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EPRI GEOTHERMAL ENERGY R&D

5-YEAR PROGRAM PLAN

(1975-1979)

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Acknowledgement

The EPRI Geothermal Energy Research and Development Program Plan was developed during the summer of 1974, by a task team composed of the EPRI Solar and Geothermal Program Manager, Dwain F. Spencer; Dr. Gary Underhill, summer visiting professor from the University of Texas, Austin; Mr. Larry Beaulaurier, a senior program manager from the Bechtel Corporation, and a number of university consultants familiar with geothermal development problems. In addition, electric utility representatives provided major program direction at the Geothermal Workshop held July 16-18, 1974, and through numerous follow-up discussions held with them subsequent to the Workshop. This close interrelationship between EPRI technical staff and interested electric utility representatives was instrumental in defining a meaningful, focused EPRI program in geothermal energy R & D.

EPRI GEOTHERMAL ENERGY R&D

5-YEAR PROGRAM PLAN

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I SUMMARY AND RECOMMENDATIONS

The recommended EPRI Geothermal Research and Development 5-Year Program Plan has been defined to complement and provide focus for federally sponsored geothermal energy R&D efforts. The EPRI Geothermal Recommended Program cost estimates represent approximately 6.0% of the expected federal funding and approximately 2.5% of EPRI's projected budget over the next five years. The recommended budget is 15.6 million dollars for EPRI with an additional 18.0 million dollars expected from the electric utilities for the demonstration plant for the period 1975-79. The scope of the program includes:

- . Verification of hydrothermal reservoir capability and low salinity brine heat transfer characteristics at a potential demonstration site followed by design, development and construction of a Low Salinity Hydrothermal Demonstration Plant in conjunction with an electric utility or utility consortium.
- . Development of a comprehensive set of Guidelines Manuals for use by utility management and engineers spanning the full range of geothermal resource utilization from exploration through plant start-up, including not only technical, but environmental, institutional and regulatory factors.
- . A subprogram to define the potential and requirements for Geothermal Systems. This effort will assess the potential of geothermal energy for electric power production including economic and operational analysis of powerplants for various type geothermal sources and definition of national R&D and commercialization strategies and requirements.
- . A Supporting Research and Technology subprogram oriented toward minimizing the risk associated with utilization of low and high salinity hydrothermal sources.

- . An Advanced Research and Technology subprogram to assess the potential of geopressure resources in conjunction with the federal government and limited R&D on advanced concepts for utilization of hydrothermal fluids.

The EPRI Geothermal R&D Program primarily focuses on low salinity, hydrothermal sources since these are expected to be the next commercially viable geothermal alternative. Further, the program has been defined to provide a basis for extrapolating planned federally supported experimental test beds (pilot plants) to commercial scale powerplants.

Implementation of the program will be accomplished by a phased management plan which provides for the achievement of specific objectives with scheduled major milestones. Program elements in each of the subprograms will be executed by a procurement approach which primarily utilizes formal requests for proposals (RFP's). Proposals will be evaluated and awards made on a "best" performer basis. The results of the program will be communicated to the utilities by means of formal contractor oral and written reports, workshops, and periodic summary reports prepared by the EPRI staff.

This program should place the western electric utilities in an informed position to determine the problems and potential of low salinity, hydrothermal systems.

II INTRODUCTION

A. Overview of Problems Facing the Electric Utilities

Electric power generation has been increasing at a rate of almost seven percent per year, whereas the rate of increase of all forms of energy in the United States is about four percent per year. From an energy standpoint, a continuation of this trend to electrification is desirable because of the wide range of fuels that can be used. In 1973, coal generated 44% of the electricity, oil and gas about 37%, and hydropower accounted for most of the remainder. With only twenty-five stations on-line at the start of 1974, nuclear powered electricity has been a small part of the nation's present energy supply.

