TREE-1278

SEMIANNUAL PROGRESS REPORT

FOR THE IDAHO GEOTHERMAL PROGRAM

OCTOBER 1, 1977 TO MARCH 31, 1978

Approved:

L. F. Burdge, Director
Programs

J. H. Ramsthaler, Manager
Geothermal Electric

R. J. Schultz, Manager
Program Management and Technology Transfer

R. R. Stiger, Manager
Advanced Programs

TREE-1278

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Geothermal Energy

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OCTOBER 1, 1977 TO MARCH 31, 1978

EG&G IDAHO, INC.

IDAHO NATIONAL ENGINEERING LABORATORY
IDAHO FALLS, IDAHO 83401

Edited by G. L. Blake

July 1978

PREPARED FOR THE
DEPARTMENT OF ENERGY
DIVISION OF GEOTHERMAL ENERGY AND IDAHO OPERATIONS OFFICE
UNDER CONTRACT NO. EY-76-C-07-1570

ABSTRACT

This report discusses the research performed by the Idaho Geothermal Program between October 1, 1977, and March 31, 1978. It describes well drilling, pipeline construction, and pump tests at the Raft River Geothermal Site. It summarizes reservoir engineering experiments and injection tests. Studies of scaling, fouling, and corrosion are discussed. The report details the design of the facility's first electrical generator, a small prototype unit. Plans for two 5-megawatt pilot plants are described. The report also describes experimenters' preparations for testing a fluidized-bed industrial dryer. The aquaculture, agriculture, and heat-dissipation/soil-warming experiments continued during the period; the report describes modifications to the aquaculture and heat-dissipation facilities, and it discusses the analysis of crops from the agriculture experiment. The report outlines the workings of a feasibility study, which is identifying federal installations that could use nearby geothermal resources for space conditioning. Tests of both vertical and horizontal liquid-fluidized-bed heat-exchanger models are described. The University of Utah's work with direct-contact heat exchangers is summarized. The report discusses reservoir engineers' assessment of low-temperature resources near Boise, Sugar City, and elsewhere. The Geothermal Program's environmental effort, which comprises studies of fluorosis and the ferruginous hawk, is also described.

SUMMARY

The Raft River fluid supply and injection system, which will be able to carry enough geothermal fluid to power the first 5-megawatt pilot plant, was expanded during the period. The pipeline network was enlarged, and production and injection pumps were tested. Reservoir engineers conducted a number of tests to help them better understand the Raft River resource. Experimenters performed injection tests on well RRGI-4, filtration tests at RRGE-3 and RRGI-4, and scaling tests with mixtures of water from different wells. Samples of metals which may be used in heat exchangers were studied in the test loop at Raft River. Admiralty brass and type 316 stainless steel showed good resistance to fouling and corrosion.

The Raft River prototype generator was readied for initial startup. Researchers also completed Title II design work on the first 5-megawatt pilot plant and began design studies for the second. The first pilot plant will use conventional shell-and-tube heat exchangers; the second plant will test new direct-contact components.

Direct-use experiments also continued at Raft River. Researchers prepared to test a fluidized-bed industrial dryer. The shrimp, catfish, and tilapia that are being cultured for the aquaculture experiment were moved to improved raceways. Shrimp living in geothermal water and eating nothing but waste organic material from upstream raceways exhibited phenomenal growth rates. Crop samples from the agriculture experiment were analyzed, and new crops were planted. Hardware from the heat-dissipation/soil-warming experiment was modified. Researchers also undertook a survey of federal buildings in the U.S., to see how many are close enough to geothermal resources to consider their conversion to geothermal space conditioning.

Models of liquid-fluidized-bed heat exchangers, which use a bed of floating sand to continuously clean metal parts and improve heat transfer, were tested at Raft River. Both vertical and horizontal configurations were used. The vertical unit exhibited more uniform flow distribution, but horizontal designs offer more cross-sectional area for heat transfer. Engineers began designing a horizontal model which should embody both advantages.

The Idaho Geothermal Program has also supported the development of direct-contact heat exchangers. Engineers at the University of Utah analyzed different system designs, modified computer program DIRGEO, and constructed and tested a direct-contact condenser. They also studied the effects of metastable liquids and prepared a chapter for the sourcebook on geothermal energy.

Reservoir engineers also studied areas other than Raft River. Relatively low-temperature resources near Boise, in Sugar City, and throughout the Snake River Plain were investigated. At the end of the report period, many developers were beginning to plan uses for identified reservoirs.

Environmental researchers continued to gather baseline information in the Raft River Valley. The ferruginous hawk was very carefully studied. Investigators from Utah State University began clinical dental examinations, to obtain baseline data about human fluorosis. Crews began drilling the first in a series of shallow environmental-monitoring wells. The wells will be used to test the effects of fluid injection.

CONTENTS

FIGURES

TABLES

SEMIANNUAL PROGRESS REPORT

FOR THE IDAHO GEOTHERMAL PROGRAM

OCTOBER 1, 1977 TO MARCH 31, 1978

I. THE RAFT RIVER RESOURCE

Four deep geothermal wells supplied fluid to a number of experiments during the period. In preparation for a 5-megawatt power plant soon to be constructed, scientists planned an expanded supply and injection system, which will include three new wells. Crews also began drilling a series of shallower wells, which will monitor the effects of fluid injection. About half of the pipelines necessary for the power plant were completed, pump tests were performed, and new buildings were constructed at the Raft River site. In addition, scientists conducted a number of experiments to help them better understand the geothermal reservoir itself.

1. WELLS – L. G. Miller, J. H. Lofthouse

The four deep geothermal wells were used extensively during the report period, supplying as much as 48 liters per second (760 gallons per minute) at temperatures approaching 150°C (300°F). (Table I details flow rates and water temperatures, and Figures 1 and 2 show the wells' locations.) RRGE-1[a] produced water continuously. The well supplied water for fouling and corrosion experiments (see Section I-3); for fluidized-bed and direct-contact heat-exchanger tests (see Section IV); for fish-farm, soil-heating, and irrigation experiments (see Sections III-2, 3, and 4); and for space heating at the Raft River site. Crews readied RRGE-2 for the installation of a downhole pump. Reservoir and pump tests were conducted at RRGE-3 on an intermittent basis. As much as 38 liters per second (600 gallons per minute) of fluid from the third well supplied injection tests on RRGI-4 (see Section I-3).

The first 5-megawatt power plant (see Section II-2) will require a total of seven wells: three production wells, two injection wells, and a reserve well of each type. Planning and procurement activities for well drilling proceeded during the report period. Site and conductor construction were completed for RRGP-5 and RRGI-6. RRGP-5 will be completed with multiple legs to enhance its production capability. RRGI-4, which was used as a test injection well, will be deepened for use as a production well.

[a] RRGE stands for Raft River Geothermal Exploratory well; an I or P in place of the E would indicate the well was intended for either Injection or Production.

TABLE I

PRODUCTION FROM RAFT RIVER GEOTHERMAL WELLS

	Flow Rate (L/s)	Flow Rate (gal/min)	Wellhead Temperature (°C)	Wellhead Temperature (°F)
RRGE-1	3 to 16	50 to 260	135	275
RRGE-2	1 to 30	20 to 500	133	272
RRGE-3	1 to 50	20 to 800	144	292
RRGI-4	36	570	122[a]	252[a]

[a] Downhole temperature.

Crews began drilling the first in a series of shallower wells that will be used to monitor the effects of fluid injection. A 150-meter (500-foot) well was drilled between November 17, 1977, and January 6, 1978. The well (designated MW-1 for environmental Monitoring Well) will flow 2 liters per second (30 gallons per minute) with a bottom-hole temperature of 107°C (225°F). A deep monitoring well, MW-2, was begun on January 18, 1978. It was completed to 405 meters (1328 feet) on March 16, 1978. The second well is located about a quarter mile southeast of RRGI-4. (See Section VI for a discussion of the environmental program. Figure 28 shows a map of the wells' locations and a cross section of the first two wells, and Table IX describes their water chemistry.)

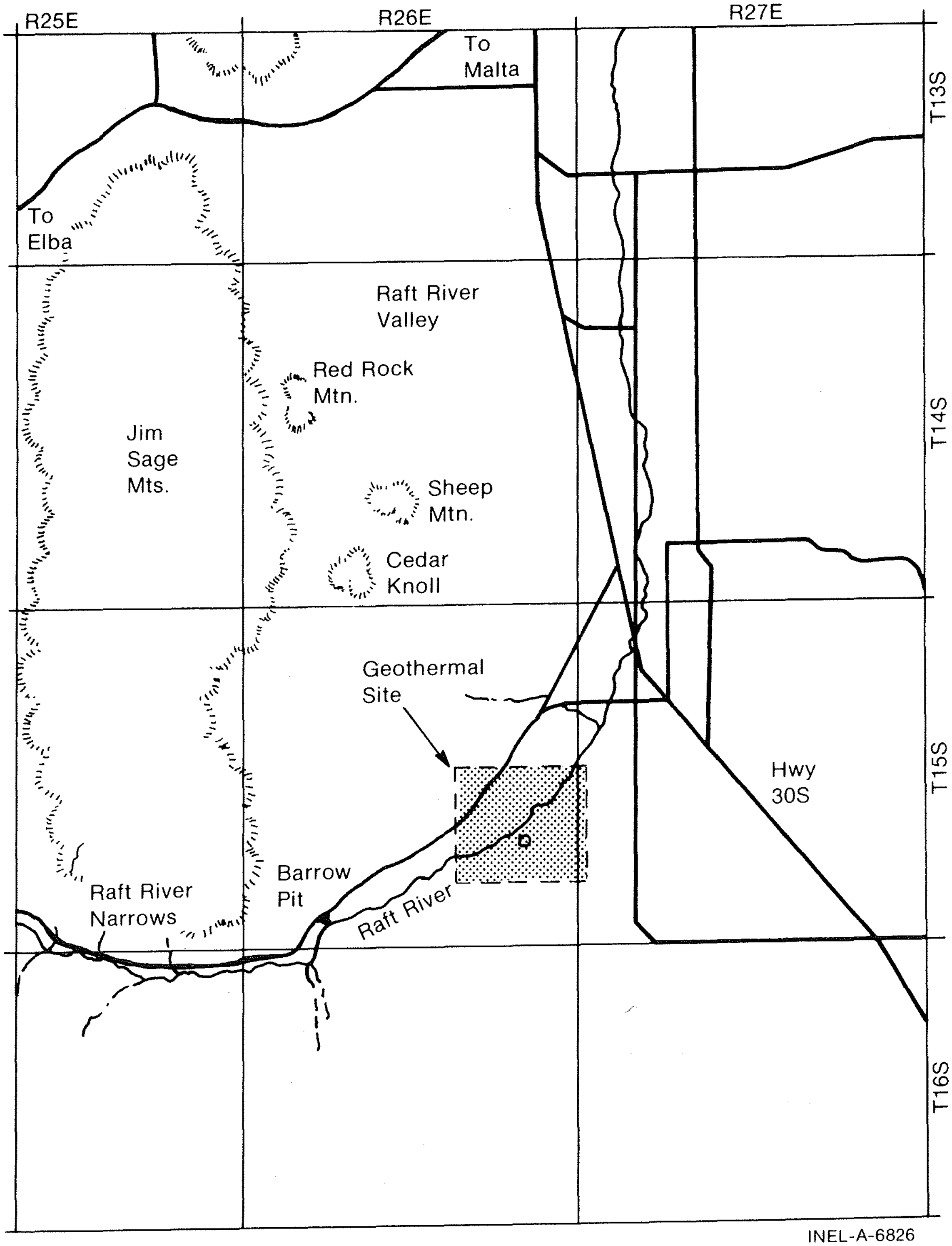


Fig. 1 Location of Raft River Geothermal Site.

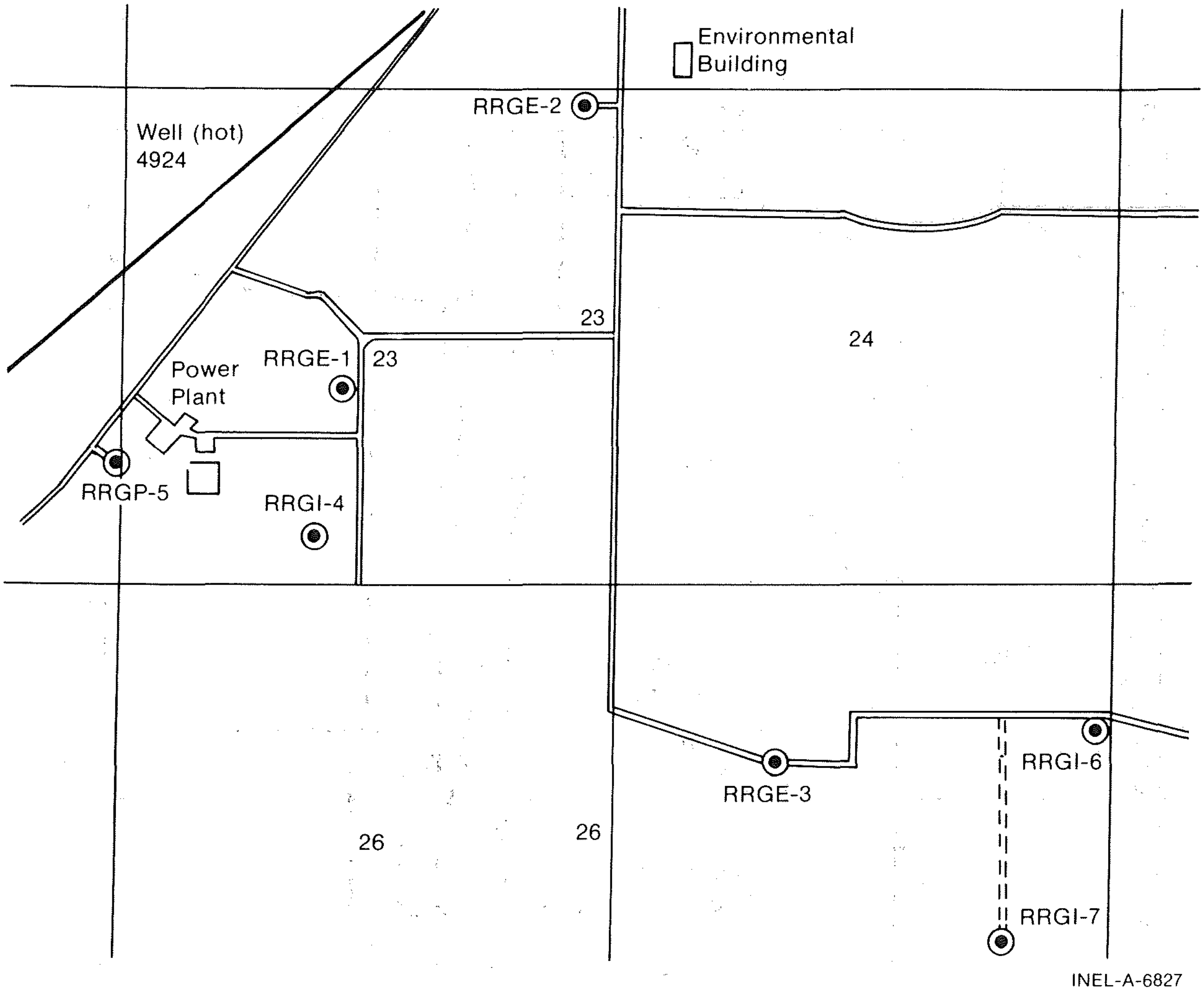


Fig. 2 Location of Raft River geothermal wells.

2. PIPELINES, PUMPS, AND SITE FACILITIES – L. G. Miller, J. H. Lofthouse

Approximately 50% of the piping required to carry fluid to and from the first 5-megawatt power plant is now complete. The lines connecting RRGE-1 with RRGE-3 and RRGI-4 were completed and are now in service (see Figure 3). (For a description of the test injection of RRGE-3 fluid into RRGI-4, see Section I-3.) A subcontract for installing the line between RRGI-6 and RRGP-3 was awarded. The design of piping connecting RRGP-5 to the line between RRGE-1 and RRGI-4 was also completed. As in the past, all lines will be made of inexpensive asbestos-cement buried at least 0.6 meters (2 feet) deep, and covered with 25 millimeters (1 inch) of spray insulation. The remainder of the pilot-plant piping system will be designed and constructed during the coming period. Until the pilot plant is ready to be connected and tested, a temporary crossover will allow engineers to test the pipeline system.

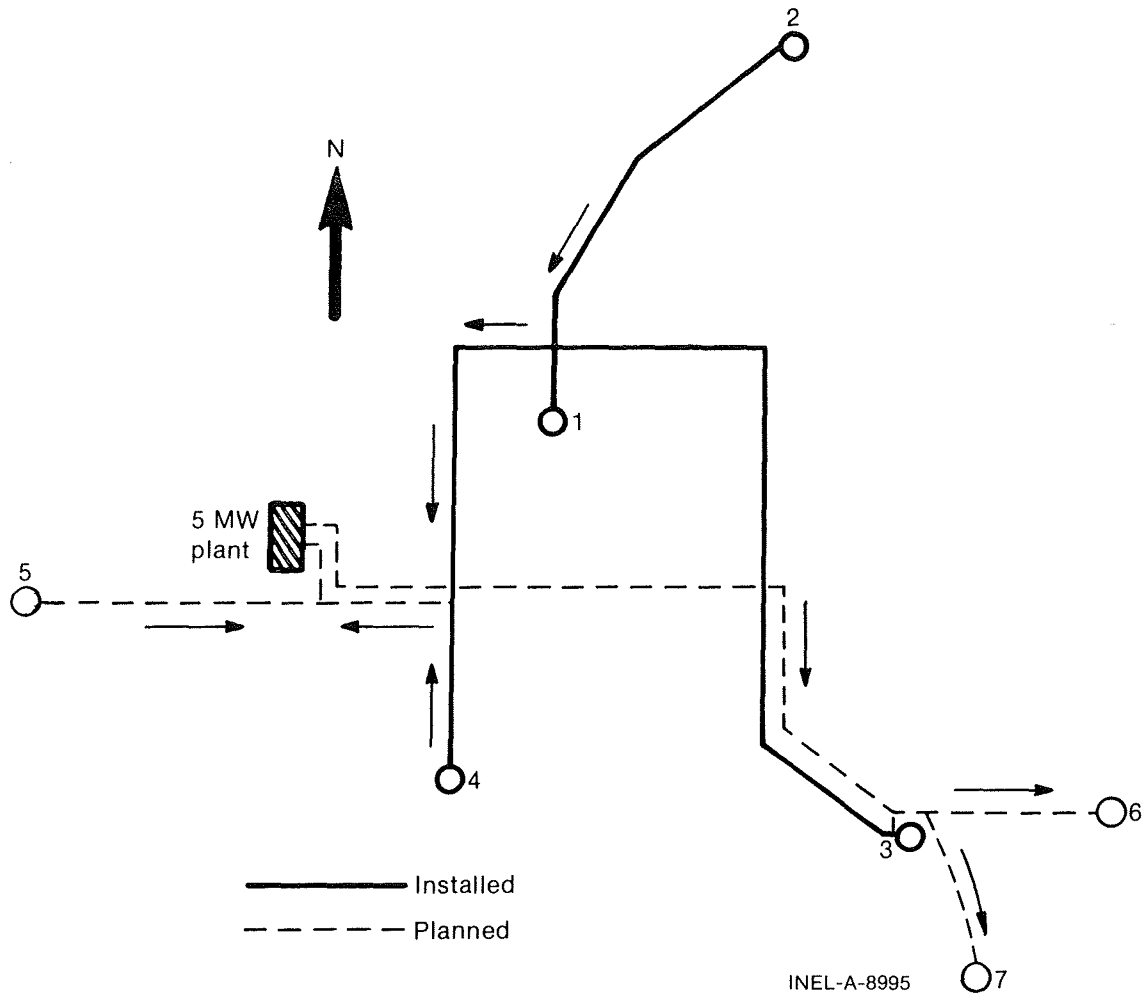


Fig. 3 Raft River pipelines.

One new pump was tested during the period. A submersible pump was set in RRGE-3 on May 7, 1977, and it has since operated for a total of over 1300 hours. A series of one-day tests was run during this period. A 24-day test at 38 liters per second (600 gallons per minute) began on November 28, 1977, and a 10-day test at 41 liters per second (650 gallons per minute) began on January 31, 1978. Additional tests are scheduled for April 1978. This pump has supplied the water for the RRGI-4 injection test, which is discussed in the following section.

Three new buildings were constructed at Raft River during the first half of FY-78. Crews built an 18 x 18-meter (60 x 60-foot) storage warehouse south of the fenced storage area at the RRGE-1 site. They also erected a 9 x 22-meter (28 x 48-foot) building to house direct-applications experiments. It is located 11 meters (35 feet) south of the RRGE-1 compound. Finally, a 9 x 22-meter (28 x 72-foot) building was constructed in the southeast corner of the first well's compound. This building will provide a receiving area for equipment, a control room for the prototype generator (see Section II-1), and space for a conference room and office. Plans were also made for an addition to this building. It will include a computer room, restrooms, and a lunch and dressing area for the craftsmen. This is the only construction proposed for the second half of FY-78.

