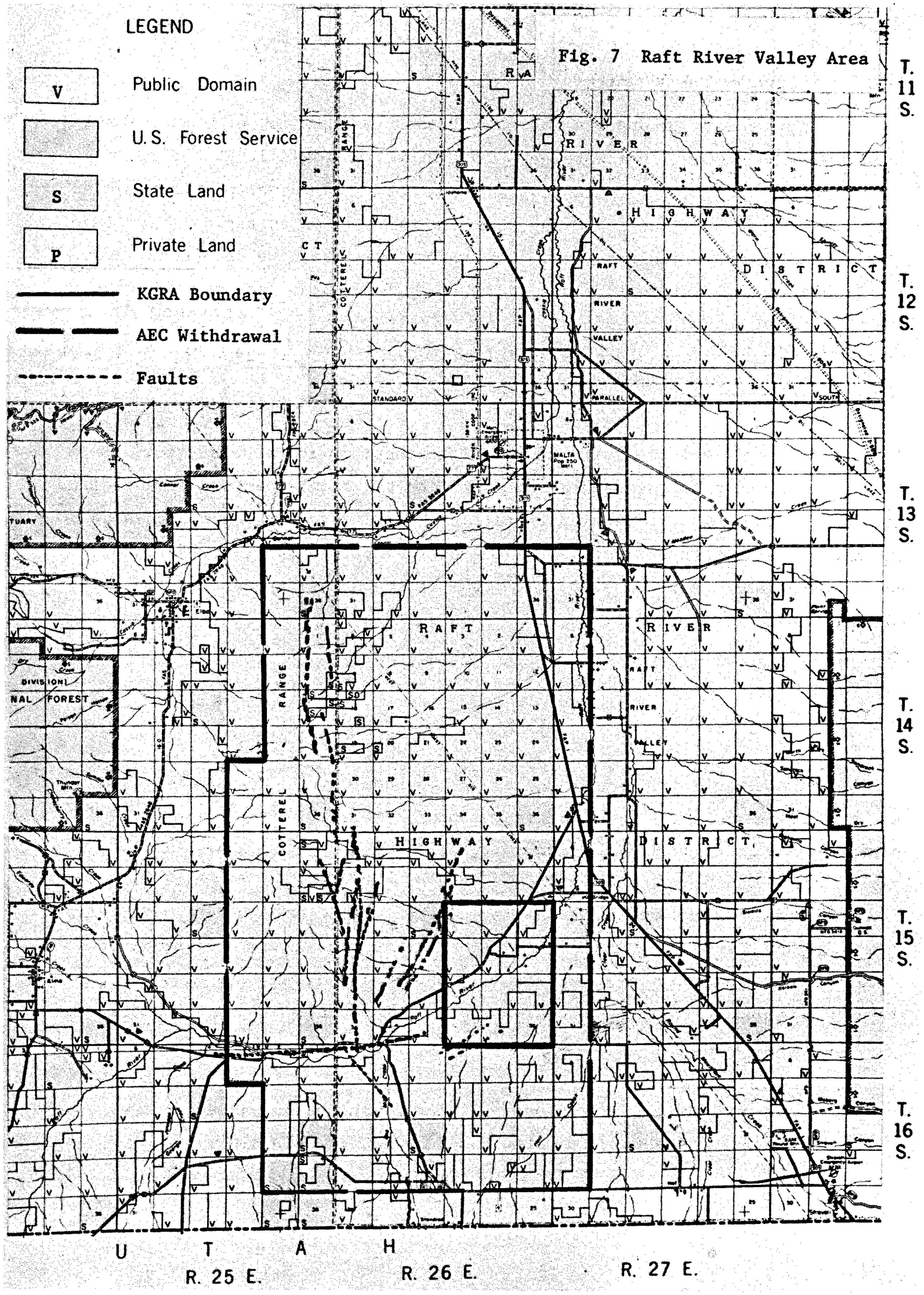

Fig. 7 Raft River Valley Area

5.0 SCHEDULE AND BUDGET

The need is imperative for a research demonstration of a geothermal power plant operating on low temperature fluid. The dwindling supplies of power in the northwest require that additional thermal power plants be added quickly. Therefore, the following schedule is based on as rapid as feasible design and construction schedule. Certain constraints have been considered, particularly the fact that fiscal year 1974 budget authorizations for geothermal research and development are not likely to be large. The scheduled activity, however, shows a substantial scale up of effort beginning in fiscal year 1975.