The total 1973 generating capacity was 435 Gigawatts electric (MWe). By 1985, this capacity is expected to more than double to about 980GWe and by the year 2000, more than quadruple to nearly 2,000 Gigawatts. This projected growth is expected to lead to a significant change in the fuel mix toward coal and nuclear powerplants. Although the capacity of oil and gas fired plants would remain about constant, it is anticipated that they would be utilized principally for intermittent cycling and peaking generation, and thus their fuel consumption may decline.

The expansion of generating capacity to the projected level together with concurrent expansion of transmission and distribution networks, would involve high costs. It is estimated that the

electric utility industry will require 350 billion dollars of capitalization between now and 1985. This represents an annual rate of expenditure of over \$30 billion, more than triple the \$10 billion invested in 1970.

Further, because there is no substantial capacity to store electrical energy, supply-demand relationships are measured in essentially instantaneous terms. Energy consumption (Kwh) and peak capacity (installed and available kw) are separate subjects, and both are important. Daily, weekly, and seasonal variations in load affect both of these and require that some power generation units be predominantly steady-state (base-load), while other units vary with load swings (cycling), and yet others are utilized only to meet short term peak demands (peaking).

In some parts of the country, because of air conditioning, summer peak loads are 40% greater than the winter peaks. In other portions of the country, winter peak loads are greater than summer peaks. The capacity required to satisfy such peak loads is greater than the baseload, and any steps to make demand more uniform would make the overall generating system more economical. System economics and, recently in many parts of the country, environmental quality requirements govern the allocation of plant types to these various services.

While coal-fired units have supplied both base-load and cycling functions, particularly in Northeastern utility systems, modern coal-fired units have tended to become more inflexible; and the largest units today provide mainly base-load power. Growing particulate, sulfur, and nitrogen oxide stack gas emission controls have caused losses in both flexibility and availability.

Some years ago, the promise of low fuel costs and the clean air aspects of nuclear plants began to attract the attention of the electric utilities. In addition, the utilities foresaw a potential freedom from the month-to-month dependence on continual flow of coal. With strengthened environmental standards in the offing, new coal-fired plants began to suffer from serious inroads made by new nuclear plant orders and accelerating conversion to oil and gas firing.

As regulatory and equipment delays began plaguing the nuclear construction program and the opposition to burning high-ash, high-sulphur coal increased, more orders went for oil fired stations to fill the gap being rapidly created. The Northeast black-out in 1965 led to increased grid system interconnections, and the rising summer peak loads led to greater numbers of gas turbine peaking units. All of these factors increased the utilization of gas and oil firing, until natural gas producers began to refuse to renew or make long-term gas contracts and until the Organization

of Petroleum Exporting Countries (OPEC) began serious oil price increases. In the last few years OPEC countries have escalated the delivered price of fuel oil from \$1.25 per barrel a few years ago, to \$13 to \$15 per barrel today. Finally, the availability of natural gas for electrical power plant utilization has been sharply limited, and the price of natural gas has risen from 30¢ per million BTU to over \$1.00 with future projected costs of \$1.50 for LNG sources.

The highly escalating costs of plants, equipments and money, the rapid rise in fuel costs, and decreasing plant load factors have placed a large number of electric utilities in an extremely difficult financial position. Electric utilities are faced with an increased requirement to seek rate increases for PUC's which are under heavy public pressure to maintain low electric rates, while at the same time the public is increasing its demands for more electricity (during 1974, the electric utilities have experienced a demand decline). In parallel, environmental concerns associated with thermal discharges from powerplants and stack gas/particulate emissions from fossil fuel plants, public concern with large scale utilization of nuclear reactors and associated fuel element and radioactive waste handling problems, technological problems facing developments of the fast breeder reactor, and the depletion of natural resources, particularly oil and gas, have given rise to renewed requirements for clean, alternative energy sources.

B. Potential of Geothermal Energy

Geothermal energy, as it develops, will provide a supplementary fuel for power generation. Present indications are that it is a competitive fuel and that it can be developed in an environmentally acceptable manner. Its major impact in the United States is expected to be in the West, Southwest, and Gulf Coast areas. In these regions it may ultimately contribute on the order of 5-10% of regional electrical energy generation.