3. THE RESERVOIR

3.1 Reservoir Engineering – W. L. Niemi

Reservoir engineers continued to test and evaluate the Raft River geothermal reservoir. RRGE-1 supplied water for various experiments connected with resource development. These experiments involved a corrosion test trailer, model heat exchangers, agricultural experiments, and a prototype generator. RRGE-1 water heated office buildings, work facilities, and living quarters at the well site. Approximately 195 million liters, or 195,000 cubic meters (51.4 million gallons) were used in connection with the experiments. During January alone, 40,500 cubic meters (10.7 million gallons) of the first well's water supplied the experiments.

Additional flow tests were conducted on RRGE-3 and RRGI-4. RRGE-3 was pumped at a rate of 38 liters per second (600 gallons per minute) during two tests – once for three days and once for 24 days. These tests yielded drawdown curves comparable with those generated by previous pump tests. Results continue to show the low potential of RRGE-3 for either yielding or accepting water.

RRGI-4 was flowed under controlled artesian conditions at 6 liters per second (100 gallons per minute) for nine days, and at 9.5 liters per second (150 gallons per minute) for 16 hours. The results of these flow tests showed the reservoir Kh (transmissivity, a measure of the ease with which water can be transmitted through an aquifer) of the intermediate aquifer in the vicinity of RRGI-4 to be 20,000 millidarcy-feet. These tests are being futher evaluated as injection testing continues at RRGI-4.

Injection testing of well RRGI-4 began in late March, 1978; tests were conducted on March 21, 22, and 30, and continued into the next period. These tests were of short duration (one to five hours) because of equipment malfunctions, but they yielded valuable information. The reservoir Kh for the aquifer near RRGI-4 was calculated to be 20,000 millidarcy-feet, a value which agrees with that derived from the controlled artesian flow tests at the well. A transmissivity (the rate of flow of water through a vertical section of the aquifer under a unit hydraulic gradient) of 0.003 square meters per second (2,000 gallons per day per foot) was calculated for the intermediate aquifer in the vicinity of RRGI-4. Water for the injection testing was supplied by well RRGE-3.

The calculated values for reservoir Kh and transmissivity did not live up to researchers' expectations. Reservoir engineering personnel believe, however, that the tests are indicative of the intermediate aquifer in the vicinity of RRGI-4, and they are satisfied with the reproducibility of the results. Longer injection tests will use Raft River exploratory wells or environmental monitoring wells as observation wells, and should enable engineers to better define the Raft River geothermal reservoir.

In order to test geothermal wells, engineers need accurate downhole measurements of pressure. The downhole pressure measurements are essential to the correct evaluation of geothermal reservoirs, because surface pressure measurements are influenced by small changes in temperature. If downhole pressure measurements are inaccurate, well tests can be incomplete and misleading – particularly for the early portion of the tests (the early portion of a well test is most critical in determining aquifer parameters).

Reservoir tests have not been generating reliable surface pressure data. For example, Figure 4 shows the response of the Boise geothermal reservoir (to be discussed in Section V-1) to a controlled artesian flow test conducted on well BHW-1 (Beard Well). The well was flowed at 6 liters per second (100 gallons per minute) for one day. Pressure changes were measured at the wellhead with a digiquartz pressure-transducer system, and at a depth of 38.7 meters (1270 feet) with a Hewlett-Packard temperature-pressure probe. After an initial decline, wellhead pressure seemed to increase throughout the test, but the decline had absolutely no correlation with real pressure changes in the reservoir. The rise in wellhead pressure was apparently caused by thermal effects in the wellbore. As cool water flowed out of the well, to be replaced by hotter water, the wellhead pressure increased. The pressure rose because hot water is not as dense as cool water. Wellhead pressure continued to increase until thermal equilibrium was achieved between the well and the reservoir. The wellhead pressure response, as shown in Figure 4, was therefore useless for determining reservoir characteristics.

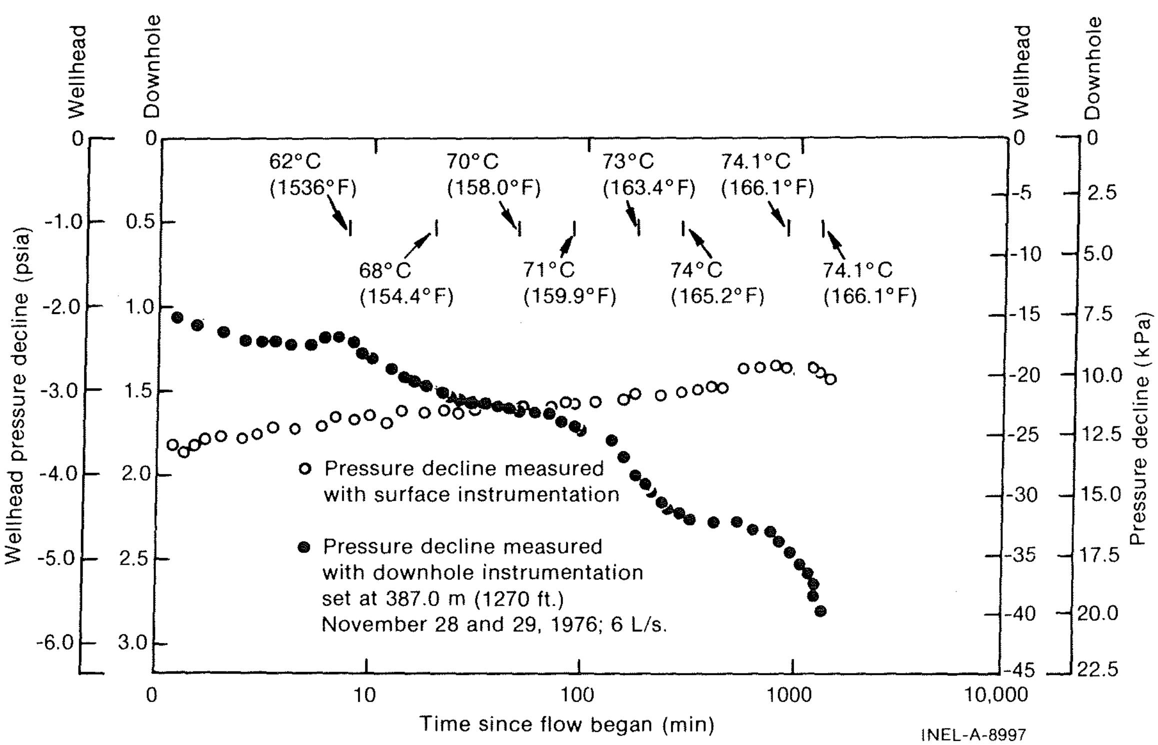


Fig. 4 Pressure response of Boise geothermal reservoir to artesian flow test at BHW-1.

Engineers attempted to measure downhole pressure changes during the injection tests on RRGI-4, using the Idaho National Engineering Laboratory's Hewlett-Packard temperature-pressure probe. The probe failed during these tests, however, probably because of electrical shorting in the borehole geophysical logging cable. The shorting was caused by corrosion when geothermal water leaked through the cable's Teflon insulation. Sulfide in the water formed copper (II) sulfide (CuS) and copper (I) sulfide (CuS_2) and pitted the copper conductors in the cable. Researchers cut used cable from the logging spool in the INEL logging truck, hoping to leave only uncorroded cable on the spool. This scheme has not yet proved successful. Researchers are searching for new and better cable, and they hope a new cable can be purchased, installed, and made available for use by the summer of 1978.

The INEL borehole geophysical logging truck continued to be used in support of Raft River drilling programs. Borehole geophysical logs of fluid temperature and acoustic cement bonds helped to place and evaluate well castings. Renovation and upgrading of the logging truck is a continuing program among reservoir engineering personnel.

Further evaluation and definition of the Raft River geothermal reservoir will be conducted during the spring and summer of 1978. These plans include:

(1) The drilling, coring, and borehole geophysical logging of wells RRGI-6 and RRGI-7. Both wells will penetrate the intermediate geothermal aquifer (below 60 meters, or 200 feet).

(2) The drilling, coring, and borehole geophysical logging of well RRGP-5. This well will penetrate the deep geothermal aquifer.

(3) The continued injection testing of well RRGI-4.

(4) The deepening of RRGI-4 to penetrate the deep geothermal aquifer (below 1200 meters, or 3900 feet). The intermediate aquifer which RRGI-4 now penetrates will be cased off, and the well will then be designated RRGP-4.

(5) The drilling and borehole geophysical logging of monitor wells associated with wells RRGP-5, RRGI-6, and RRGI-7.

(6) The pump and artesian flow testing of old and new wells penetrating the Raft River geothermal reservoir.

(7) The monitoring and sampling of domestic and irrigation wells.

3.2 Raft River Valley Water – W. L. Niemi

Table II describes the pH of surface and well water in the Raft River Valley. The table indicates that wells RRGE-1, RRGE-2, and RRGE-3 contained relatively neutral water during the sampling program. These wells all penetrate the deep geothermal aquifer. Neutral

TABLE II

pH OF RAFT RIVER VALLEY WATER

	Raft River	RRGE-1	RRGE-2	RRGE-3	RRGI-4	BLM	Crank	Wright/ Griffin	Crank Monitor	Domestic Well 1	MW-3
Total Depth (m)	--	1500	2000	1600	866	126	165	2069	175	± 60	± 60
Casing Depth (m)	--	1100	1300	1288	555	--	--	193	--	--	--
Week Ending Jan. 25, 1978 (pH)	8.2	6.8	7.4	7.3	8.2	7.5	7.9	9.1	7.4	7.5	7.3
Week Ending Feb. 15, 1978 (pH)	8.1	7.1	7.4	6.6	8.2	7.4	--	9.2	7.3	7.7	7.1
Week Ending Feb. 25, 1978 (pH)	8.2	7.3	7.4	6.7	7.4	7.6	7.6	--	7.2	7.6	7.4
Week Ending Mar. 3, 1978 (pH)	8.3	--	7.4	6.8	8.2	7.8	7.9	--	--	7.6	7.5

water is apparently present in the geothermal aquifer. Well RRGI-4, the Raft River, and the private- and company-owned monitor wells were slightly alkaline. Since RRGI-4 is slightly more alkaline than the shallower monitor wells, alkalinity in the intermediate aquifer may increase with depth. (The Wright-Griffin well is not included in the analysis, because it is so far from the other wells.) Only tentative conclusions can be drawn from the existing pH data, due to the scattering of data and the brevity of the sampling program, but there appear to be at least two distinct geothermal aquifer systems in the Raft River Valley.

Table III describes the conductivity of surface and well water in the Raft River Valley. Conductivity is a measure of the water's ability to conduct an electrical current. The presence of charged ions in solution makes water conductive, though conductance is not directly related to the total quantity of solids dissolved in the water. The conductance of pure water may be as low as 50 microsiemens (50 micromhos), and sea water can have a value as high as 50,000 microsiemens (50,000 mocromhos). Table III indicates that wells RRGE-1, RRGE-2, and Domestic Well 1 are deriving water from the same source. Again, though, because of the brief sampling period and the data scattering, only tentative conclusions can be drawn from the conductivity data.

Conductivity and pH data from surface and subsurface waters in the Raft River Valley indicate the presence of at least two aquifers. Well water seems to come from either an intermediate or a deep geothermal aquifer. The alkalinity of the intermediate aquifer is comparable with surface waters. In terms of conductance, neither the intermediate nor the geothermal aquifer is similar to surface water.

The pH and conductivity data must now be compared with well production or injection records, as well as with sampling procedures, if they are to be of use in defining aquifer characteristics. The surface and subsurface waters should be monitored continuously, at set intervals, to achieve a good historical record of hydrology in the Raft River aquifers.

3.3 Injection Filtering Tests – C. A. Allen, L. T. Cole, and R. E. McAtee (Allied Chemical Corporation)

Particle-distribution tests were conducted in conjunction with the RRGI-4 injection tests on March 21 and 22, 1978. A series of filters mounted at RRGE-3 (which supplied water for the tests) and RRGI-4 (into which the water was injected) separated and sorted suspended particles from the geothermal water.

On March 21, 24.2 liters (6.39 gallons) were filtered at the RRGE-3 wellhead. On March 22, 4.4 liters (1.16 gallons) were filtered at the RRGI-4 injection pumps. The filtering apparatus contained an ordered series of filters, successively trapping particles larger than 90, 60, 15, 2, and 0.45 microns in diameter (350, 240, 59, 7.9, and 1.8 x 10^{-5} inches). This separated the filtered residues into size groups as shown in Table IV. The table also shows the weights of particles collected in each filter, as well as the percentage of total residue trapped at each stage.

TABLE III

CONDUCTIVITY OF RAFT RIVER VALLEY WATER[a]

	Raft River	RRGE-1	RRGE-2	RRGE-3	RRGI-4	BLM	Crank	Wright/ Griffin	Crank Monitor	Domestic Well 1	MW-3
Week Ending Jan. 25, 1978	990	2475	1750	6000	7490	2700	4600	650	4450	1700	5900
Week Ending Feb. 15, 1978	1050	2800	1900	7200	9000	3250	--	800	5700	2000	6900
Week Ending Feb. 25, 1978	1150	2750	1950	7150	8800	3200	5400	--	5500	2000	6550
Week Ending Mar. 2, 1978	1050	--	1900	7050	7800	3050	5350	--	--	2000	6700
Average	1060	2675	1875	6850	8272	3050	5117	725	5217	1925	6512
Mean	1050	2750	1900	7050	7800	3050	5350	--	5500	2000	6550

[a] Conductivity in siemens per meter.

TABLE IV

RESULTS OF PARTICLE DISTRIBUTION TESTS

Particle Size (μm)	RRGE-3[a] (mg/L)	Total Residue (%)	RRGI-4[b] (mg/L)	Total Residue (%)
0.45 to 2.0	0.87	18	1.49	2
2.0 to 15.0	2.12	44	8.12	11
15.0 to 60.0	0.56	12	6.54	9
60.0 to 90.0	0.51	11	6.41	9
90.0 & larger	0.72	15	51.6	69
TOTAL	4.78	100	74.16	100

[a] Water from RRGE-3 collected at RRGE-3.

[b] Water from RRGE-3 collected at RRGI-4.

RRGE-3 flowed at low artesian rates for several days, and at higher rates for several hours before the injection test, so that the sample collected at the wellhead was representative of production water. The residues collected at RRGI-4 contained mostly particles 90 microns or more in diameter; these were probably materials picked up in the pipeline between the two wells. An analysis of the 0.45- and 90-micron residues showed them to be predominately SiO_2, or probably sand from the transite pipe.

The filtering tests will be continued throughout the injection tests, and a particle size distribution will be established for undissolved solids in Raft River well water. This information will be valuable when engineers size filters for the injection wells.

3.4 Scaling Tests – C. A. Allen, L. T. Cole (Allied Chemical Corporation)

Researchers designed and fabricated a scaling test assembly in order to determine the propensity for mixtures of water from two or more wells to form mineral crystals and deposit them on the exposed surfaces of a heat-exchanger tube. The apparatus has a design similar to that of an assembly successfully used in the Imperial Valley by Pennsylvania State University. This apparatus is being installed in the mobile corrosion test trailer at the Raft River test site. A diagram of the test is shown in Figure 5.

As mixed waters become available for testing, this apparatus will be put into use. The data from these studies will help engineers to estimate the tendency of the waters to form

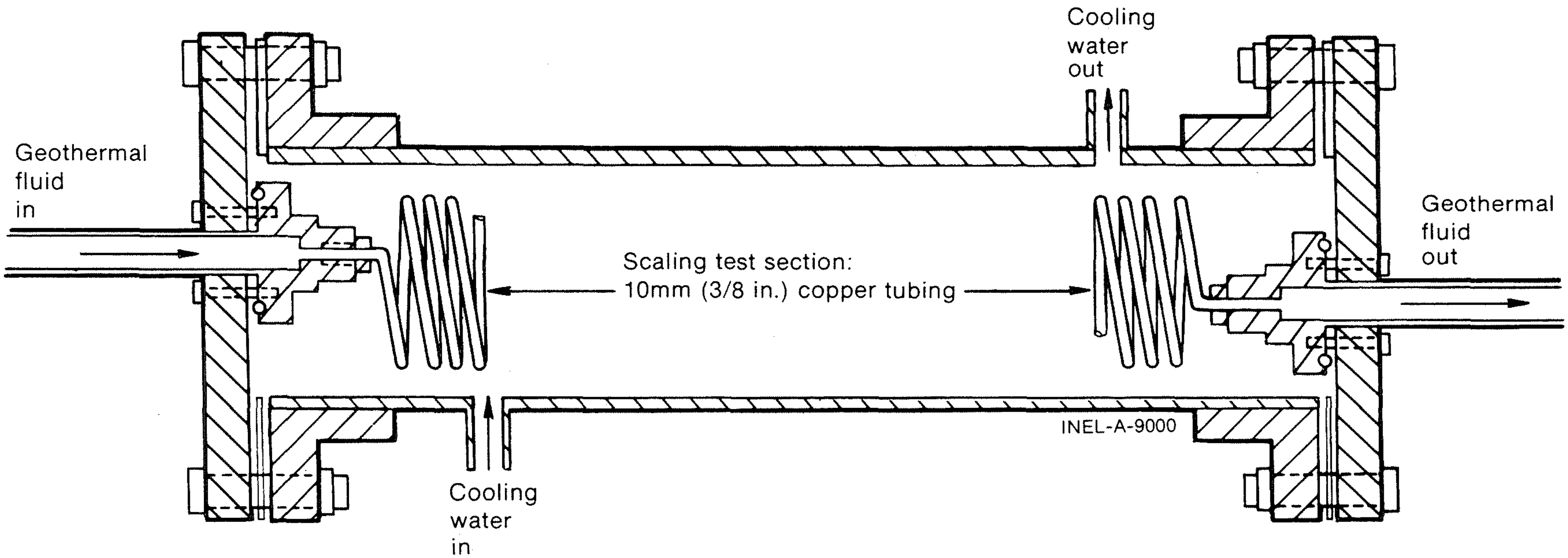


Fig. 5 Scaling test assembly.

scale when mixed. These data are important in predicting the probability of scaling of transfer pipelines and heat-exchanger tubes.

3.5 Fouling and Corrosion Tests – T. W. Lawford, R. L. Miller

In support of both the electric and nonelectric programs, researchers conducted experiments designed to test the ability of different metals to withstand the fouling and corrosion that geothermal waters can cause. Fouling tests measured resistance caused by scale on heat-exchange surfaces, while corrosion tests studied the effects of a flow of brine on coupons made of different metals.

The fouling tests were designed to measure the thermal resistance of mineral-deposit buildup, as well as the resistance of a combination of mineral-deposit and corrosion-product buildup on heat-exchange surfaces. These tests were conducted over a 100- to 150-day period, beginning in the spring of 1977.

Admiralty brass and type 316 stainless steel, candidate materials for the heat exchangers in the first 5-megawatt pilot plant, were tested in the experiment loop at RRGE-1. This sequence of tests was to last a minimum of one year, in order to measure the annual fouling resistance and determine whether or not an "induction" period existed after which the fouling rate increased.

Because of the inability to control the inlet temperatures of the cooling water, the data were very erratic. Figure 6 illustrates the problem (in this case, for type 316 stainless steel); these results are almost impossible to interpret.

New evaluation methods were needed. A Wilson plot technique was developed; however, it did not accommodate changes in cooling-water temperature during the collection of a set of data (an eight-hour period). A multivariate analysis method that could account for daily and seasonal changes in cooling-water temperatures was finally derived. Using this method of analysis, the fouling resistances, as shown in Figure 7, were obtained for the admiralty brass tubes. Each point shown on Figure 7 is the result of 130 data sets; this helped eliminate any random readings or measurements. Margins of error are also indicated by bars around each data point in Figure 7. Extrapolating for one year, the admiralty brass would have an annual fouling resistance of 3.06×10^{-5} m^2-sec-K/J-yr (1.73×10^{-4} ft^2-hr-^oF/Btu-yr). This was much less fouling than had been anticipated [1]. The value is slightly over one eighth of the fouling resistance specified when the heat exchangers were ordered (2.64×10^{-4} m^2-sec-K/J-yr).

These tests have been run at velocities, temperatures, and pressures anticipated during normal operation of the first 5-megawatt facility. Additional tests will vary the fluid parameters and establish operating conditions that could significantly increase the fouling rate.