The critical items which govern the construction schedule for the steam power plant demonstration phase are the completion of conceptual design and the authorization of Title I final design. A three month lapse between these events is assumed. The steam power is shown ready for check out and operation approximately 15 months after the beginning of Title I design, 18 months after the start of deep drilling of the first of three to four wells needed for production. Thus, the bidding authorization for drilling this first well must be under the research phase of the program and need not await the construction phase.

The estimated budget is based on a schedule which would see the steam turbine phase of the plant operational by early in 1977, and the binary cycle (or possibly a second stage flash cycle) operational about one year later. The initial research and development phase is estimated to cost $2.5 million. Construction and siting cost of the first 10 MW(e) power plant operating on the steam cycle is approximately $5.0 million.* The cost of constructing the binary cycle plant is expected to be somewhat higher, approximately $7 million. Its construction must be preceded by a significant amount of additional research and conceptual design, perhaps totalling $1 million.

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* Plus an additional $1.0 million unallocated contingency added to the construction data sheet estimate (Schedule 44, # 75-ID-010).

6.0 PARTICIPANTS AND FUNDING ARRANGEMENTS

The proposed demonstration project is being undertaken by two principal partners--Aerojet Nuclear Company of Idaho Falls, a prime contractor to the Atomic Energy Commission, and Raft River Electric Company, an electrical cooperative serving 10,000 square miles covering portions of Idaho, Utah, and Nevada. Aerojet will also subcontract portions of the research effort to three state-funded universities, University of Utah, in Salt Lake City, Idaho State University in Pocatello, and Boise State College in Boise, Idaho. Thus, the state governments of both Idaho and Utah will have direct access to the research and development information from this project.

All of the involved parties are undertaking this project as a non-profit research and development effort. Funding is being proposed as originating mostly from the federal government, with the Atomic Energy Commission (AEC) administering the program and Aerojet Nuclear Company as the prime contractor. Direct AEC administrative control would be with the Idaho Operations Office in Idaho Falls, approximately 100 miles from the Raft River Electric Co. offices. The National Reactor Testing Station, where most of the preliminary design and development work will be performed is 40 miles north of the Raft River Electric Co. service area.

Associated organizations of the Raft River Electric Co., namely the Snake River Power Association and the Public Power Council have contributed appropriate "seed" funding during the early phases of the project. But since these organizations are non-profit, regulated, and consumer owned, their resources for research are quite limited. Their contribution therefore is expected to be less than 3% of the total estimated project cost of $16 million over 4 years. Raft River Electric will supply the switch gear and transmission lines so as to appropriately utilize the power generated by the plants. As of March 1974, Snake River Power Association and Raft River Rural Electric have invested approximately $60,000 into geological studies and the acquiring of leases. Federal funding from the Atomic Energy Commission will total approximately $200,000 through June 1974. A nominal 40% of this total is being directed toward additional geological and geophysical work by the U.S. Geological Survey.

Once the plants become operational, Raft River utility or the Snake River Power Association will be responsible for the routine daily operation. The federal government, however, will retain ownership throughout the research and testing phases and may pre-empt operation for research testing purposes. At such time as the plants are no longer needed for research, the Raft River Rural Electric Coop. will be given the option of either purchasing the plants or of leasing the plants from the government.

During the research phases of the work, the net worth of all power generated will be calculated, and that portion which would be characteristic of average fuel costs for a conventional thermal power plant will be used to determine the lease royalties (typically 10% of the resource value).

It is anticipated that the routine operational costs (borne by Raft River Electric Company) for these plants will be less than the current wholesale electric power costs in the area (∿4 mills in 1974). If indeed this is the case, then the difference may be used for appropriate amortization of the plant costs (not the research costs).

Note added August 10, 1973

On August 10, 1973, the Northwest Public Power Association and the Public Power Council testified to the Senate Interior Subcommittee on Water and Power that they endorsed and would support the proposed Raft River Geothermal Demonstration Power Plant. Specifically, the Public Power Council will supply, through its 104-member organizations, financial backing to the Raft River Rural Electric Cooperative. Such support would include the generation switchgear, geothermal leasing, and some geological information and consulting costs which would be the responsibility of the utility. Letters of intent to support such project involvement have been received from a large fraction of the 104 utility membership. Funding details are currently (March 1974) in the process of being determined.

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