During 1974 geothermal energy will contribute about 0.1% of the nation's electrical energy supply from California's Geysers geothermal field. Growth in generation at the Geysers could increase the contribution to 0.2% by 1985 if total electricity consumption in the United States increased according to projections. Three additional known geothermal resources in the West might boost geothermal's contribution to 0.4% by 1985. To provide an overview of possible growth of geothermal's contributions, EPRI geothermal program staff and consultants have estimated the on-line geothermal electricity generating capacity up to 1985 as shown in Table II-1.

Many exploration projects are underway on private land in the West, and the leasing of federal lands with geothermal potential has just begun. In addition, interest in the geopressure resource along the Gulf of Mexico has resulted in some exploration activity, and development has begun for hot, dry rocks.

TABLE II-1:

EPRI PROJECTION OF GEOTHERMAL ELECTRICITY GENERATING
CAPACITY THROUGH 1985

<u>Resource:</u>	<u>Field:</u>	Projected Capacity (MWe)		
		<u>1975:</u>	<u>1980:</u>	<u>1985:</u>
Vapor-Dominated	Geysers, Calif.	500	900-1000	1200-1500
Hydrothermal;				
a) Low-Salinity	East Mesa, Calif.	0	5-10	100-200
	Heber, Calif.	0	50	250-400
	Mammoth, Calif.	0	10	100-200
	Surprise Valley, Calif.	0	0	50-100
	Valles Caldera, N.M.	0	100-200	600-1200
b) High-Salinity	Niland, Calif.	0	5-10	100
Geopressure	Texas, Louisiana	0	0	10
Hot, dry rocks		0	0	10
<u>Total:</u>		500	1100-1200	2400-3700

However, owing to the embryonic and fragmentary resource assessment data presently available, the contributions yet to be discovered, and proven fields of unproven resources cannot be estimated at this time.

C. Current Status of Geothermal Energy Development

1. Resource Development:

At the present time geothermal energy's main impact economically manifests itself as electricity generation; world installed capacity is now approximately 1200 MWe. Additional fields are under development world-wide, but it is unlikely that total world electricity generating capacity using geothermal will exceed 4000 MWe by 1980. That capacity would amount to less than four large nuclear fission power reactors.

Total United States generating capacity from geothermal is approximately 500 MWe from one site, the vapor-dominated field at the Geysers. This capacity is expected to increase yearly to take advantage of currently known reserves; additional drilling is underway in areas adjacent to the known field and further reserves are expected to be proven. No other vapor-dominated fields are currently known. Elsewhere in the world, two vapor-dominated resources are known -- Lardarello in Italy (358 MWe) and Matsukawa in Japan (35 MWe). In general, the technology for development of vapor-dominated fields is well known although some problems do exist as release of hydrogen sulfide and other non-condensable, noxious gases during well clean-out and venting and during power station bypass caused by equipment outages.

No hydrothermal (liquid-dominated) resource is now being used for generating electricity in the United States although the hydrothermal resource finds limited use in heating for buildings and for agriculture. At least three fields in the United States, two in the Imperial Valley and one at Valles Caldera (Jemez Springs) in New Mexico, are well enough known and have sufficiently high fluid enthalpies that development can proceed once technological and environmental problems are solved. At one of these, an extensive drilling program is underway and the operator has commenced planning a commercial installation. Several other hydrothermal fields have been found; a small pilot hydrocarbon cycle plant is planned for one of these. Considerable exploration activity has discovered additional hydrothermal resources, but none of these can yet be considered commercial; in some cases down hole pumps will be required to obtain well completion.

Five hydrothermal fields outside the United States have an aggregate installed capacity of about 500 MWe and industrial heat production of about 50 MWe equivalent. All of these fields use the flashed-steam process; none meet the strict environmental standards imposed in the United States. At least eight overseas hydrothermal fields are in various stages of development. In general, these will probably be developed using the flashed-steam cycle; environmental concerns will probably not impair the development of these resources.