The exposure phase of a short-term corrosion test on admiralty brass and related materials was completed during the period. Weight-loss determinations have been made, and

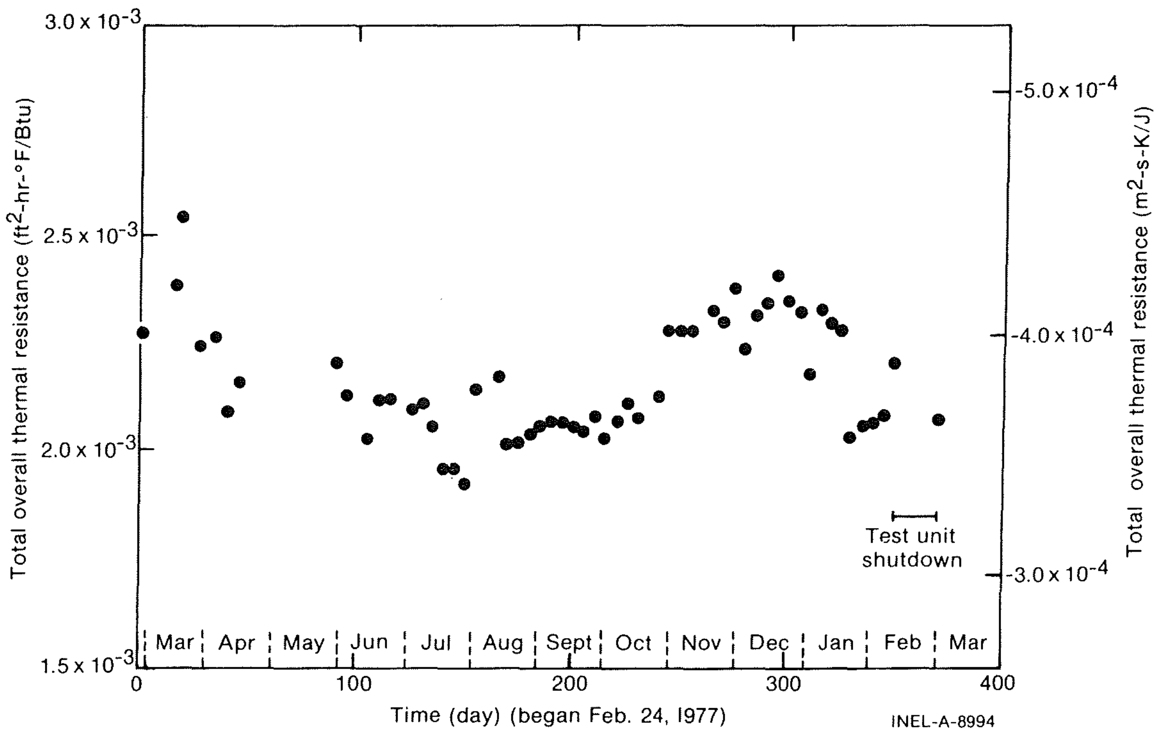


Fig. 6 Fouling test results for 316 stainless-steel tube.

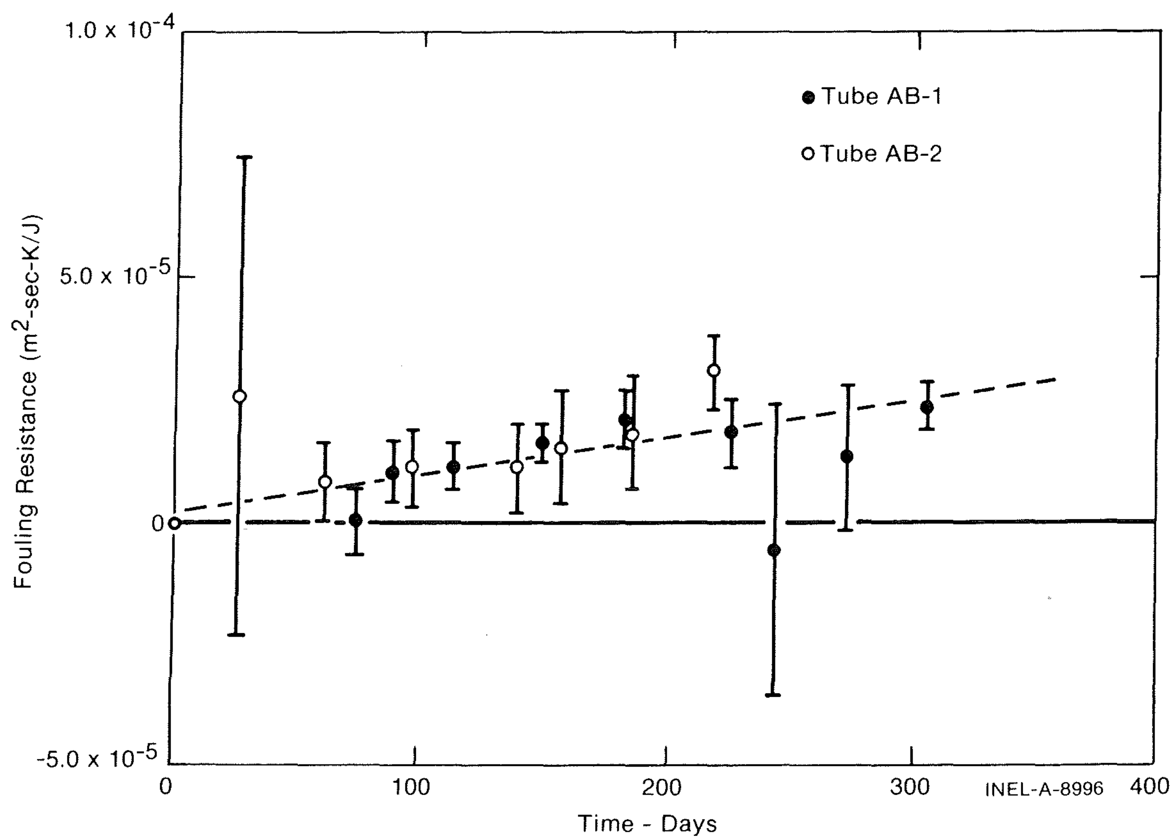


Fig. 7 Multivariate regression analysis, admiralty brass fouling test.

corrosion rates have been calculated. The cleaned coupons will be examined for visual evidence of corrosion attack.

Additional tests are now underway or are being planned. Various metals will be studied for galvanic and weld-decay corrosion, and for stress-corrosion cracking. The effects of different fluid velocities will also be studied. In addition, researchers are designing a test to evaluate the corrosion-sensing transducers that will be used in the first 5-megawatt power plant.

II. ELECTRIC APPLICATIONS

The central objectives of the Raft River project are to study the economics of a dual-boiling binary cycle and provide a technical demonstration of a facility using such a cycle. The project will determine whether economically competitive electricity can be generated from a medium-temperature resource. Other U.S. geothermal power plants, now in operation or under construction, are designed for use with fluids of over 176°C (350°F). The Raft River geothermal water is not as hot – about 148°C (298°F) when it is pumped out of the well, and less than 143°C (290°F) when it reaches the central facility at RRGE-1. While high-temperature geothermal reservoirs are rare, moderate resources like that at Raft River seem to be common throughout the West. If these medium-temperature waters can produce electricity at competitive prices, geothermal energy can supply much of the West's growing need for energy.

The idea is to use a binary cycle. Hot geothermal water passes through heat exchangers, where it heats a secondary fluid. Secondary fluid vaporizes and expands as it is heated, driving a turbine connected to a generator. The system is self-contained, and no steam escapes; the hot waters are injected back into the ground. The working-fluid vapor cools in a condenser, liquefies, and returns to the heat exchangers to begin another cycle.

The first Raft River electrical generator, a small prototype unit, was readied for operation during the report period. In addition, engineers completed design work for the first pilot power plant, a 5-megawatt system that should be operational in the summer of 1980. The two facilities are discussed in this section, as are design work on a second 5-megawatt pilot plant. Heat-exchanger work is described later in the report, in Section IV, and nonelectric uses of geothermal water are discussed in Section III.

1. THE PROTOTYPE GENERATOR – R. R. Piscitella

The prototype generator (see Figure 8) was readied for initial startup. The system will soon undergo low-power tests, and it will feed electricity to the power grid that supplies Malta and other towns near the Raft River Valley. This will be the first time a commercial power grid has been supplied with electricity generated with a binary system using medium-temperature geothermal water.

A single boiler is used (see Figure 9). It flashes isobutane at 98°C (208°F) and 1.93×10^6 pascals (20 atmospheres, or 280 pounds per square inch gauge). This is the input to a single-stage, axial-flow turbine. Back-pressure conditions, established by a small, wet-cooling-tower condenser circuit, will initially be 63°C (145°F) and 6.6×10^5 pascals (7.4 atmospheres, or 96 pounds per square inch gauge).

The preheater, boiler, and condenser are aftercoolers from a surplus compressor system. The units are not optimized to boil and condense isobutane. Condenser conditions

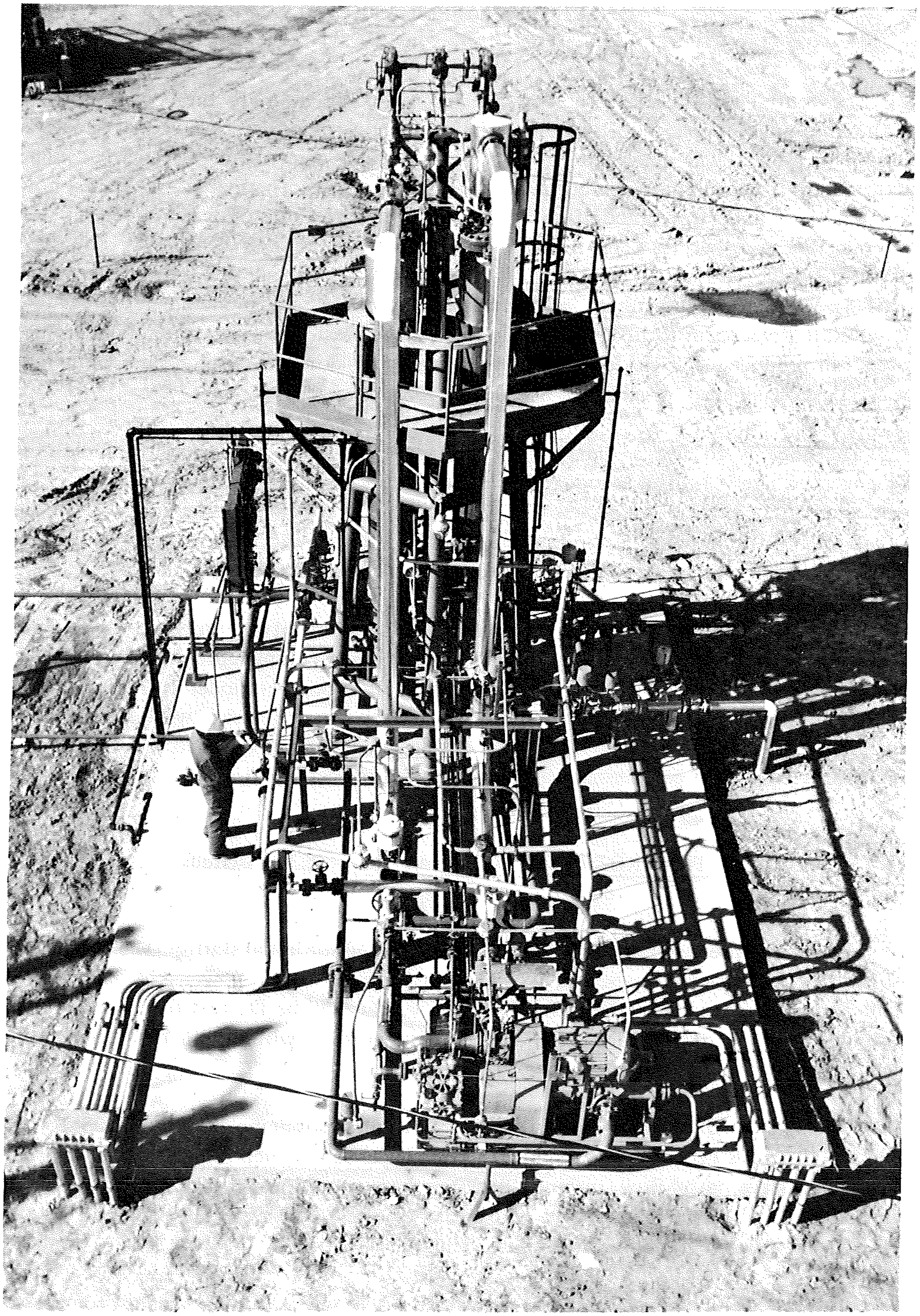


Fig. 8 The prototype generator.

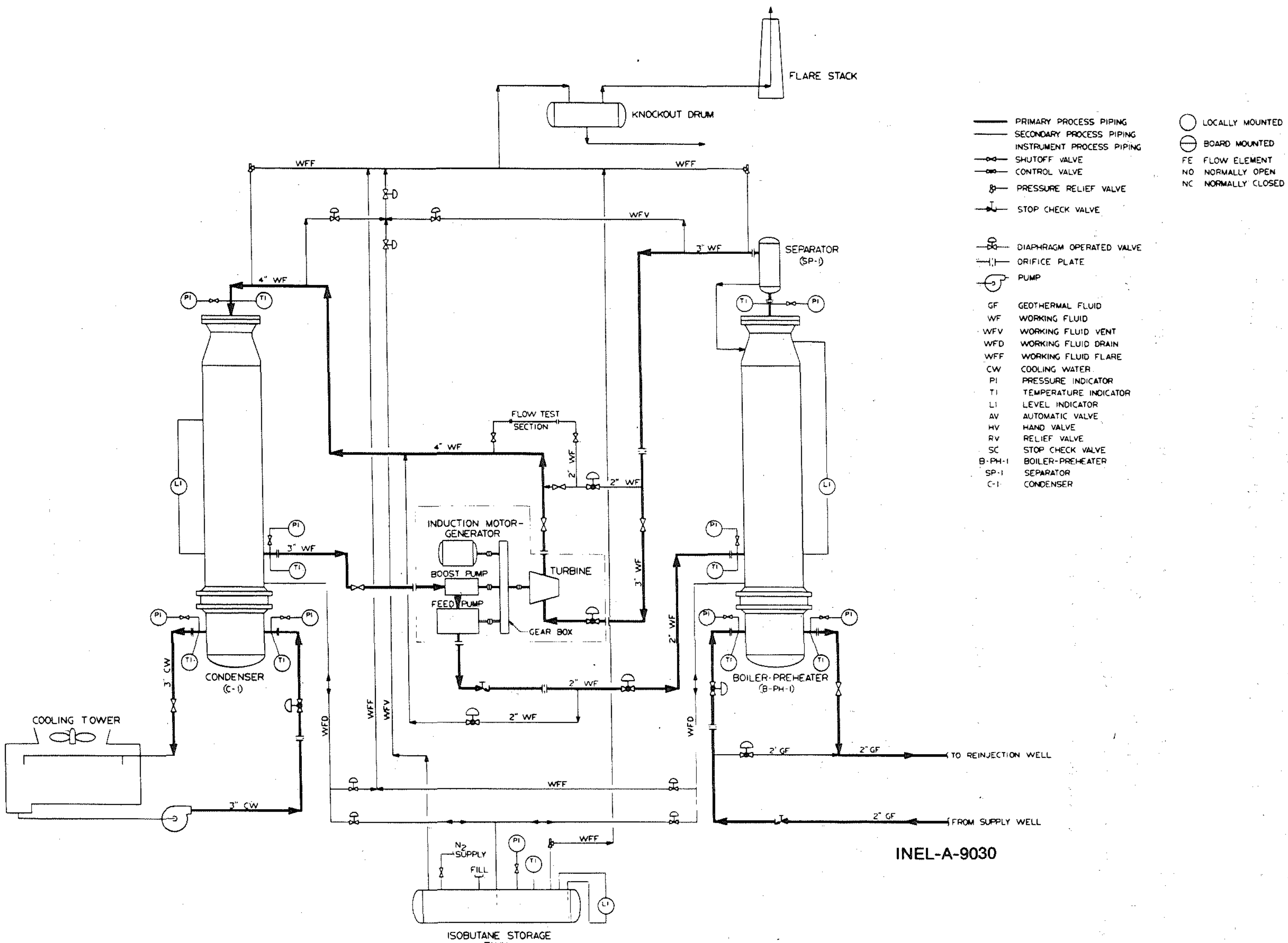


Fig. 9 Flow diagram of the prototype generator.

will eventually be established by a variety of test cooling devices, to determine their effectiveness in reducing the turbine back pressure. It will be reduced to levels as low as economically feasible and technically practical throughout the annual range of weather conditions.

The turbine is geared to a 3600-revolutions-per-minute AC induction motor/generator. This unit first runs as a motor to drive the pumps for loop startup; then, as the turbine is brought up to speed and as the flow of isobutane increases, the induction motor becomes a generator and feeds power into the power grid.

2. FIRST 5-MEGAWATT PILOT PLANT – R. R. Piscitella

Title II design for the first Raft River thermal loop was completed during April. Researchers obtained approval to incorporate a turbine generator; the facility will be a 5-megawatt (electric) pilot power plant (Figure 10). The facility will be located west of RRGE-1 and east of RRGP-5. The plant process area will contain the heat exchangers, turbine-generator, and feed pumps (Figure 11). Storage tanks for the flammable working fluid will be buried near the process area.

A number of working fluids and a variety of cycles were studied as the plant was designed. When resource temperatures are below 149°C (300°F), as is the case with the Raft River fluids, the studies indicated a dual-boiling cycle would perform significantly better than either a single-boiler cycle or a supercritical cycle. For a 143°C (290°F) geothermal fluid, the dual-boiling cycle performs 23% better than the other cycles. The cooler the resource, the greater the superiority of the dual-boiling cycle; for fluids hotter than 171°C (340°F), there is no merit in the use of the dual-boiling configuration. The facility will be able to use either isobutane or propane as a working fluid. The Raft River resource temperature is such that either fluid could be used effectively. If the temperature were a bit higher, isobutane would be the better choice; for a cooler resource, propane would be preferred.

In the resulting design (Figure 12), condensed isobutane will be heated to about 82°C (180°F) in the low-pressure preheater. The flow of working fluid will split when it leaves this preheater, with about two thirds continuing to the high-pressure preheater. This flow will be heated to 111°C (240°F) before it enters the high-pressure boiler, where it will be vaporized. The other third will be vaporized in the low-pressure boiler.

The turbine will be of radial inflow design. Specifications permit either single or double casing units, to accommodate the high- and low-pressure flows. A single generator is required.

Specifications require heat exchangers of the dimensions shown in Table V.

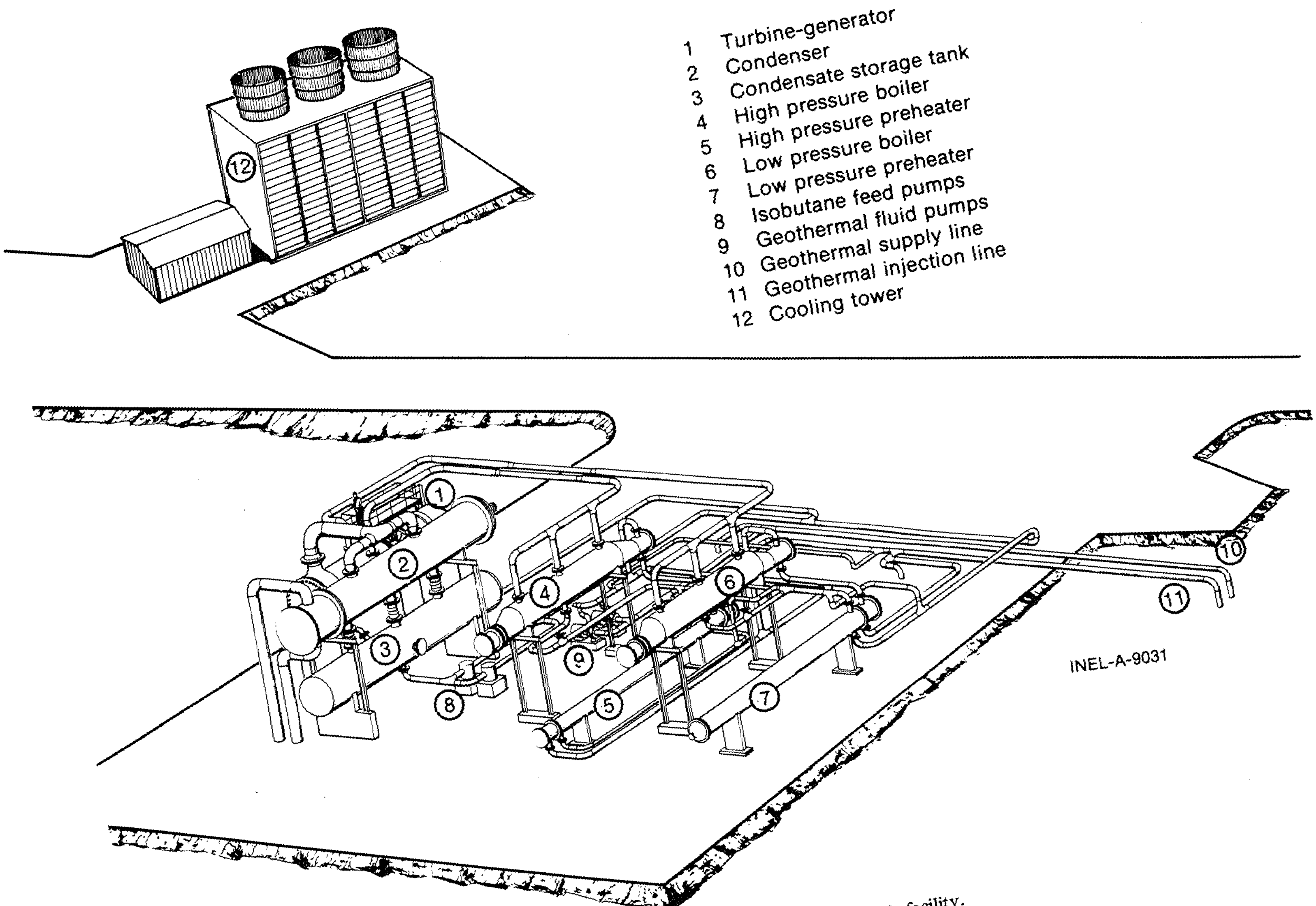


Fig. 10 Raft River 5-megawatt binary power cycle facility.