Exploration for hot, dry rocks, financed by the federal government, is underway at two sites in the Western United States. Thus far the results have not been consistent with expectation; possibly another year of work will be required before one can assess the results of these two projects. Certainly, many technical and environmental problems remain to be solved before the economics of producing energy from hot, dry rocks can be assessed. No work is currently known outside the United States although the Soviet Union may be active.

Limited geological assessment, both privately and federally financed, has been accomplished for the geopressure resource in the United States. All effort has focused on the Gulf of Mexico basin although other geopressured basins are known to exist. One private company has announced plans for a geopressure resource drilling and pilot plant project and the federal government has expressed interest in building a regional laboratory for geopressure technology development. No work on geopressure resources outside the United States is known although appropriate sedimentary basins are known to exist.

2. Utilization Technology Development:

One can not stress too strongly that resource development is one of the key issues to be addressed in geothermal power development.

But, without technology to utilize resources economically and in an environmentally acceptable manner, the investment in resource development may be amortized only slowly or not at all. Furthermore, each resource has its own unique problems.

a. Vapor-dominated resources:

Except for problems with nuisance type non-condensable gases, the main problem with vapor-dominated systems seems to be hydrogen embrittlement or stress corrosion problems which lead to failure of turbine blades. The down time caused by this materials problem appears to become progressively worse as a function of turbine age and size.

b. Hydrothermal (liquid-dominated) resources:

Problems associated with hydrothermal resource utilization generally are a function of the total dissolved solids in the fluids as well as of the absolute concentrations of the various constituents and gases. Compared to steam from the vapor-dominated resource, the lower enthalpies characteristic of hydrothermal resource fluids complicate resource utilization and adversely affects the efficiency and economics of energy conversion. These problems manifest themselves over the entire spectrum of operations: production wells, gathering systems, energy conversion equipment, reinjection wells, and reservoirs.

None of the total flow concepts has been developed sufficiently to construct a pilot plant for extensive testing. Scaling, corrosion, and erosion are significant impediments which must be overcome or mitigated. Successful development of any of the proposed total flow prime movers is not assured and, certainly, large-scale demonstrations are at least ten years away.

c. Geopressure and hot, dry rocks:

A complete process for conversion of the energy in the geopressured fluids has not yet been developed. The hydrocarbon expander cycle may be the leading power conversion contender for the hot/dry rocks resource. Total flow concepts may also be important, but development of this conversion concept is too embryonic to draw conclusions.

Production wells, if produced to allow flashing in the formation adjacent to the well or in the well itself, will often shut themselves down owing to solids deposition in the production string, in the adjacent formation, or both. Should the bottom-hole fluid enthalpy or pressure not be high enough, a well will be incapable of flowing spontaneously. Both the well and formation plugging problem and the well completion problem require a competent down-hole pump for mitigation or solution. At this time no down-hole pump amenable to deep, high temperature, saline water application is available, although federally-funded down-hole pump research is underway.

Energy conversion equipment for hydrothermal resources classifies into three categories characterized by the process used to extract heat energy from the geothermal fluid:

- 1) Flashed-steam process -- the fluid passes through a single or multiple stage steam flashing unit and through a steam-water separator; steam from the separator is then expanded directly through a steam turbine unless dissolved solids carryover is sufficient to require steam scrubbing first,
- 2) Hydrocarbon expansion cycle -- the geothermal fluid passes through the primary side of a heat exchanger, transferring heat to a hydrocarbon fluid on the secondary side and causing that fluid to boil. The hydrocarbon vapor is then expanded through a hydrocarbon turbine,

- 3) Total flow process -- the geothermal fluid is passed directly through a prime mover such as impulse turbine, helical screw expander, "bladeless" turbine, or roto-oscillating vane assembly.

The flashed-steam process is the only hydrothermal resource energy conversion method proven in commercial scale application; it is currently in use at Wairakei, New Zealand (165 MWe), Kawerau, New Zealand (50MWe thermal equivalent), and Cerro Prieto, Baja California, Mexico (75 MWe). Solids carryover at these plants presents little problem. At Wairakei, failure of turbine blades owing to hydrogen embrittlement or stress corrosion is a continuing but manageable problem. No flashed-steam equipment is installed in the United States although one field (Valles Caldera) could possibly use it effectively.

Hydrocarbon expansion cycle equipment has been installed at only one site -- on the Kamchatka Peninsula in the Soviet Union -- and that installation is too small to obtain operational and economic data appropriate to judging its market penetration potential. Dissolved solids scaling of the heat exchanger primary side presents a significant impediment to widespread application. Other hardware problems are the size scale-up and speed regulation of the hydrocarbon turbine.

D. Nature Of Geothermal Resource And System Problems

1. Resource Types and Distributions

Geothermal resources may be characterized according to their geophysical and geological origins and according to the presence and composition of fluids in the resource deposit. Hence, the gross distribution of particular types of resources in a given region can be inferred from an understanding of the geology, geophysics, geochemistry, and hydrology of that region. At this time, however, it is impossible to learn the abundance of deposits of a geothermal resource type except from field exploration and development.

a. Geological patterns in the U.S.

Knowledge of the gross geological patterns of North America allows general conclusions as to the distribution of geothermal resources in the United States. The geological theory of plate tectonics considers that the West Coast of the United States lies at the western edge of the northern sector of the American plate. The adjacent plate to the west, the Pacific plate, is being subducted beneath the continental margin of the American plate. This action had generated the major Pacific coast earthquake zones and recent and past volcanism. Examples of the latter are the Cascades Range, the Columbia Basin Basaltic flows, and the Snake River Plain. The subduction is believed to play a major role in the development of the Basin and range geological province.

The subduction process produces a number of blocks of crust, movement along the boundaries of which are responsible for the creation of mountain ranges separated by basins and for manifestations of volcanism. The Rocky Mountains form the eastern boundary of the Basin and Range province.

To the east of the Rocky Mountains, a number of ancient basins have been filled by alluvial action of ancient and modern river systems draining primarily toward the Gulf of Mexico. The Gulf itself, forms one of the world's great basins. The Gulf is a shallow body of water, the entire basin having been virtually filled by alluvial deposits originating from the vast expanse of the central region of the United States. The successive deposits of alluvial materials have resulted in elongated deltaic and shore-formed lenses of sand bounded by clastics (shales) and entrapping water. The original deposits have been displaced by the development of growth faults as successive layers of alluvial materials have been deposited. The increasing depth of overburden has resulted in a deepening of the Gulf of Mexico Basin, a pressurization of the trapped waters, and a diagenesis of the shales to expel fresh water into the sands and to increase the pressure of the trapped fluids.

The eastern coast of North America lies far to the west of the eastern edge of the northern sector of the American plate. Thus, one should not expect and does not find evidence of recent volcanism or areas which are highly active seismically in the eastern half of the United States.

b. Resource Distribution in U.S.

The distribution of geothermal resources in the United States follows from the above general comments on North American geology. The "fractured" plate region along the West Coast and in the Basin and Range province provides many opportunities for heat energy to rise via magmatic intrusions and for water to penetrate to these intrusions. Hence, the occurrence of many hot springs and of hot rocks throughout the Western United States and in coastal Alaska. Here, too, are located the known geothermal fields -- the Geysers, Imperial Valley, Valle Caldera. Geopressured hot water may be found in the alluvial basins east of the Rocky Mountains -- the Gulf of Mexico and the Anadarko.