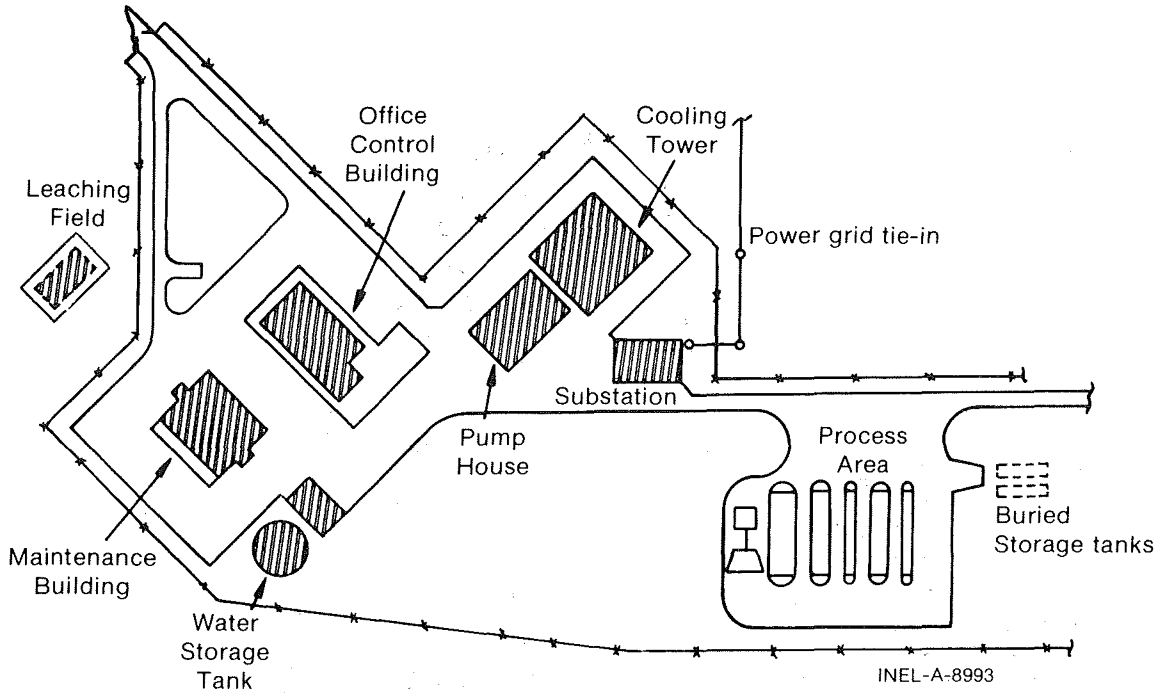


Fig. 11 Plan for Raft River 5-megawatt facility.

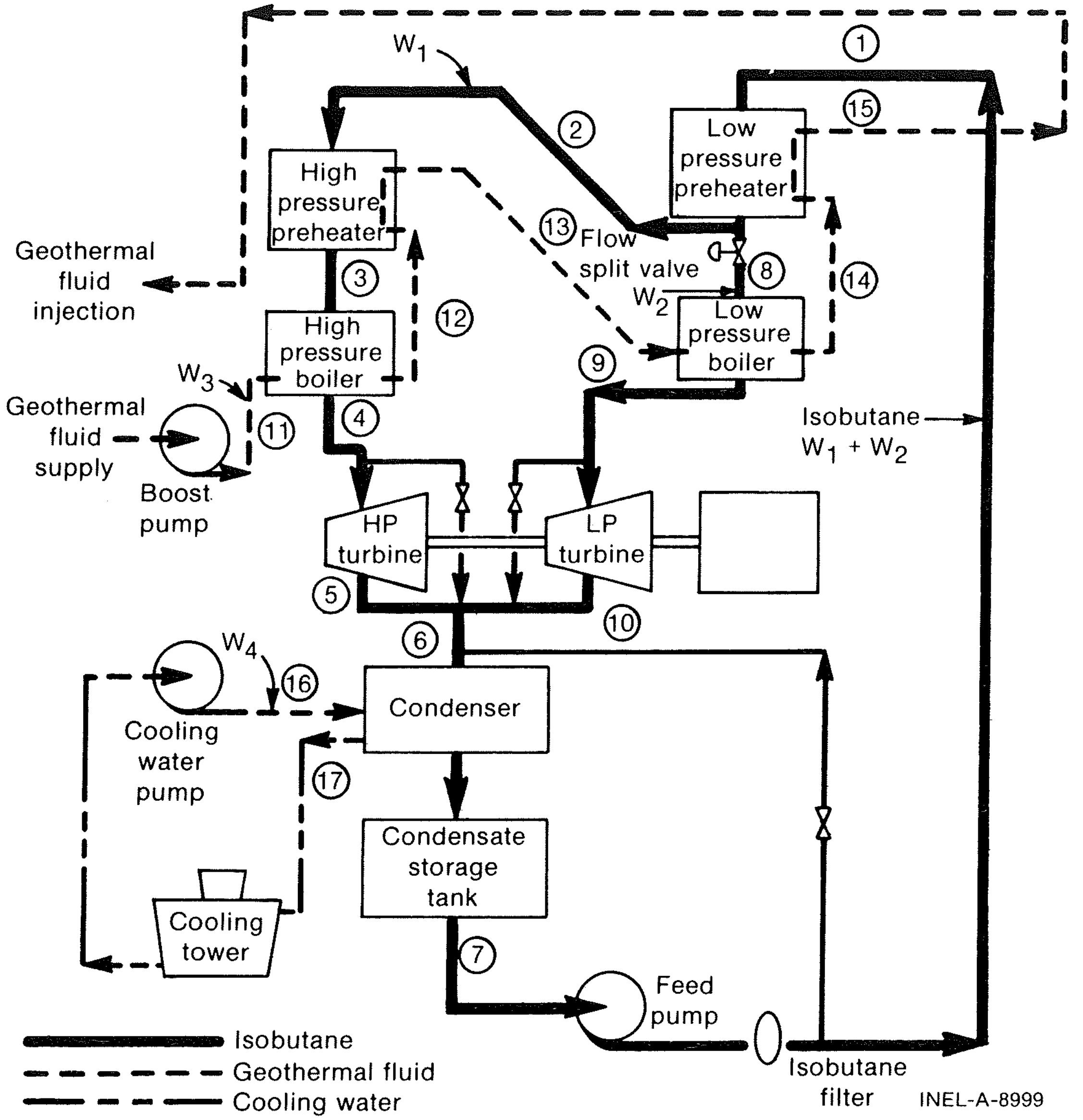
The tube material in all preheaters and boilers is admiralty brass. The condenser tube material is carbon steel. Tube sheets are aluminum-bronze-clad carbon steel. The preheaters and boilers were designed for geothermal-side fouling factors of 2.6×10^{-4} K-m^2/W (1.5×10^{-3} hr-ft^2-^{o}F/Btu) and for isobutane-side factors of 8.8×10^{-5} K-m^2/W (5×10^{-4} hr-ft^2-^{o}F/Btu).

The cooling tower is a cross-flow, two-cell, mechanical-draft, wet cooling tower. It is constructed of treated Douglas fir and redwood. Pumps circulate 968 liters per second (15,373 gallons per minute) of coolant. Treated geothermal water will be used for coolant makeup.

Two parallel, vertical-turbine pumps, each rated at 461 meters (1514 feet) and 110 liters per second (1747 gallons per minute), provide the feed pumping. Each pump has six stages and a 373-kilowatt (500-horsepower) motor. The pump efficiency at rated conditions is 78%. The pumps are sized for the minimum condenser pressure of 2.9×10^5 pascals (42 pounds per square inch absolute).

The geothermal boost pump provides the head required to pump the geothermal fluid through the heat exchangers and the transmission lines to the injection pumps. Two parallel, radial-centrifugal pumps provide this capability. Each has a head of 83 meters (272 feet) at a flow of 70 liters per second (1,115 gallons per minute). Their efficiency at this operating point is 80.5%. Each is driven by a 93-kilowatt (125-horsepower) motor.

The geothermal systems have a design temperature and pressure of 1.7×10^6 pascals (250 pounds per square inch gauge) and 160^{o}C (320^{o}F). The isobutane condensate system



Isobutane System
W1 7,060kg/s (9.34x10^5 lbm/hr)
W2 4,630kg/s (6.13x10^5 lbm/hr)

Geothermal Water System
W3 7,860kg/s (1.04x10^6 lbm/hr)

Cooling Water System
(1)W4 56,900kg/s
(7.53x10^6 lbm/hr)

1 41°C (105°F)
2 82°C (180°F)
3 116°C (240°F)
4 116°C (240°F)(381.6 psia)
5 54°C (130°F)
6 53°C (128°F)
7 38°C (101°F)(77.5 psia)(2)
8 82°C (180°F)
9 82°C (180°F)(203.0 psia)
10 51°C (123°F)

11 143°C (290°F)
12 121°C (250°F)
13 106°C (222°F)
14 88°C (190°F)
15 62°C (144°F)

16 24°C (75°F)
17 35°C (95°F)

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

Fig. 12 Raft River 5-megawatt geothermal pilot-plant dual-boiling cycle.

TABLE V

SPECIFICATIONS FOR HEAT EXCHANGERS IN FIRST 5-MEGAWATT PILOT PLANT

Heat Exchanger	Surface Area		Length		Diameter		Weight	
	(m^2)	(ft^2)	(m)	(ft)	(cm)	(in.)	(MT)	(T)
L.P. Preheater	2,791[a]	30,039[a]	15	49	127	50	390	43
L.P. Boiler	552	5,938	13	42	84/173[b]	33/68[b]	181	20
H.P. Preheater	1,399[a]	15,059[a]	15	50	89	35	200	22
H.P. Boiler	552	5,938	13	42	84/173[b]	33/68[b]	181	20
Condenser	5,295	56,996	15	50	224	88	1,270	140

[a] Extended surface (finned tubes).

[b] Tube-bundle diameter and outer shell diameter.

is designed for 1.6×10^6 pascals (230 pounds per square inch gauge) and 138°C (280°F). The isobutane preheaters and boilers are designed for 4.5×10^6 pascals (650 pounds per square inch gauge) and 160°C (320°F).

An operating procedure for the power plant has been written. The procedure was analyzed with a digital computer model, and it was found to afford good control with minimum system perturbations. The final control scheme controls plant power output by allowing more or less of the isobutane vapor to bypass the turbine. Fluid temperatures and geothermal-fluid flow rates remain fixed, to prevent pressure and temperature fluctuations that could damage the transite pipes.

The system was designed to take maximum advantage of the area's seasonal variations in temperature. For 95% of the time, the wet-bulb temperature would be 18°C (65°F) or less. The condensing pressure corresponding to this wet-bulb temperature would be 5.4×10^5 pascals (78 pounds per square inch absolute). At minimum tower conditions, a condensing temperature of ~19°C (~66°F) is obtained (2.9×10^5 pascals or 42 pounds per square inch absolute). The resulting increase in average power production, compared to constant power, is from 20 to 25%.

At a wet-bulb temperature of 18°C (65°F) the output will be about 5 megawatts. At lower ambient temperatures, gross outputs of up to 7.4 megawatts can be generated. Table VI presents heat loads and power requirements based on a nominal output of 5 megawatts.

A construction bid package for fabrication and construction of the facility is being assembled and readied for distribution. Other long-lead procurement activities have been completed. The high- and low-pressure preheater and the condensate storage tank have been delivered and are in storage at the Idaho National Engineering Laboratory (Figure 13 shows both the preheaters and the condensate storage tank). The condenser and the low-pressure preheater await shipment. Instrumented tubes for studying heat-transfer characteristics were installed in the condenser tube bundle. Figure 14 shows the final assembly of instrumented tubes in the tube bundle. Figure 15 illustrates the installation of the condenser tube bundle. Contracts for transformers and geothermal boost pumps have also been awarded.

Facility construction should begin in August 1978. The plant is scheduled for operation in mid 1980. A complete schedule is shown in Figure 16.

TABLE VI

HEAT AND POWER BALANCE, 5-MEGAWATT PILOT PLANT

		MW
Heat addition:		
Low-pressure preheater		14.0
Low-pressure boiler		10.0
High-pressure preheater		8.5
High-pressure boiler		12.5
	Total	45.0
Heat rejection:		
Condenser		40.0
Turbine work	Gross power	5.0
Losses:		
Feed pump		0.71
Cooling tower		0.59
Geothermal booster pump		0.14
	Total	1.44
Net power, nominal condition		3.56

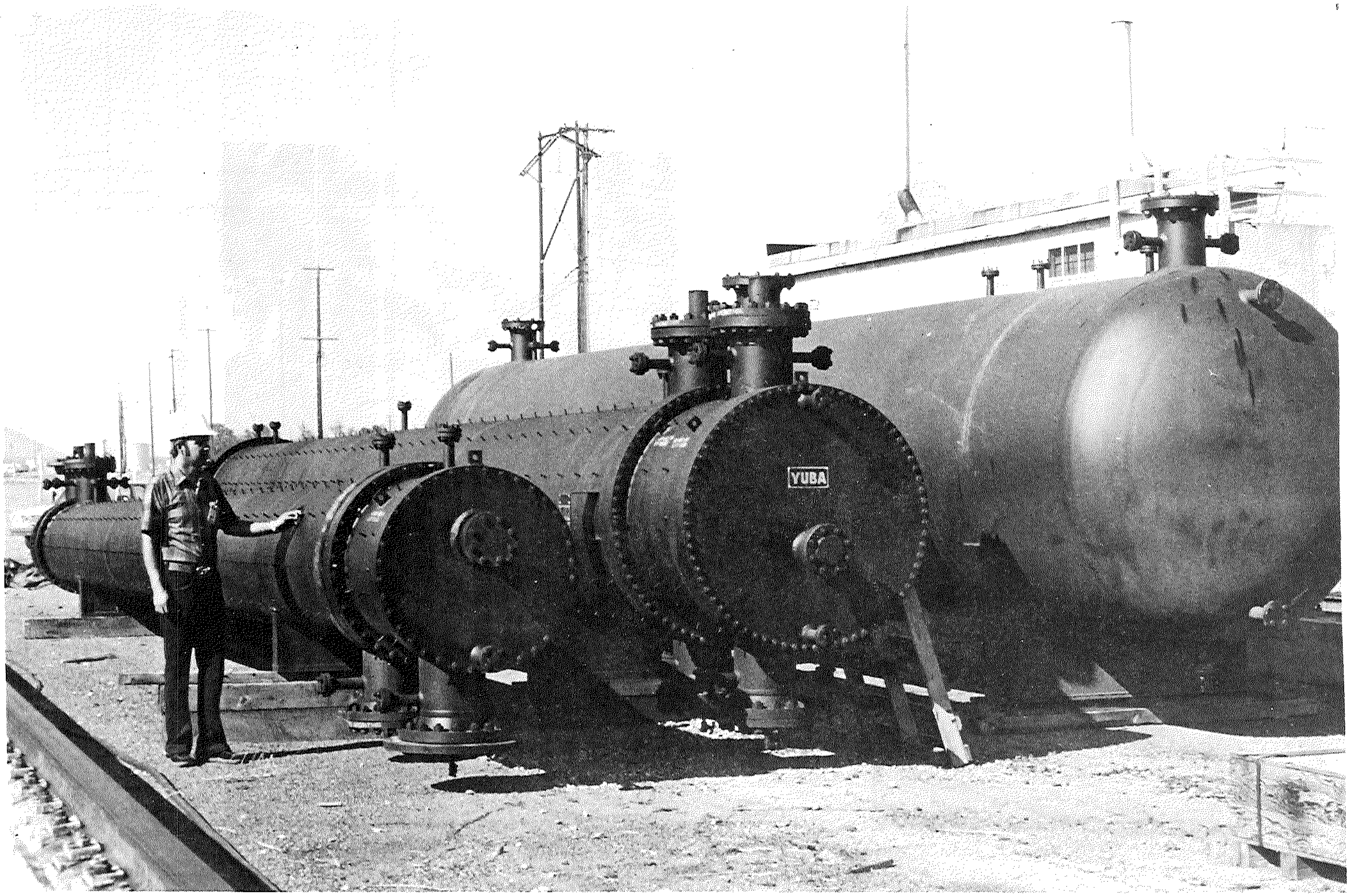


Fig. 13 High- and low-pressure preheaters and condensate storage tank.

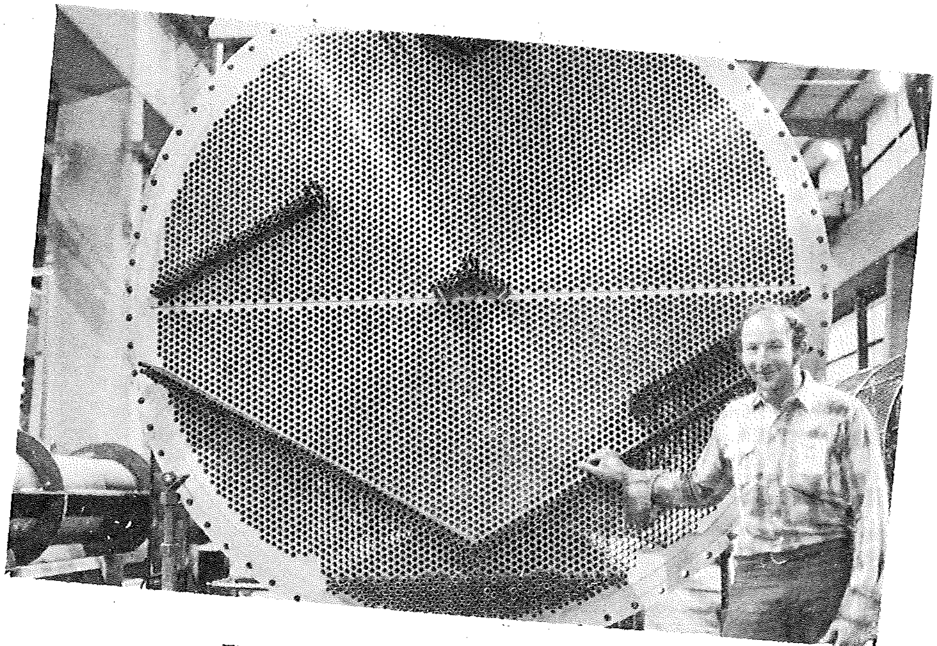


Fig. 14 Tube sheet for 5-megawatt condenser.

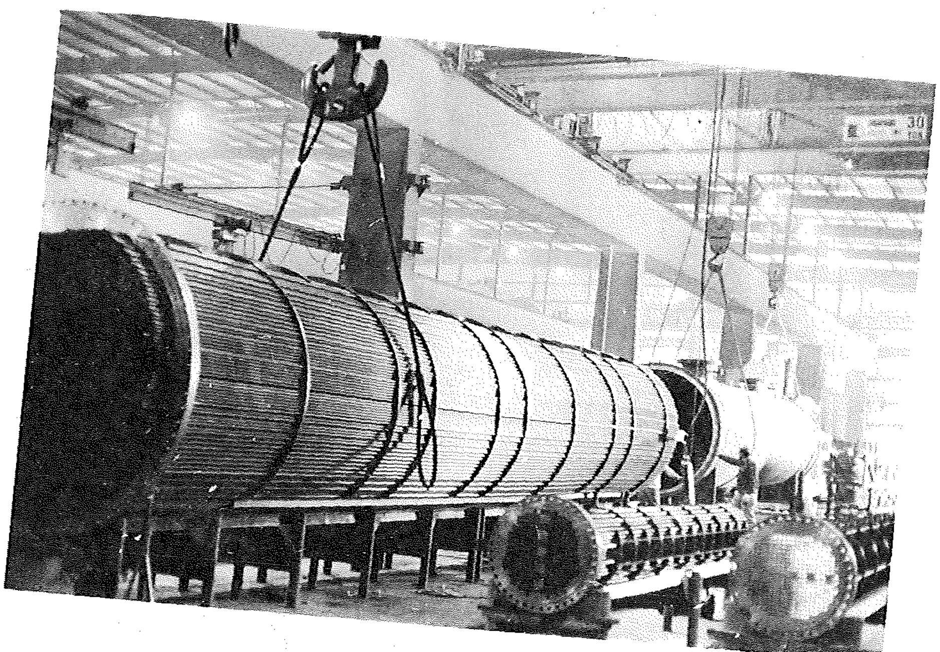


Fig. 15 Installation of condenser tube bundle.