Although hot springs occur east of the Rocky Mountains -- Arkansas and Virginia, primarily -- they number only a few and their geochemistry does not indicate high temperatures at depth. Hence, except for the Gulf Coast, one should expect to find few geothermal resources at depths drilling can currently achieve economically.

c. World Resource Distribution

A review of international geothermal field development illustrates the validity of the above resource distribution discussion. Cerro Prieto in Baja California, Mexico, lies astride the Salton Sea Rift created by the American plate's subduction of the Pacific plate; fields in El Salvador and Chile lie in this subduction zone also. The New Zealand and Indonesian fields are near the boundary between the Indian and Pacific plates, the Philippines fields near the juncture of the Indian, Pacific, and Eurasian plates, while the Japanese and Russian (Kamchatka) fields are adjacent to the boundary between the Eurasian and Pacific plate. The Iceland fields are astride the mid-Atlantic ridge (the boundary between the American and Eurasian plates) and the Italian, Turkish, and Iranian fields are near the boundary between the Eurasian and African plates. The Ethiopian, Ugandan, and Kenyan fields, along the Red Sea Rift, lie near the boundary of the African and Indian plates.

2. Geothermal System Physical Properties and Effects

From the preceding discussion of the distribution of United States and World geothermal resources, it is important to draw the conclusion that these resources need not be where the major requirements for electricity are. In addition, the geological origins and thus the geochemistry, hydrology, and physical state of

the reservoir fluids, if any, will greatly influence the successful development of geothermal resources. A list of key issues which need to be addressed in geothermal development are presented in Appendix A.

a. Geochemistry

Solids and gases in solution in the reservoir fluids present major development problems. Dissolved solids, as arsenic, may be poisonous; the presence of a number of solids in solution will result in deposition in the reservoir, in wells, and in process and energy conversion equipment. Noncondensable gases in solution reduce the efficiency of condenser systems. Both solids and gases must be disposed of either after separation from the water or by reinjection with the water.

b. Hydrology

The presence of water in a geothermal region may indicate that a reservoir of heated fluid exists. This will only be true if the heated rocks and adjacent rocks are sufficiently fractured, reservoir development requires rock fracturing and/or the introduction of water to the reservoir. The hot, dry rocks resource, for instance, requires both because fluids are not present in the reservoir.

c. Physical State of Reservoir Fluids

The temperature and pressure of reservoir fluids will dictate the type of utilization for the resource. If the enthalpy of the fluid is too low, then electric generation is excluded. Sufficiently energetic hot fluid which cannot be flashed will require a low-temperature cycle like the hydrocarbon expander cycles and flashed-steam cycles are alternatives. Finally, for vapor-dominated (steam) reservoirs, the steam is directly to turbines (although steam clean-up may be required).

In general, as the fluid enthalpy decreases from that typical of a vapor-dominated reservoir, the technology of utilization becomes more difficult and the economics of electricity generation becomes less attractive. Utilization of hot, dry rocks, because of the need for reservoir creation, and because the enthalpy of the fluid may well be low, presents technological and economic problems. Similarly, the high cost of drilling for geopressure deposits and the generally lower enthalpies make the technology and economics of geopressure utilization less attractive. However, the possible presence of methane in solution in the geopressure fluids enhances the economics; as methane concentrations increase, the economics becomes a strong function of the wellhead price of methane.

d. Geological Origins

The geological processes through which a geothermal resource is created determine the presence of fluids, the fluid enthalpy, and the presence of a reservoir, and hence its production, are determined by the rock or sediment types in the reservoir and the degree of fracturing of the rocks present. For the case of the geopressure resource, the size of the sand lenses -- in which the fluids are trapped -- predicates the cumulative production possible and hence the overall economics of utilization for the resource.

3. Institutional, Legal, and Utilization Problems

Although a reservoir's geological origins predicate the physical properties of the reservoir, successful geothermal development depends on the technologist's ability to predict reservoir behavior based on limited information (reservoir engineering), to overcome utilization problems, as discussed in Section C, and to mitigate or remove institutional and legal problems.

a. Reservoir Engineering

Reservoir performance is affected by both the long-term history of fluid withdrawal and the instantaneous draw-down demand. Consequently, design of a geothermal utilization program and the specific hardware implementing that program must be compatible with the reservoir engineering

analysis of the long-term producibility of the reservoir and with the ability of the reservoir well system to respond to short-term (order of hours) changes in fluid withdrawal requirements.