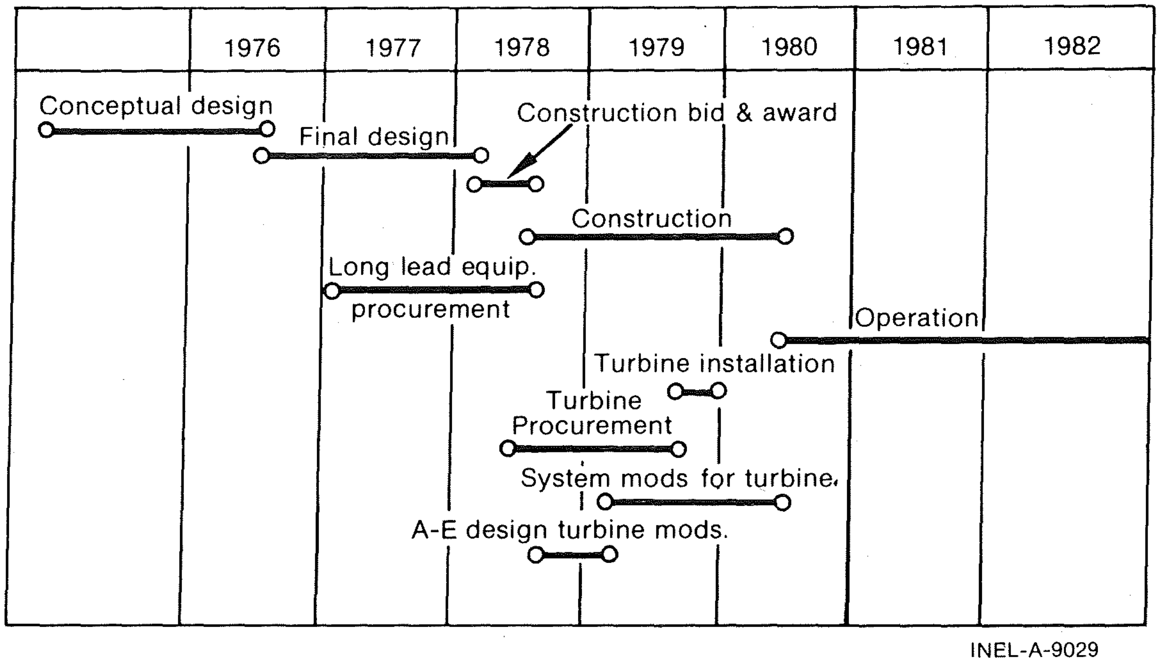


Fig. 16 Raft River 5-megawatt pilot plant schedule.

3. SECOND 5-MEGAWATT PILOT PLANT – T. W. Lawford

The second 5-megawatt pilot plant will use a number of advanced components. Direct-contact boilers, preheaters, and condensers will replace standard shell-and-tube heat exchangers in the advanced plant. During the period, preconceptual design work attempted to select an optimized cycle, define state points, and select a working fluid. This report section details researchers' efforts (1) to examine the general behavior of dual-boiling direct-contact binary cycles; (2) to compare the performance of direct-contact cycles with similar shell-and-tube cycles; (3) to investigate methods for reducing working-fluid losses to acceptable levels; and (4) to design a direct-contact cycle configuration and assess its power balance and working-fluid losses. (Research specifically concerning direct-contact heat exchangers is reported in Section IV-2.)

In general, direct-contact and conventional cycles are very similar. Because geothermal brine and working fluid are mechanically mixed in the direct-contact boilers, however, the vapor leaving a direct-contact boiler consists of both steam and working fluid. The total vapor pressure can be approximated by the sum of the working-fluid and water saturation pressures at the boiling temperature. The turbines are thus driven by a mixture that contains steam (a few percent by weight) as well as the working-fluid vapor.

Also, because the high- and low-temperature boilers have different pressures, the brine must undergo a pressure reduction as it passes from the high- to the low-temperature boiler in a direct-contact cycle. Throttling has been selected for this process. (An expander would mean a small increase in power, but the cycle would be both more expensive and more complex.)

Although the basic direct-contact cycle is substantially the same as the basic shell-and-tube cycle, significant additions must be made to a direct-contact plant if the loss of working fluid is to be minimized. The additions entail parasitic power losses that reduce the net power of a cycle. Recovery is necessary for three reasons. First, because a working fluid like isobutane or pentane is slightly soluble in brine, significant amounts of working fluid could be injected along with the cooled geothermal fluid in which it is dissolved. Reinjection of large quantities of the hydrocarbon working fluid would be environmentally unacceptable, and a continuous loss of working fluid would add a great deal to the cost of the generated power.

Second, geothermal water entering a power plant contains dissolved gasses. Most of this dissolved gas comes out of solution in the direct-contact boilers, and is carried through the turbines to the condenser. The condenser requires continuous venting in order to maintain a stable pressure. Working fluid is lost when working-fluid vapor mixes with noncondensable gasses in the condenser, and the mixed vapors are vented together. For waters with higher levels of dissolved noncondensables (as at East Mesa, California, where CO_2 concentrations can run from 1,000 to 4,000 parts per million), power penalties associated with this recovery problem may well be larger than those related to the problem of working-fluid solubility in the geothermal brine.

Third, if a wet cooling tower is used, any working fluid which has dissolved in the cooling water in the direct-contact condenser will be discharged to the atmosphere, since the partial pressure of the working fluid in the tower will be negligible relative to the air and water vapor pressures. (In addition, air will be dissolved in the cooling water during its exposure in the wet tower.) The working fluid must be recovered from the condenser cooling water if a wet cooling tower is used, and processing the cooling water to recover the working fluid would not incur as large a power penalty as using a dry cooling tower. (A preliminary assessment of conventional dry cooling towers indicated a parasitic power requirement of more than 2 megawatts, as opposed to about 0.5 megawatts for a comparable wet tower.)

A schematic of a direct-contact dual-boiling geothermal cycle, including working-fluid recovery components, is sketched in Figure 17. For a 5-megawatt plant using such a cycle, working-fluid loss should amount to no more than about 3.8 grams per second (30 pounds per hour). In order to evaluate the power penalties associated with recovering the working fluid that would be injected with spent brine, vented from the condenser, or evaporated from a wet cooling tower, researchers analyzed state points and power balances for direct-contact cycles. Their analyses considered two types of geothermal water: brine at 143°C (290°F) with 52 parts per million dissolved nitrogen, as would be found at Raft River, and brine at 171°C (340°F) with 2000 parts per million dissolved carbon dioxide.

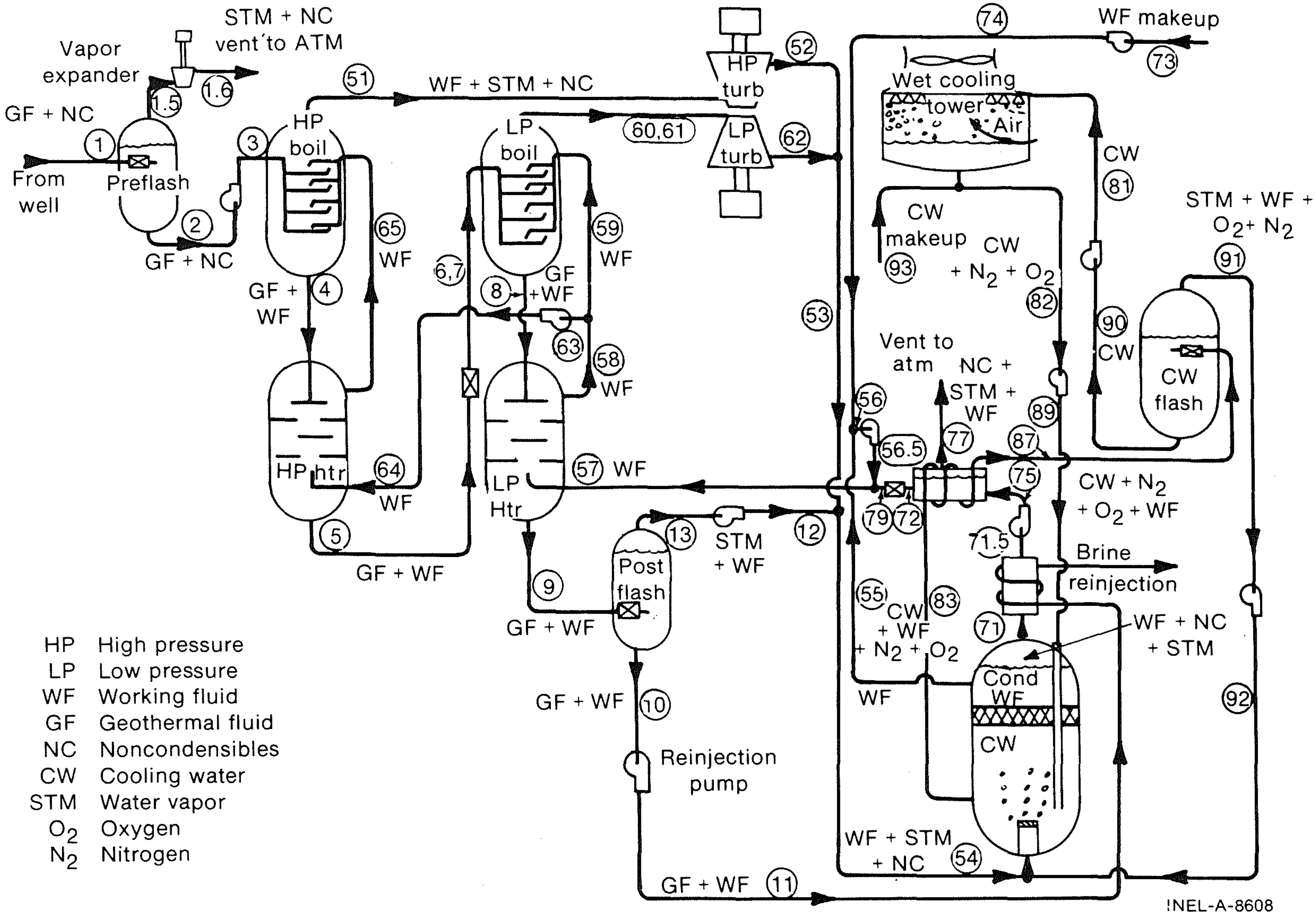


Fig. 17 Schematic of dual-boiling direct-contact geothermal cycle.

3.1 Cycles Using Raft River Brine

Scientists analyzed both pentane and isobutane cycles for use with Raft River brine. Power requirements for recovering working fluid were assessed parametrically, as functions of fluid loss, for several recovery approaches. For recovering fluid dissolved in the brine, the brine would be flashed just before injection. To recover working fluid from the condenser vent, three approaches were evaluated: (1) refrigerating the condenser-vent products; (2) compressing and cooling the vent products; and (3) preflashing the brine upstream of the boiler. The best way to recover fluid from cooling water, the scientists decided, would be to flash the cooling water (only wet towers were considered in this study).

Figure 18 summarizes the condenser-vent working-fluid recovery analyses for Raft River brine. The optimum points for the three recovery methods are plotted with turbine power minus condenser-vent recovery power as a function of condenser-vent pentane lost to the atmosphere. (The short dashed line depicts a correction to the solid curve representing the pressurization and cooling of condenser-vent products. It accounts for the use of a condenser-vent vapor preheater, rather than a low-efficiency compressor, for avoiding working-fluid condensation.) The figure shows the compression and cooling of condenser-vent vapors to be the best of the methods analyzed for use with Raft River brine. Because preflashing the brine resulted in values so much lower than the other methods, approaches combining preflashing with the other methods for retrieving working fluid from Raft River brine were not studied further.

Figure 19 shows cycle power penalty plotted as a function of the mass of pentane injected with Raft River brine. The brine is flashed after it leaves the low-pressure heater. The power penalty consists of the extra power required to pump brine from the flash pressure, rather than from the heater pressure, to the assumed reinjection pressure of 7×10^5 pascals (100 pounds per square inch absolute), and of the power required to pump the mixture of working-water vapor and pentane vapor from the flash pressure to the condenser pressure. The flash pressure is shown on the right-hand scale as a function of pentane loss rate. The figure shows that the power penalty for very low pentane loss rates would be severe; however, there is a knee in the curve at a point that corresponds to a pentane loss rate of from 0.6 to 0.8 grams per second (5 to 6 pounds per hour). With a parasitic power loss of only about 0.06 megawatts, all but 0.8 grams per second (6 pounds per hour) of working fluid could be recovered from the brine. Vapor compression is not required at a pentane loss rate above about 2.6 grams per second (20 pounds per hour); without any recovery, the rate of loss would reach about 10 grams per second (80 pounds per hour).

For Raft River brine, a dual-boiling cycle using all direct-contact components could potentially produce energy less expensively than could a shell-and-tube cycle. With moderately optimistic working-fluid-recovery and pinch-point assumptions, the brine effectiveness of such a cycle should be almost equal to that of a shell-and-tube dual-boiling cycle using isobutane (within about 3%).

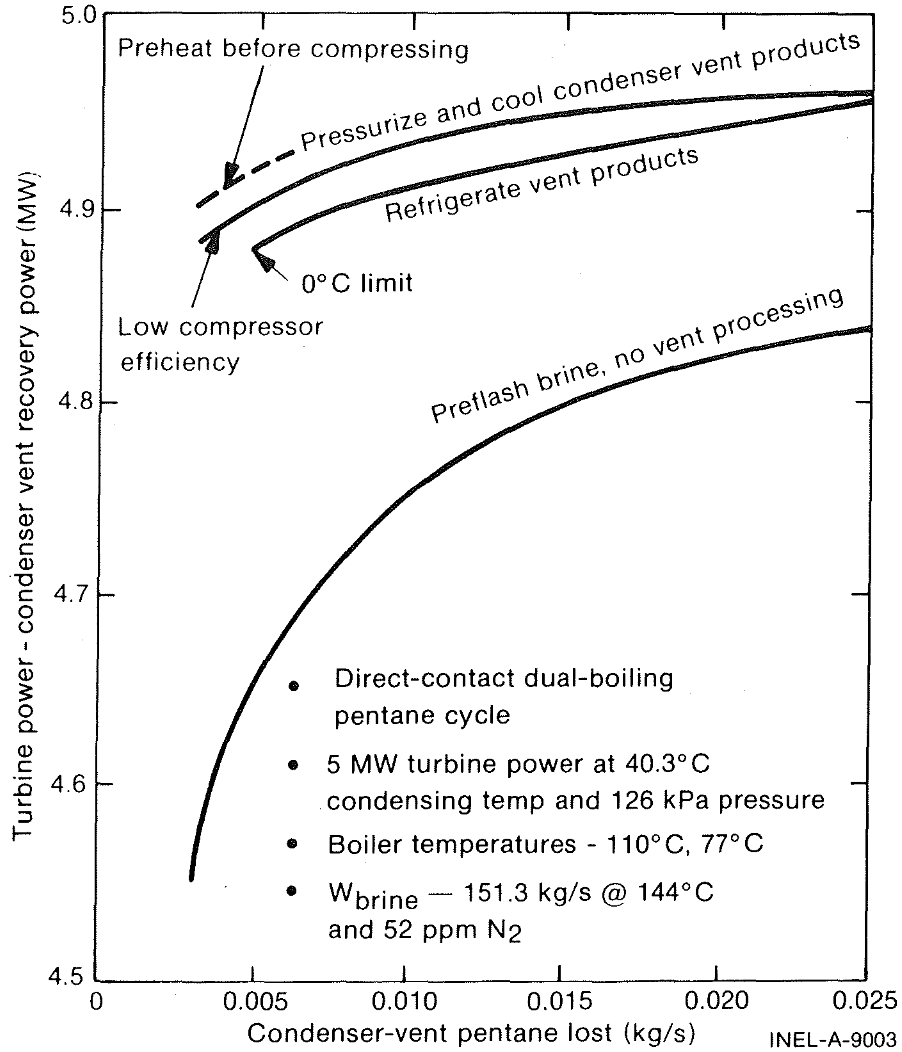


Fig. 18 Effect of recovery of condenser-vent pentane on cycle performance.

The Raft River direct-contact cycle would probably use pentane, rather than isobutane. Parasitic losses associated with brine-delivery pumping and with working-fluid recovery were higher for isobutane than for pentane. And if direct-contact condensers are employed, the differences between the parasitic losses for isobutane and pentane cycles are even greater.

The net brine effectiveness (energy per unit time, per unit mass of brine; commonly represented as watt-hours per pound of brine), is comparable for isobutane and pentane dual-boiling direct-contact cycles utilizing Raft River brine and employing surface condensers. Without use of auxiliary brine and cooling-water expanders, the pentane cycle was calculated to have a slight advantage (about 1% of net brine effectiveness). With utilization of the auxiliary expanders, the isobutane cycle showed a slight advantage (about 3%).

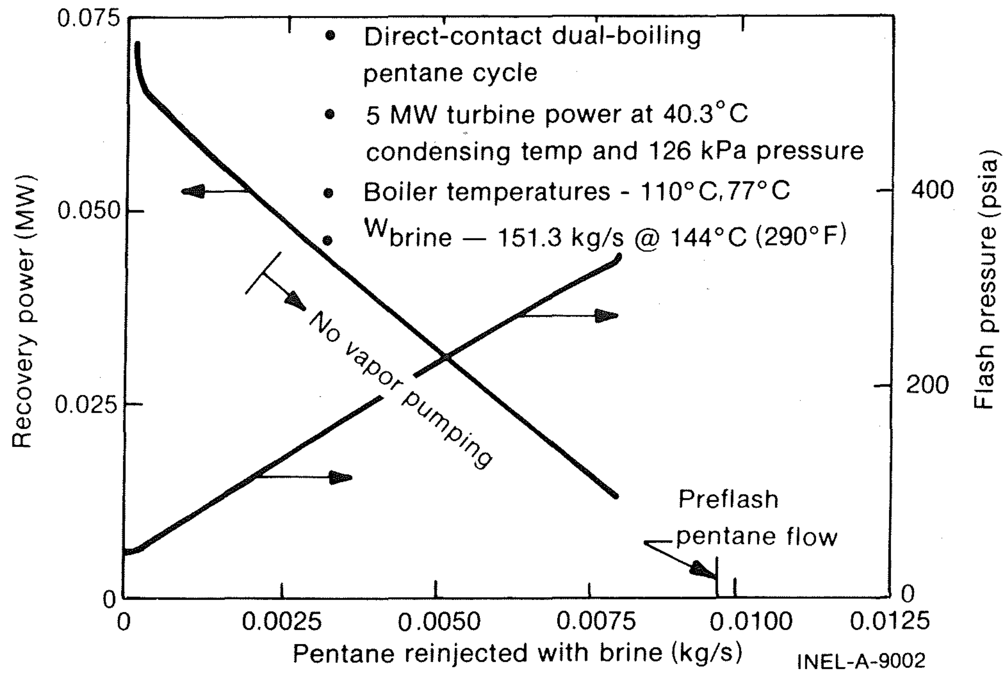


Fig. 19 Power required for recovery of dissolved pentane by brine-flashing process.

Comparing isobutane and pentane dual-boiling direct-contact cycles having direct-contact condensers and utilizing Raft River brine, the pentane cycle showed higher net brine effectiveness without use of auxiliary expanders (15 to 19%). Use of auxiliary expanders in both cycles brings the brine effectiveness values closer (with pentane now showing about a 3 to 6% advantage, depending on assumptions about cycle pinch points and parasitic losses associated with working-fluid recovery).

With moderately optimistic assumptions regarding working-fluid recovery, with pinch points of 3°C (5°F), and with the use of auxiliary expanders, an all direct-contact dual-boiling pentane cycle operating with Raft River brine was estimated to have an effectiveness essentially equivalent to that of a near-optimum shell-and-tube dual-boiling cycle (31,400 joules per kilogram; 3.96 watt-hours per pound of brine). With comparable plant assumptions, the highest net brine effectiveness estimated for an isobutane direct-contact cycle was within 1% of that value. That particular direct-contact plant would require a surface rather than a direct-contact condenser, however.

3.2 Cycles Using High-Temperature Brine

A pentane cycle was regarded as most appropriate for use with 171°C (340°F) waters with high concentrations of dissolved noncondensables (about 2000 parts per million dissolved carbon dioxide). A working-fluid loss of 3.2 grams per second (25 pounds per hour) was selected in this case. Recovery of working fluid from the condenser vent was studied as a function of condenser pressure. The brine would be preflashed, and the condenser vent products would be compressed and cooled.

The results from the analysis of cycles using the 171°C (340°F) water are plotted in Figure 20. Power is shown as a function of the partial pressure of carbon dioxide in the condenser. Curves are shown for cycles without preflash, and for cycles preflashing the fractions 0.00475 and 0.0111 of the brine to steam. At each point on the curves, sufficient condenser-vent compression and cooling were accomplished to bring the pentane loss to the selected value of 3.2 grams per second (25 pounds per hour). The dashed curves represent cycles that use expanders to recover power from the expansion of the flashed steam and carbon dioxide to atmospheric pressure. The solid curves depict values derived from cycles that do not. The power values for the solid curves represent turbine power minus condenser-vent compression power minus brine-delivery pumping power; for the dashed curves, the power recovered with a flashed steam expander (0.7 efficiency) has been added. As a reference point, the turbine power minus brine-delivery pumping power for water without carbon dioxide (no preflash) is plotted at $P_{CO_2} = 0$.

Several conclusions can be drawn from Figure 20. First, with or without an auxiliary steam expander, a combination of preflashing the brine and compressing and cooling the condenser-vent vapors results in more plant power than with either recovery method applied separately. Second, with some increase in plant cost and complexity, about 0.15 megawatts can be recovered by using a steam expander with atmospheric back pressure. Last, recovery of the working fluid from brine with 2000 parts per million dissolved carbon dioxide would mean an expenditure of about 0.5 megawatts. That figure does not include the power required to handle the extra noncondensables introduced into the condenser from the cooling-water flash process shown in Figure 17.

For direct-contact cycles, the penalty in net brine effectiveness was 5 to 10% higher for the hotter brine containing more noncondensables, depending on assumptions about pinch points, use of expanders, techniques for recovery, and selection of surface or direct-contact condensers. Corresponding increments in the parasitic penalty assignable to the direct-contact cycle ranged from 0.2 to 0.4 megawatts for the 5-megawatt gross power cycles.

For higher-temperature brines containing more noncondensables, direct-contact cycles should be less attractive. A flashed-steam plant, however, which would free the brine of noncondensables and allow it to energize a dual-boiling, direct-contact bottoming cycle, may be an attractive application of the direct-contact concept.

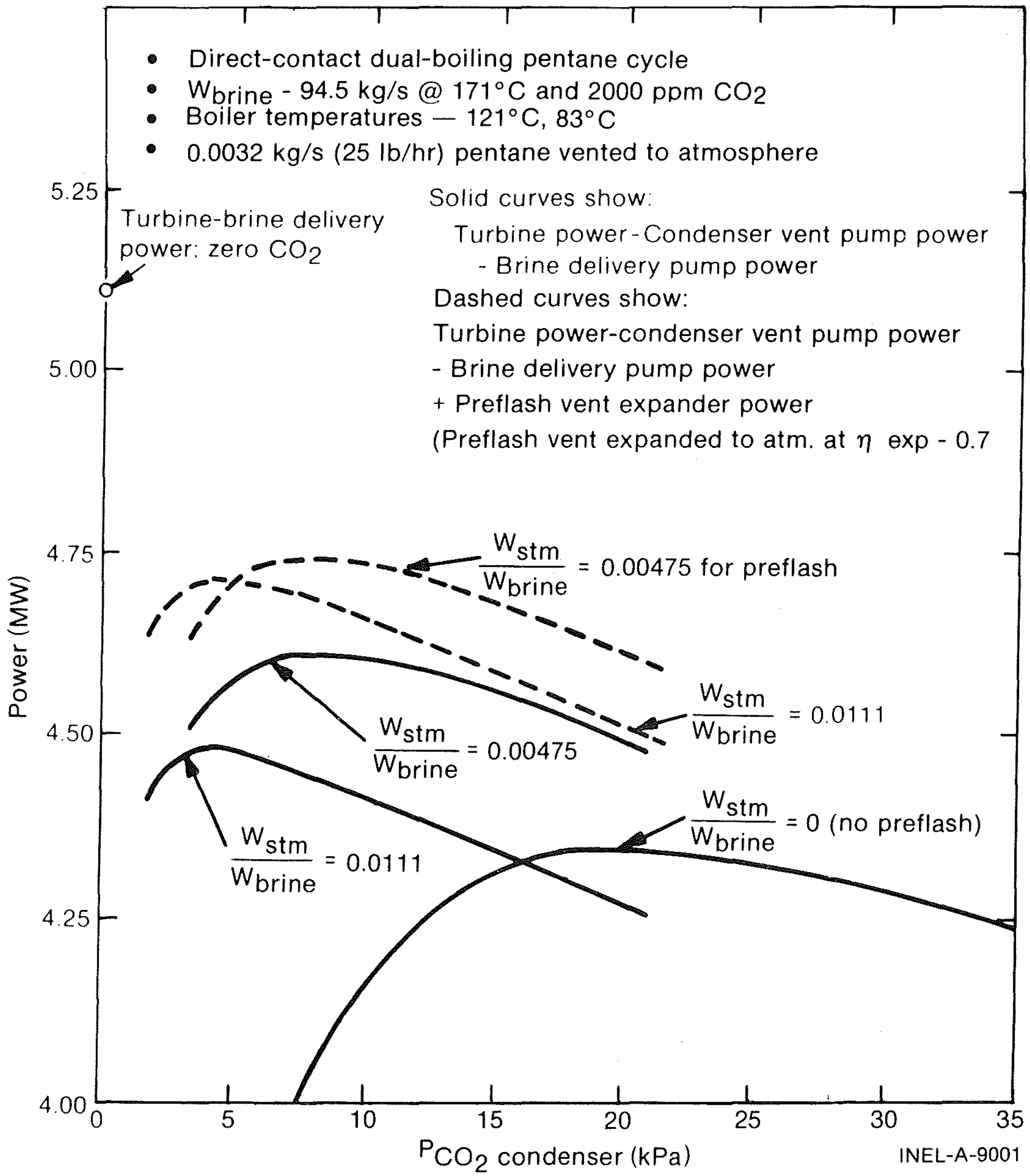


Fig. 20 Effect on cycle performance of preflashing brine.

III. DIRECT APPLICATIONS – R. J. Schultz

Aside from producing electricity, there is a great deal geothermal energy can do. Relatively cool waters can be used directly in all kinds of applications. In fact, some researchers predict that geothermal energy will make its most important contribution by heating and cooling our homes. Such brines may occur naturally, or they may be the by-product of a power plant.

The direct-applications activities at the INEL and the Raft River Geothermal Site spanned many areas of investigation, including geothermal drying, agriculture, aquaculture, and soil warming and heat dissipation, as well as space conditioning. Researchers also began a survey to determine how many U.S. federal buildings are located near known geothermal resources. The following sections provide discussions of the progress that has been made in these areas.

1. FLUIDIZED-BED LOW-TEMPERATURE GEOTHERMAL DRYING – R. C. Schmitt

A series of low-temperature geothermal drying experiments was planned, and equipment was readied by the end of the reporting period. These experiments will investigate the use of geothermal heat for drying, recovering, and handling waste materials, for processing and drying foods, and for drying agricultural materials. Initially, experimenters will attempt to dry both activated sludge biomass slurry and waste potato solids from the J. R. Simplot Company potato processing plant at Burley, Idaho. The J. R. Simplot Company is a participant in the experiment, and other industry representatives have also been invited to participate. The biomass material is currently part of the treatment in the Burley plant's waste stream, and it poses problems of disposal. When dewatered and processed, the material can be a protein food suitable for animal and fish consumption. A companion experiment will involve feeding operations and diet studies, using the dried materials at a commercial fish farm. The material will be partially dewatered by centrifuge at the Burley treatment plant before it is delivered to the Raft River site. Waste materials for the experiment will have a moisture content of from 60 to 90%.

The dryer will use a gas-fluidized-bed system. Thermal energy for drying will come from geothermal water of about 132°C (270°F). The hot brine will circulate through the tube side of one or two heat-exchanger-tube bundles (see Figure 21), each of which will have a heat-transfer area of 1.8 square meters (19 square feet). Each tube bundle is capable of supplying 38 kilowatts (thermal), or enough heat to vaporize 53 liters of water (14 gallons) in an hour. The material to be dried will be passed through a colloid mill for uniform particle sizing of about 1.27 microns, atomized with an atomizing nozzle, and injected as an atomized slurry into the heated bed. Air will be used for the atomizing nozzle, but the use of flashed geothermal water to produce steam for the atomizing nozzle will also be investigated.

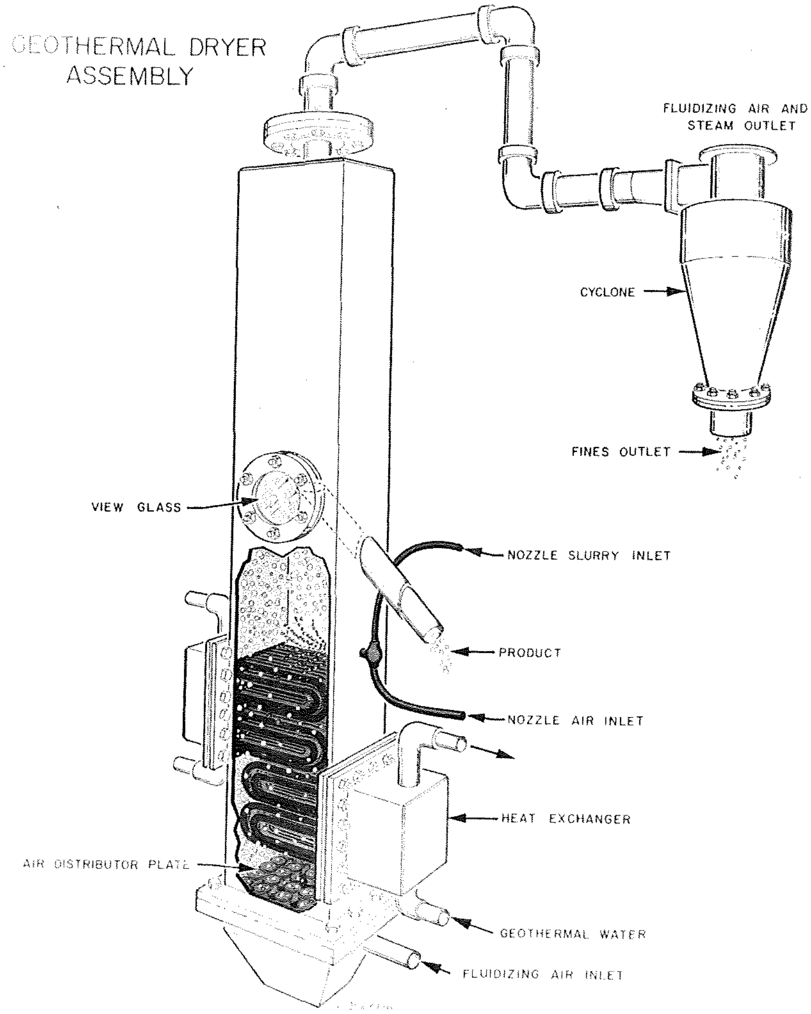


Fig. 21 Fluidized-bed dryer system.

To start the process, a seedbed of sand will be added to the dryer. A jet of air with a velocity of 0.3 meters per second (1 foot per second) will enter from the bottom of the dryer, fluidizing the seedbed. The wet, atomized material will fall into the hot agitated bed, and will dry almost instantly. The dried material will accumulate, mixing with the seedbed, and the level of the bed will rise. The mixture of seedbed and granular or pelletized product will exit through an overflow tube. After a day or two all of the seedbed will have passed out of the system, and a flow of pure, dried product will be available for packaging and use.

The fluidized bed will operate isothermally, and will be stabilized at the boiling temperature of water. The apparatus stands approximately 2.74 meters (9 feet) tall and is made from a piece of 0.25 x 0.25-meter (10 x 10-inch) square structural tubing. The heat-exchanger bundles are bolted into the side of the dryer in two places, as shown in Figure 21.

2. AQUACULTURE – J. F. Sullivan

Biologists have continued culturing three species of aquatic organisms directly in geothermal water. The researchers are attempting to prove the commercial feasibility of geothermal aquaculture. Juvenile channel catfish, tilapia, and giant freshwater shrimp are stocked at or above commercial densities, and the time it takes them to reach marketable size is being monitored. The possible accumulation of fluoride and heavy metals by the organisms is also under investigation.

Both indoor and outdoor raceways are used in the experiment. Preliminary data indicate that in the Raft River facility the food-conversion efficiencies for channel catfish are better for the fish grown in the outdoor raceways. This phenomenon may be due to raceway geometry; it bears further investigation. In addition, biologists are studying the growth rates of shrimp fed only with waste organic material from upstream raceways. The shrimp are exhibiting phenomenal growth rates, approaching three times those commonly encountered by culturists.

The aquaculture facility has been modified extensively during the period to improve operational characteristics and reliability of temperature and flow control. The aquaculture program has been evaluated in detail, and a new program has emerged that will emphasize both polyculture (the combined culturing of two or more species, each occupying a different niche in the culture system) and the nutritional requirements of species reared in geothermal water.

3. HEAT-DISSIPATION/SOIL-WARMING EXPERIMENT – N. E. Stanley

The heat-dissipation/soil-warming experiment tests the feasibility of using an underground pipe grid to dissipate waste heat from a geothermal power plant. Such a system could conserve the water normally lost from evaporative cooling towers, reduce the adverse environmental impacts of waste heat rejection, and increase crop production rates on the warmed soils.

Phase I of the heat-dissipation studies began with intermittent system operation and data collection. This operation revealed several problem areas in the system design, resulting in some proposed modifications and a formal design review. Researchers agreed on modifications designed to ensure the operational integrity of the system and facilitate maximum heat-dissipation objectives. These modifications were being undertaken at the end of the reporting period. The heat-dissipation aspects of the system will be emphasized.

D. L. Slegel (a recognized expert in soil heat-transfer modeling) began work to develop a computer program that will predict the performance of soil heat-dissipation systems.

Plans for Phase I surface-management and crop-response studies were also finalized. These secondary studies will focus on the system's ability to moderate a cool climate and increase selected crop-production rates. Four field crops, nine vegetable crops, three herb varieties, nine tree species, and ten to twelve range grasses and forbs will be cultured and observed. Yield data, produce values, production costs, system costs, and pumping costs, as well as the estimated value of conserved water, will be considered in an attempt to determine the economic feasibility of heat-dissipation/soil-warming systems. Phase II will analyze the responses of perennial crops during future periods.

4. AGRICULTURE – N. E. Stanley

The Raft River irrigation experiment examines the possibility of using cooled geothermal water to irrigate crops. The benefits to the arid West are obvious; instead of consuming cooling water, as a conventional power plant must do, a geothermal facility could produce valuable water for irrigation. The process could also reduce costs of injecting fluids that have been used to generate power.

The second year (Phase II) of the experiment was completed during the period. Crop samples collected during the season were analyzed for food value and fluoride content. A laboratory experiment using agriculture plot soils and RRGE-1 water was also performed to aid in predicting the effects of the long-term application of geothermal water to soils. Results of the crop analyses and the laboratory experiment will be reported during the coming period.

The third and final scheduled phase of the agriculture experiment was planned and initiated. Soil preparation and seeding began, and will be completed during the coming period. About 10 hectares (25 acres) will be cultivated for this final phase.

5. FEDERAL BUILDING PROGRAM – W. D. Gertsch

The direct-applications program is supporting the Department of Energy by analyzing the extent to which a program to convert federal buildings might accelerate the commercialization of geothermal energy. The locations of federal installations in the United States have been coded with respect to known geothermal wells and hot springs. The study has located facilities administered by the Departments of Defense and Interior, the Post Office, and the General Services Administration. Figure 22 shows the positions of these buildings. Work is continuing on facilities of the Public Health Service, the Bureau of Prisons, the Veterans' Administration, NASA, and the National Laboratories.

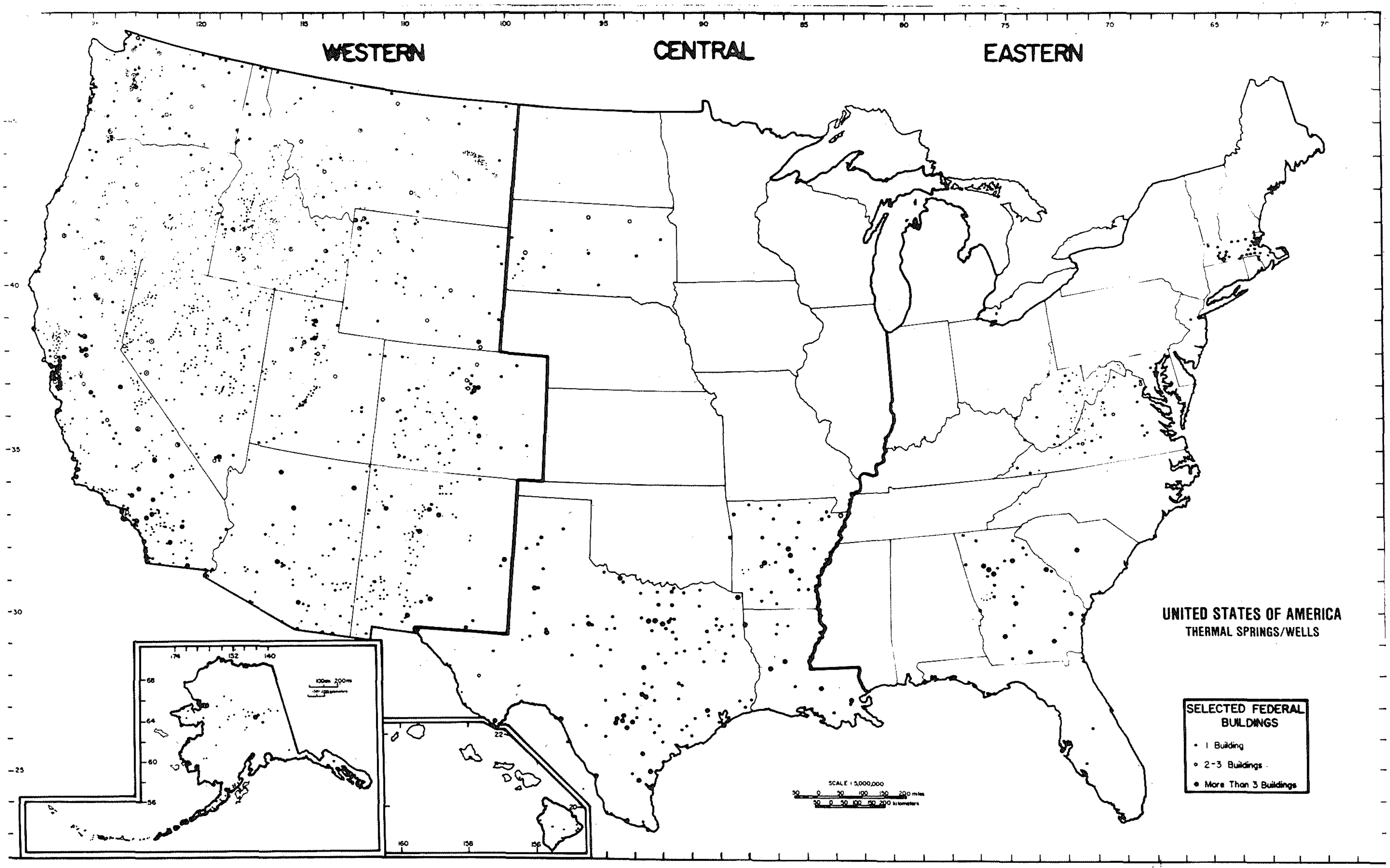


Fig. 22 Locations of some federal installations.

IV. ADVANCED HEAT EXCHANGERS

Much of the Geothermal Program's research and development effort has been specifically directed toward the development of advanced heat exchangers. Because the heat exchangers will be the most expensive components of any geothermal power plant, they are a natural target for cost reduction. Researchers have also been concerned about the corrosion and deposition that the brines could cause, and have attempted to solve the problem with new heat exchanger designs. In addition, most geothermal facilities will be using brines of relatively low temperature, and heat exchangers must use the brine's heat very efficiently. So, in addition to reducing the cost of heat exchangers and improving their ability to withstand corrosion and scaling, designers must make them as efficient as possible. Two new designs are being tested. At Raft River, engineers are testing liquid-fluidized-bed models. At the University of Utah, researchers are studying the merits of direct-contact heat exchangers.

1. LIQUID-FLUIDIZED-BED HEAT EXCHANGERS – C. A. Allen, L. T. Cole, R. E. McAtee (Allied Chemical Corporation)

In a liquid-fluidized-bed heat exchanger, a bed of sand surrounds the tubes through which the secondary fluid flows. If the hot geothermal water rises through the sand at a sufficient velocity, it causes the bed to fluidize. The sand then softly scours the tubes, continuously cleaning their surface and improving the heat-transfer properties of the heat exchanger. Liquid-fluidized-bed development tests were performed on an existing horizontal model and on a newly installed vertical model. The tests included observations of flow distribution and measurements of outside heat-transfer coefficients.

The horizontal unit is a vessel less than 1 meter (3 feet) in diameter and 0.3 meters (1 foot) wide. It contains dummy 1.9-centimeter (0.75-inch) diameter plexiglass heat-exchanger tubes, which can be replaced by instrumented heater rods to determine external heat-transfer coefficients. The vertical unit is 1.2 meters (4 feet) high and 25.4 centimeters (10 inches) in diameter (see Figure 23). It has dummy 1.9-centimeter diameter vertical tubes which can also be replaced with instrumented rods for determination of convective heat-transfer coefficients. Both models are constructed of clear Plexiglass, so that experimenters can observe the motions of the fluidized beds.

Visual observations clearly show that flow distribution is more uniform in the vertical than in the horizontal unit. The vertical unit is also comparatively trouble-free, while in the horizontal unit shifting currents create dead areas and pile sand atop the tubes. Results of the outside heat-transfer coefficient tests are shown in Figure 24. The vertical unit with a fluidized bed has higher coefficients than the horizontal unit. This is due to more complete fluidization in the vertical unit. Heat-transfer coefficients are reduced in the horizontal unit because of the separations in flow and the eddying on top of the tubes.

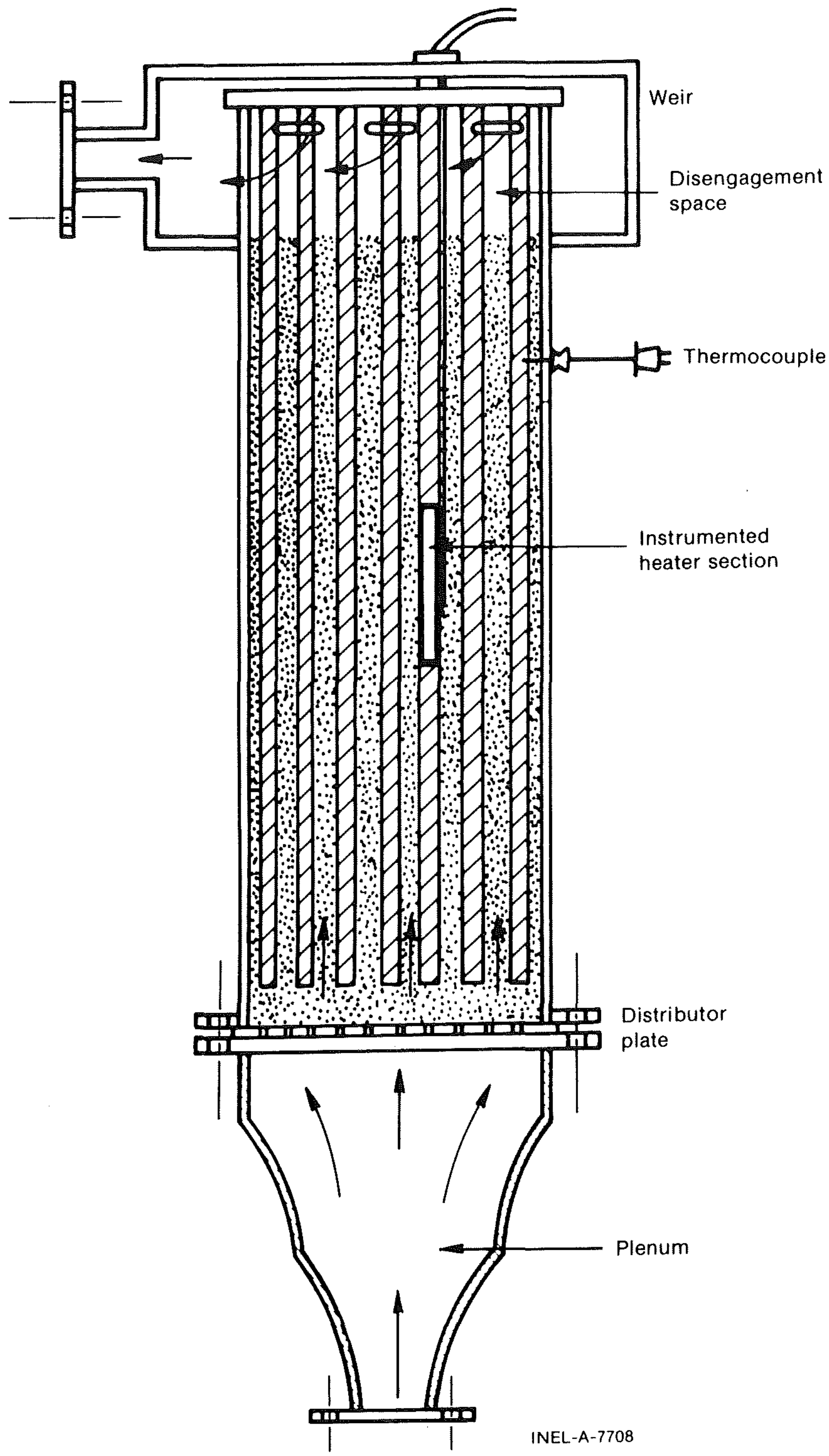


Fig. 23 Vertical fluidized-bed heat-exchanger model.

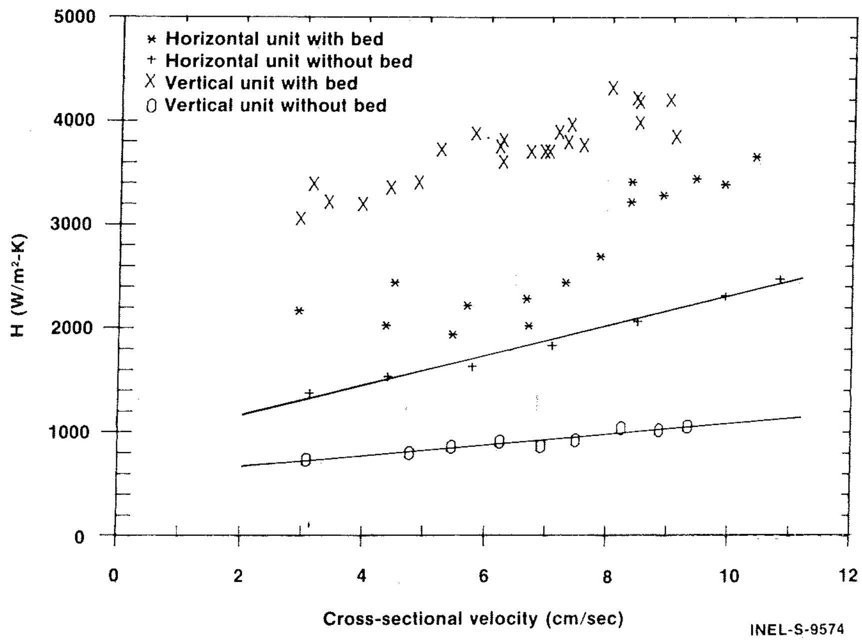


Fig. 24 External heat-transfer coefficients for vertical and horizontal fluidized-bed exchangers.

Flow distribution presents a problem in the horizontal unit because, as the geothermal water rises in the cylinder, the water encounters variations in the area of horizontal cross sections. In other words, a horizontal cylinder is narrow at the bottom and the top, but wide in the middle; this variation in area continuously changes the velocity of the geothermal water. The flow slows down at the outside edges of the middle section, and the activity of the sand in these areas subsides. Experiments with different distributor plates have led to the conclusion that the dead areas cannot be completely eliminated. Thus, a design which maintains a constant cross-sectional area, such as that shown in Figure 25, is recommended. The blocked-off shell area can be used for geothermal water transport, and the design eliminates some of the external piping which would normally be required.

Horizontal fluidized-bed units do have one advantage over vertical exchangers. Because the geothermal fluid must flow at a certain fixed velocity in order to properly fluidize the bed and maximize heat transfer, the important variable is the cross-sectional area of the tubes with which the brine comes in contact. Horizontal models offer more cross-sectional area for the same tube length. If flow-distribution problems can be solved, horizontal units could more efficiently handle the large flow rates necessary for producing electricity.

Tests of both designs will continue during the coming period, and engineers will write a report on their work with liquid-fluidized-bed heat exchangers.

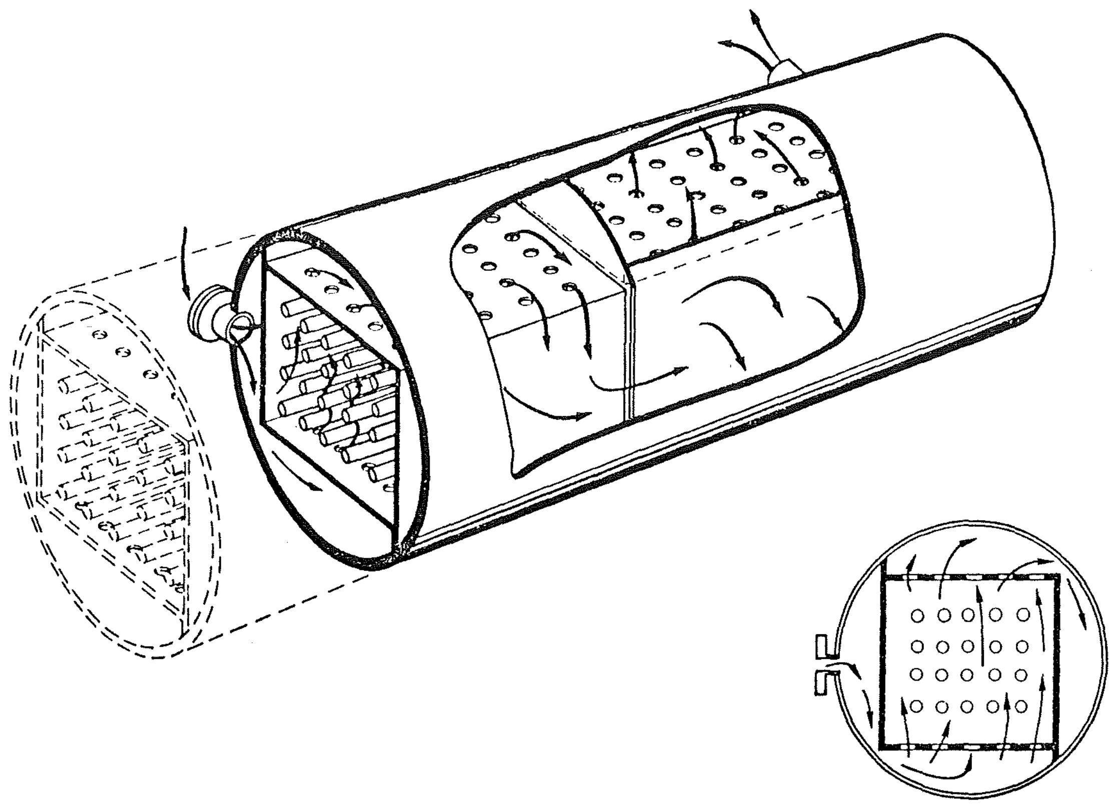


Fig. 25 Proposed horizontal fluidized-bed heat-exchanger design.

2. DIRECT-CONTACT HEAT EXCHANGERS – R. Boehm, H. Jacobs, C. Kodres, K. Thomas (University of Utah)

In a direct-contact heat exchanger, the hot geothermal fluid actually mixes with the secondary fluid. The secondary fluid is usually an organic liquid such as isobutane and pentane. Such liquids boil at relatively low temperatures, and they are almost insoluble in water. When the secondary fluid mixes with the hot water, it vaporizes, expands, and escapes to drive the turbine. Again, as in the liquid-fluidized-bed heat exchangers, corrosive brines are kept away from expensive turbine machinery. If the direct-contact exchangers are practical, they will have one distinct advantage; because the network of heat-exchange tubing can be eliminated, the direct-contact exchangers should be much less expensive.

During the report period, researchers at the University of Utah undertook system analyses of power-plant designs incorporating direct-contact heat exchangers. Engineers also evaluated direct-contact condensers and preheaters, studied the effects of metastable liquids, and wrote a chapter for a sourcebook on geothermal energy.

2.1 System Analyses

University of Utah researchers conducted preliminary analyses of a 500-kilowatt (electric) binary power plant now being built by Barber-Nichols for the Lawrence Berkeley Laboratory. The skid-mounted test plant, which will use direct-contact components, will be tested at both East Mesa, California, and at Raft River. University engineers analyzed the system for use with brines from both locations.

For a simple direct-contact binary power cycle, isobutane was clearly the preferred working fluid at East Mesa. Assuming 137.8°C (280°F) temperatures at Raft River, cycle analysis indicated either pentane or isobutane would be suitable. Analyses predicted a significantly smaller heat exchanger could be used with pentane. A consideration of turbine costs, however, indicated that for this low power rating a less expensive plant could be built if isobutane were used. For that reason, and because the demonstration plant will first be used at East Mesa, engineers decided to design the unit for use with isobutane. (For related systems analysis, dealing primarily with secondary-fluid loss and recovery, see Section II-3.)

In related work, researchers conducted bottoming (multiple-cycle) analyses to determine methods for maximizing brine utilization. The idea is to use a different secondary fluid for the low-temperature boiler cycle, a fluid exactly suited to the particular range of temperatures. They analyzed simple direct-contact binary cycles, as well as two variations. In one variation, direct-contact binary cycles made sequential use of the same brine (Figure 26). The second variation (Figure 27) used only enough brine in the preheater to maintain a temperature difference of 5°C (9°F), and divided the flow of brine between parallel paths. The analysis postulated a well temperature of 143°C (290°F) and a condenser temperature of 26.7°C (80°F). Tables VII and VIII indicate typical results. Current studies will provide results for other temperature conditions. A report of this work has been submitted for presentation at the Geothermal Resources Council meeting in July 1978.

The DIRGEO computer program (DIRect-contact; GEOthermal) is currently being modified to include a number of preliminary design routines for various direct-contact, counter-current preheaters.

2.2 Condensers

A direct-contact film-type condenser was constructed during the period. Data were obtained for the condensation of Freon-113 on water at atmospheric pressure. The condenser consisted of a 15.0-centimeter (5.9-inch) diameter glass column packed with 3.2-centimeter (1.25-inch) diameter ceramic spheres, which were included to increase the residence time of the coolant. The coolant was distributed over the packing at the top of the tower and filtered down through the bed, coating it with a thin, laminar film on which the Freon condensed. To aid in the elimination of non-condensable gases, the hot vapor was injected at the base of the tower.

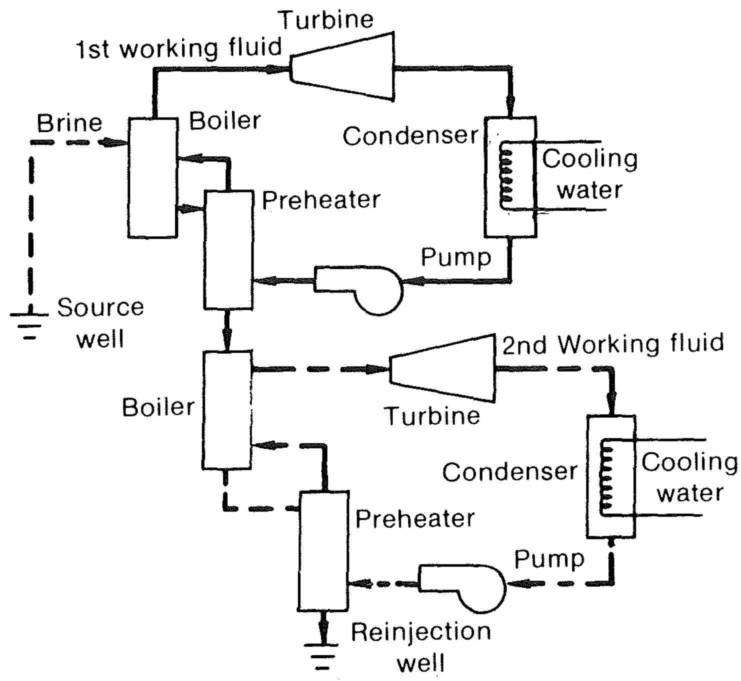


Fig. 26 Series-type direct-contact cycle.

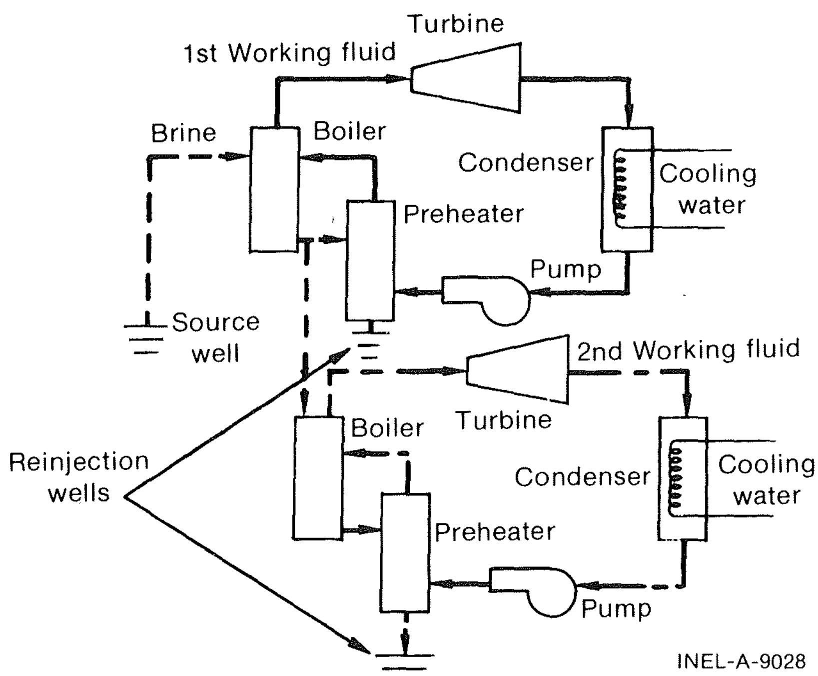


Fig. 27 Split-type direct-contact cycle.

TABLE VII

SYSTEMS ANALYSIS OF SERIES-TYPE DIRECT-CONTACT CYCLE WITH TWO WORKING FLUIDS[a]

First Working Fluid	Second Working Fluid	Flow Rate Second Fluid (kg x 10^5/hr)	Exit Temperature (^oC)	Gross Power (MW)	Net Power (MW)
Pentane[b]	Hex	1.23	71.1	7.07	6.96
	R-12	6.40	57.2	6.87	6.32
	Isob	2.34	60.0	6.70	6.39
	R-114	6.69	54.4	6.69	6.52
	Isop	1.93	65.6	6.57	6.42
	Pent	2.04	57.2	6.52	6.40
Isobutane[c]	Hex	1.04	51.7	6.77	6.03
	R-12	3.89	51.7	6.49	5.67
	Isob	1.50	51.7	6.43	5.69
	R-114	3.85	51.7	6.45	5.69
	Isop	1.31	51.7	6.42	5.67
	Pent	1.23	51.7	6.40	5.66

[a] See Figure 26.

[b] $\dot{m}_{pent} = 1.42 \times 10^5$ kg/hr.

[c] $\dot{m}_{isob} = 2.61 \times 10^5$ kg/hr.

TABLE VIII

SYSTEMS ANALYSIS OF SPLIT-TYPE DIRECT-CONTACT CYCLE WITH TWO WORKING FLUIDS[a]

First Working Fluid	Second Working Fluid	Flow Rate Second Fluid (kg x 10^5/hr)	Exit Temperature (^oC)	Gross Power (MW)	Net Power (MW)
Pentane[b]	Hex	1.00	76.7	6.76	6.65
	R-12	5.22	61.1	6.71	6.16
	Isob	1.91	57.2	6.54	6.24
	R-114	5.45	56.7	6.53	6.32
	Isop	1.57	62.2	6.42	6.27
	Pent	1.66	62.8	6.37	6.24
Isobutane[c]	Hex	0.64	76.7	7.40	6.67
	R-12	2.39	61.1	7.37	6.30
	Isob	0.92	57.2	7.24	6.36
	R-114	2.36	56.7	7.23	6.42
	Isop	0.80	62.2	7.14	6.39
	Pent	0.75	62.8	7.11	6.35

[a] See Figure 27.

[b] $\dot{m}_{pent} = 1.43 \times 10^5$ kg/hr.

$\dot{m}_{brine,\ 2nd} = 3.70 \times 10^5$ kg/hr.

[c] $\dot{m}_{isob} = 2.61 \times 10^5$ kg/hr.

$\dot{m}_{brine,\ 2nd,} = 2.79 \times 10^5$ kg/hr.

Packing height, water temperature, and both water and vapor flow rates were varied in obtaining heat-transfer data. The data acquired were reduced consistent with a semi-analytical model yielding the correlation

$$St = .0689\, Ja^{1.11}\, C^{-.246}\, H^{-.946} \tag{1}$$

where

$$St = \frac{h}{P_v C_{pv} V}$$

$$= \frac{U}{P_v C_{pv} V_a}$$

$$Ja = \frac{h_{fg}}{C_{pv}(T_{sat} - T_{avg})}$$

$$C = \frac{\dot{m}_L\, C_{PL}}{\dot{m}_v\, C_{pv}}$$

$$H = \frac{\text{bed height}}{\text{bed diameter}}$$

and

U = volumetric heat-transfer coefficient

= q/Vol/LMTD

$$a = \frac{\text{surface area of packing}}{\text{volume of condenser}}$$

v = superficial velocity of vapor at bottom of condenser

$$T_{avg} = \frac{T_{Lout} + T_{Lin}}{2}$$

m = mass flow rate

C_p = specific heat at constant pressure

h_{fg} = heat of vaporization

h = surface heat-transfer coefficient

and subscripts

L	=	liquid phase
v	=	vapor phase
LMTD	=	log mean temperature difference across the condenser
q	=	total heat transferred per unit time.

This correlation was also applied with good results to the data of C. T. Cheng[2] for the condensation of steam on Aroclor. In order to fully correlate the two systems, it was necessary to include a factor comparing the relative thermal conductivities of the coolant and condensate. Thus, the final correlation is

$$St = .0689\ Ja^{1.11}\ C^{-.246}\ H^{.946}\ K^{.239} \tag{2}$$

where

K	=	the ratio of the coolant's conductivity to the condensate's thermal conductivity.

Data are now being obtained for Freon-113 vapor condensing on water using 2.54-centimeter (1-inch) Berl saddle packing. It will then be possible to test the validity of the correlation for a variation in surface area per unit volume of the bed material.

One goal of the present study has been the formulation of a theoretical model for the direct-contact condensation of an immiscible vapor on a liquid film. This is a system for which little theoretical work has been done. The University of Utah model follows that of Murty and Sastri[3], but deals with two immiscible fluids. When the numerical solution is completed, it will be compared to data from the present general study and to the data that Tamir and Rachmilev[4] reported for the condensation of Freon-113 on water flowing over a single sphere. It should then be possible to determine whether the interfacial resistance is due to the lack of nucleation sites or to the presence of the condensate layer.

Work has also continued on collapsing-bubble-type condensers. In this kind of condenser, the hot vapor bubbles up through a bath of cooling water. Improved hydrodynamic models have been studied to provide better agreement between theory and experiment for single-bubble studies. There have been indications that the simplistic hydrodynamics in the paper by Jacobs, Fannir, and Beggs[5] were one reason the theoretical model predicted earlier bubble collapse than actually occurred in experiments. A more rigorous examination of the hydrodynamics is currently being carried out.

2.3 Preheaters

Plans have been made to continue work on various tower configurations for preheaters. The vessel used for this purpose during last period's system testing at East Mesa has been returned to Raft River. Components from that system (primarily tanks and pumps) will now be used for detailed preheater studies at the University of Utah.

2.4 Effects of Metastable Liquids

In the direct-contact heat exchangers under consideration, heat must be transferred across the interface between two liquids. Because there are few nucleation sites along such an interface, the volatile secondary fluid will be superheated (perhaps considerably) before it begins to boil. The primary mode of heat transfer would thus be evaporation rather than boiling.

Any analysis of direct-contact heat-exchanger performance should take superheating into account. Design work on direct-contact heat exchangers for geothermal applications has emphasized the configuration of the spray for the volatile liquid. To date, however, no published work relating to this type of heat exchanger has considered superheating.

Work at the University of Utah has considered the case where the specific gravity of the volatile fluid is less than that of the hot liquid; as the secondary fluid is sprayed onto the hot geothermal water, droplets float on the surface of the water. A single-droplet model has been formulated, approximating the droplet lens as a thick disk. The lens is analyzed and heat-transfer rates and evaporation times are determined. A numerical model of the evaporating lens has been completed, and an evaluation of the various parameters is in progress. The numerical results will be verified experimentally by photographing the evaporation process.

2.5 Sourcebook on Geothermal Energy

A chapter dealing with direct-contact binary cycles was written for the sourcebook on generating electricity from geothermal energy. A final, edited copy is currently being prepared, and will be submitted to DePippo at Brown University for inclusion in the sourcebook. This chapter reports not only work that was conducted at the University of Utah, but also major conclusions that can be drawn from the work of other DOE researchers.

V. LOW-TEMPERATURE RESOURCES – W. L. Niemi

While high-temperature resources are rare, and medium-temperature resources are not widespread, low-temperature geothermal waters are very common througout the West. Though they are too cool for producing electricity and accomplishing most industrial tasks, they are eminently suitable for other uses. Low-temperature fluids are perfect for space heating. Because of this prospect, and because the cooler waters are so widespread, geothermal fluids cooler than 90°C (194°F) will probably play a major role in replacing our fossil fuels.

A geothermal heating system has been operating in Boise, Idaho, since 1892. Most of the homes along Warm Springs Avenue were at one time heated with water drawn from beneath the Boise Front foothills. When fuel prices began to rise in the early seventies, Boise citizens expressed an interest in expanding the system – perhaps to include most of the government buildings in Idaho's capital city. Since then, INEL engineers have drilled and tested two new wells, and they have published their recommendations in a report to the governor[6].

In the last year or two, other intermountain communities have come to INEL for assistance in assessing and developing their geothermal resources. More and more private interests and individuals are also requesting help. Groups throughout the West are putting this unique source of energy to work. This section describes a few of the places where low-temperature reservoirs are being assessed or developed.

1. BOISE, IDAHO

Reservoir engineers conducted pump and artesian-flow tests on the two Boise wells that were drilled in 1976. Researchers ran the tests between November 1977 and February 1978, in an effort to better understand the size and nature of the Boise Front's geothermal reservoir. Specifically, scientists must determine the reservoir's ability to supply geothermal fluids for heating Boise's government buildings. All tests to date have indicated that the resource is adequate for the planned project.

The 372-meter (1222-foot) BEH-1 well (BLM) and the 391-meter (1283-foot) BHW-1 well (Beard) were tested for reservoir Kh, to determine their intrinsic permeability (K) thickness (h) product, or intrinsic transmissivity. Tests indicated a reservoir Kh on the order of 1×10^4 millidarcy-feet in the vicinity of BEH-1, 1×10^5 millidarcy-feet in the vicinity of BHW-1, and 1×10^6 millidarcy-feet for the reservoir as a whole. A transmissivity of approximately 1×10^3 liters per day per meter (or gallons per day per foot) was calculated for BEH-1, 1×10^4 for BHW-1, and 1×10^3 for the integrated reservoir. It is difficult to quantify reservoir characteristics at this time, however, because of the nature of the reservoir fracture system, the flow of fault-controlled groundwater, and the limited number of observation wells.

Decisions about future applications must now be made by the government agencies that will use the resources: the city of Boise, the state of Idaho, and the U.S. Bureau of Land Management. Reservoir engineers recommend the drilling of another well, preferably to the southeast of the tested wells. The new well should be constructed in such a way that it can later be used as a production well. Also, in order to study the effects which pumping might have on the reservoir, a monitoring program should be undertaken.

2. SUGAR CITY, IDAHO, AND THE SNAKE RIVER PLAIN

When the Teton Dam collapsed in 1976, the resulting flood completely devastated Sugar City, Idaho. As residents made plans for rebuilding the town, INEL engineers considered the possibility of heating the new buildings with geothermal water. Researchers suspected an extensive geothermal reservoir lay beneath the town site in the middle of the eastern Snake River Plain.

Not long afterward, administrators of the INEL began thinking of ways to convert the laboratory's fossil-fuel heaters and generators to a different source of energy. The INEL is situated west of Sugar City on the Snake River Plain, and the possibilities of geothermal energy seemed worth investigating. Exploration programs for both locations will be organized during the summer of 1978.

The first step for both projects will be the drilling, testing, and coring of exploratory holes (slim holes). Since basaltic deposits lie thousands of meters deep throughout the plain, geologists know little about the area's deep geology. The holes will be cored and geophysically logged to give a better understanding of the geology beneath the plain. Reservoir engineers will use the information to determine whether wells will be able to tap usable reservoirs. The data will also benefit the INEL health physicists who are studying the management of radioactive wastes.

As the period closed, plans and contracts were being finalized for drilling slim holes on the INEL and at Sugar City. The INEL holes will be 910 and 610 meters deep (3000 and 2000 feet), and the Sugar City hole will be drilled to 760 meters (2500 feet). Wire-line methods will be used to core the 15-centimeter (6-inch) holes. Also planned are extensive borehole geophysical logging and testing programs, for which scientists will use the INEL geophysical logging truck.

Information derived from the INEL slim holes will be used to select the site of a 3000-meter (10,000-foot) deep test well, which could itself become a geothermal production well. The deep well will be located somewhere near the Idaho Chemical Processing Plant. The Sugar City slim hole should help reservoir engineers decide whether further development in that vicinity is feasible. The Sugar City hole will be drilled in the city park, and if a usable reservoir is encountered, that hole could be reamed out and used as a production well.

3. OTHER LOW-TEMPERATURE RESOURCES

Reservoir engineers assisted a number of government agencies and private groups during the first half of FY-78. A preliminary assessment of geothermal resources near Hill Air Force Base, Utah, was published in February[7]. The assessment concluded that "the potential for developing hydrothermal resources at or in the vicinity of Hill Air Force Base for space heat and process applications is sufficiently encouraging to warrant further investigation and development." A 120-meter (400-foot) well at Lidy Hot Springs, about 80 kilometers (50 miles) north of Idaho Falls, Idaho, was logged with the INEL geophysical logging truck in February, 1978. Reservoir engineers intended to define reservoir characteristics, but poor well conditions and inclement weather hampered their efforts. Researchers planned to continue borehole geophysical logging efforts at Lidy Hot Springs through the fall of 1978.

Reservoir engineers also advised a Boise developer about the possiblity of heating a small housing development with geothermal water, and advised a Weiser businessman about the application of geothermal heat to greenhouses. The engineers will geophysically log wells at Pagosa Hot Springs, Colorado, and White Sulphur Springs, Montana, during the summer of 1978. A well in Monroe, Utah, will be logged in the fall of 1978. Private interests will explore and develop a resource near Mountain Home, Idaho, during the summer of 1978; their work will be monitored by engineers from the INEL.

VI. ENVIRONMENTAL CONSIDERATIONS – R. R. Stiger, S. G. Spencer

Environmental monitoring of air and water quality, terrestrial and aquatic ecology, hydrology, meteorology, seismicity, and subsidence continued in the Raft River Valley. The results of each survey will be presented in an annual environmental report to be issued in October. Researchers emphasized studies of the ferruginous hawk, monitor wells, and fluorosis, as well as a general examination of Raft River's terrestrial ecology. In a related environmental study, scientists began gathering baseline information for other areas on the Snake River Plain that might someday be affected by geothermal development.

1. THE FERRUGINOUS HAWK

Brigham Young University received a contract to assess the impact of Raft River's geothermal development on breeding raptors. Of special interest is the ferruginous hawk. The two-year study will examine the hawks' reactions to a variety of stimuli. Anticipated impacts will be simulated. Perturbations will include constant, low-level human activity (as from roads or farms), local foot traffic, open motor traffic, closed motor traffic, constant moderate activity (such as a generator), and intermittent human activity (such as rifle shots). Each disturbance will gradually approach a pair of nesting hawks. When the hawks show overt signs of discomfort, the distance to the nest will be measured. That value will then be regarded as a critical distance for that kind of disturbance, and appropriate buffer zones can be established.

The experiment will sample active nests in the Raft River Valley; nests in the Curlew Valley will comprise the control group. The study is being coordinated with the U.S. Fish and Wildlife Service, the BLM, and the Idaho Department of Fish and Game.

2. INJECTION-MONITORING WELLS

The major environmental concern associated with the development of geothermal resources in the Raft River Valley is the possibility that shallow aquifers may be contaminated. Since little is known of the interactions between the shallow aquifers and the geothermal production and injection zones, a series of monitor wells is being drilled. A total of seven wells, ranging in depth from 150 to 460 meters 500 to (1500 feet), will be drilled this spring and summer. They will be monitored during injection tests at RRGE-3, RRGI-4, RRGI-6, and RRGI-7, to see if the injection has any effect on the shallow aquifers.

Two of the wells were completed during the report period: a 170-meter (570-foot) well just west of the greenhouse hot well, and a 400-meter (1310-foot) well southeast of RRGI-4 (Figure 28). The water chemistry of these two wells, of RRGI-4, and of the greenhouse well are shown in Table IX.

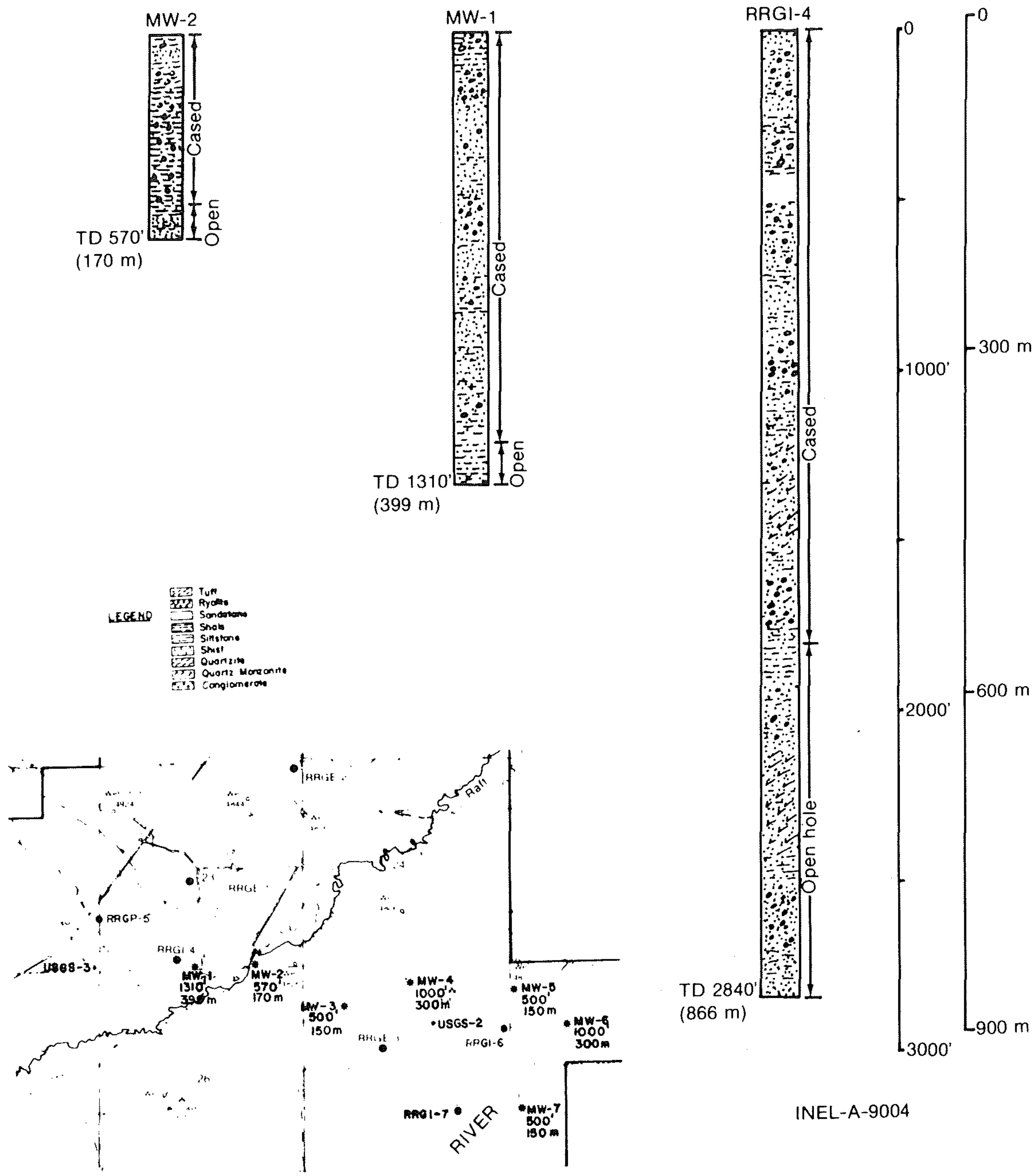


Fig. 28 Environmental monitoring wells.

The first response of the aquifer to geothermal injection would probably be a change in pressure. Therefore, each of the monitor wells will be equipped with either a recording pressure transducer or a water-level recorder. The water chemistry of each monitor well will be analyzed extensively before and after each injection test. In addition, the water level in two USGS core holes and in ten exploratory and irrigation wells will be recorded. The flow from the greenhouse well and the BLM well will be monitored daily. Results of the injection tests will be reviewed by the USGS and the Idaho Department of Water Resources and used to determine the environmental acceptability of long-term injection into each of the injection wells.

TABLE IX

WATER CHEMISTRY OF RAFT RIVER WELLS

Chemical Species	MW-1[a]	MW-2[a]	Greenhouse Well[a]	RRGI-4[a]
Ca	168	99	86	147
Fe	0.08	0.4	<0.06	--
K	32.4	26.1	29	28
Li	3.75	2.53	2.3	3.1
Mg	0.4	0.72	0.6	0.17
Na	2192	2378	1450	1525
Cl	3594	1660	1694	2575
CO_3	2	<0.1	<1	--
F	2.5	4.33	5.35	4.5
HCO_3	20	31	35	24.4
NH_4	4.5	0.1	0.2	--
NO_3	1.2	0.02	0.02	--
SO_4	64	57	55	61
SiO_2	81	91	95	105
pH	8.4	7.6	8.0	--
Conductivity	12,300	6400	6370	7448
TDS	6350	3204	3276	4579

[a] Except for pH and conductivity, all values are ppm.

3. FLUOROSIS

Investigators from Utah State University began a clinical evaluation of human dental fluorosis in the Raft River Valley. The purpose of the study is to document background levels of fluorosis and to provide recommendations for treatment if a problem does exist. This study will be coordinated with surveys of actual and potential drinking water sources, which have indicated fluoride levels ranging from 0.2 to 5.2 milligrams per liter.

4. TERRESTRIAL ECOLOGY

Students from Brigham Young University investigated the characteristics of the Raft River Valley's biotic communities. They gathered baseline information about the physical, chemical, and biological features of the communities necessary to maintain interactions among soil, vegetation, birds, small animals, aphids, and ants. (Figure 29 provides a graph of background temperatures at Raft River.) In addition, the university researchers studied

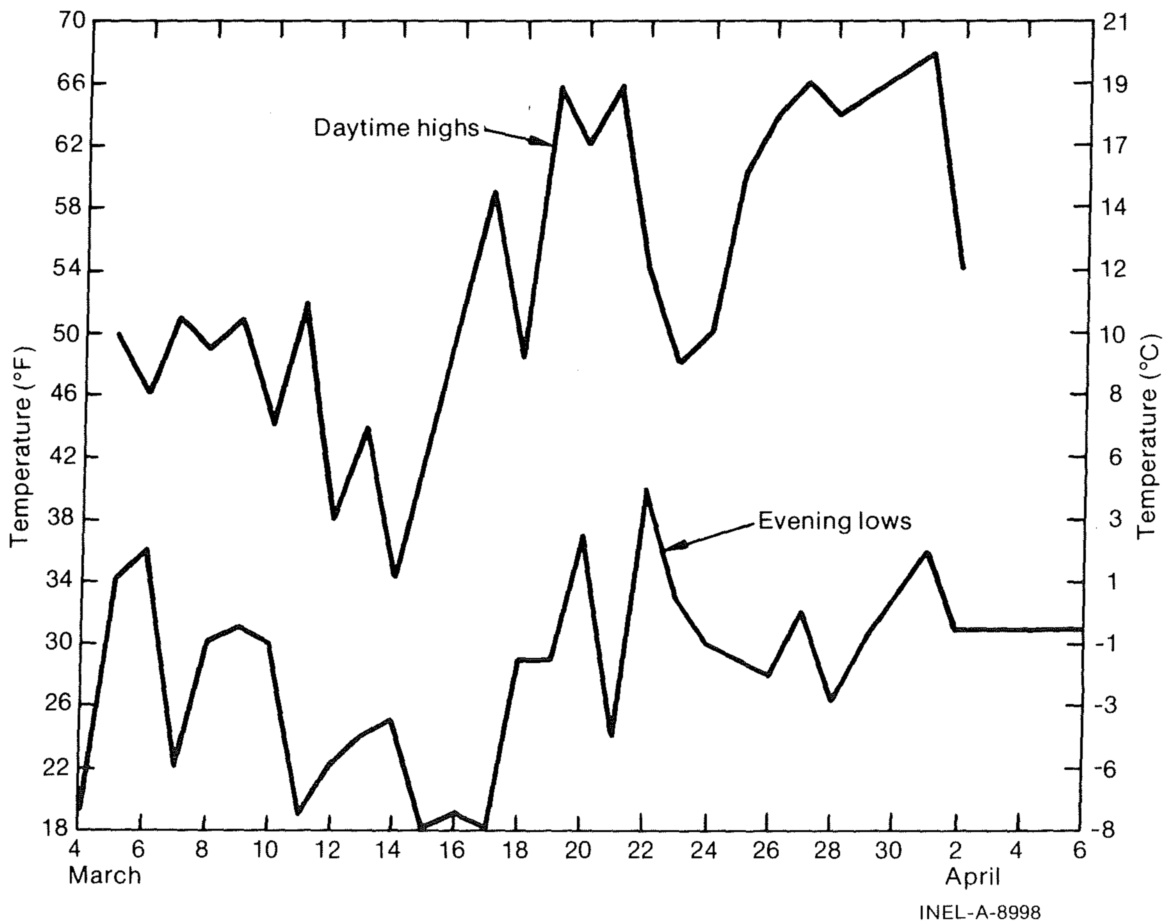


Fig. 29 Raft River temperature log.

various types of terrestrial animal communities and described their key species, soils, meteorology, physiography, and other essential ecological characteristics. The reproductive processes of selected plants and animals were analyzed in terms of their sensitivity, in order to assess the changes development could bring.

Researchers established a grid system to study species distribution and population estimates for small mammals. They discovered that densities vary appreciably with respect to biotic community and season. These data will provide a basis for monitoring population changes caused by yearly variation, as well as those caused by geothermal development.

Certain common birds that are restricted in their habitat selection were studied to help assess possible overall impacts. Brewer's sparrows, horned larks, sage sparrows, and sage thrashers were selected. Researchers discovered, however, that the Raft River region does not support diversity, and that densities of breeding birds do not vary greatly throughout the region. Sage sparrows appear to be the most selective in their choice of habitat, and are probably most affected by disturbances. Changes in distribution or numbers of this species, as well as changes in the absolute density of breeding birds, should be indicators of environmental impacts resulting from geothermal development.

Rather than studying the immense community of arthropods, researchers regarded the ant-aphid system as a model of the larger community. These organisms may be closely tied through symbiotic relationships, and ants compete with birds and mammals for seeds. Continued long-term sampling will be necessary before conclusions are available.

5. SNAKE RIVER PLAIN

The Snake River Plain environmental preplanning effort began in February. This effort will determine what baseline environmental data exist for areas on the Snake River Plain that have been declared KGRAs or that are thought to have significant geothermal resource potential. The program includes: (1) compiling and evaluating available environmental data; (2) coordinating with other federal, state, and local agencies, as well as industry, in order to establish a clearinghouse for regional evironmental data; and (3) sponsoring a series of workshops which will give the public a chance to identify and discuss key issues, and which will increase awareness of proposed developments.

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