Geothermal reservoirs, like oil and gas reservoirs, are considered to have a finite lifetime during which they can be produced profitably. Unlike oil reservoirs, geothermal reservoirs may have a very long production life as new fluids may be added to the reservoir, partially or totally compensating for withdrawn fluids. The recharge fluids may be due to reinjection of fluids originally withdrawn from the reservoir or to intrusion of water of meteoric or other origins. The hydrology of a specific reservoir will determine the probability and rate of recharge.

Reservoir engineering has been adapted to the geothermal reservoir from the oil reservoir. New phenomena, not present in the oil reservoir (i.e., heat flow, phase change, multiphase flow, diagenesis of reservoir materials, chemical kinetics) need to be added to the simulation. Further, only the Geysers vapor-dominated reservoir has been sufficiently documented and has had sufficiently long production to test reservoir engineering models. Reservoir engineering for hydrothermal resources, and for geopressure and hot/dry

rock resources as well, is only in its infancy; no commercial field data of sufficient quality exists yet to test the model methods.

A typical geothermal well must be opened-up and shut-down slowly as rapid changes in withdrawal rate can result in production of particulates from the producing formation and can result in undesirable chemical kinetics effects. Geothermal plants are generally not suitable for other than base load electricity generation unless the resource had multiple use and other uses are by passed during peak load or emergency load periods. As wells cannot be shut-down quickly, generation equipment outages require that the produced geothermal fluids bypass the power plant.

Utilization facility effluents, (usually thermally degraded and in a less stable chemical kinetics and dynamics state) must be disposed of either by treatment (typically desalination) or by reinjection back into the reservoir of origin or into an adjacent reservoir. If the geothermal system design requires reinjection (subsidence mitigation, environmental protection or inability to desalinate will dictate reinjection), requirement for equipment outage bypass means that the reinjection well system must be able to accomodate two considerably different reinjection fluids, in rapid succession, without causing damage to the reinjection reservoir:

- (i) bypassed geothermal fluid having characteristics similar to those in a producing well
- (ii) utilization facility effluents having degraded thermal characteristics compared to those in a producing well

Experience with this kind of reinjection system is nil; in fact, experience is very limited with injection of fluids representative of utilization facility effluent.

b. Institutional and Legal

The institutional and legal problems which attend any resource development project are amplified in the case of geothermal resource development projects. The additional problems stem primarily from two sources:

- (i) the different objective and the different organizational characteristics of the resource company and the power company
- (ii) the current status of the legal position of the resource

Resource companies, especially those practiced in petroleum resource development, typically work with high risk, short-term investments. Hence resource companies tend to be very

circumspect concerning the information they release; most information is typically considered proprietary. Regulation of resource companies by federal, state, and local governments has mainly centered on environmental issues. Power companies, on the other hand are closely regulated monopolies, the entire business operation of which is regulated by the federal, state, and sometimes, local governments. As publicly regulated monopolies, most actions and activities of power companies are reviewed by regulatory agencies and become public record. Power companies, of course, invest in low-risk, long-term ventures.

The geothermal resource does not yet have a universally agreed upon legal definition. The current range of legal definition assigns geothermal resources as

- (i) water resource
- (ii) mineral resource
- (iii) land resource
- (iv) others or none at all

The ramifications, especially for federal government tax treatment, are many. The effect on state and local taxes varies by state and legal definition in that state.

The long delay time between discovery of a geothermal resource and its revenue-earning production results in a difficult tax position if an ad valorem tax is assessed. On the other hand,

a severance tax also has disadvantages. A new or modified tax concept may be required if fair and equitable tax treatment of geothermal resources and installations is to eventuate.

E. Rationale for EPRI Geothermal Program

1. Importance to Utility Industry

A modest geothermal energy research and development program at EPRI is important to the electric utility industry since, over the last two years, public and governmental interest in geothermal energy has mushroomed. Specific aspects of importance include:

- . Demonstrates to the public that the electric utility industry is genuinely interested in geothermal energy applications.
- . Low salinity, hydrothermal, geothermal sources show promise of being commercially viable and could be on line in the early 1980's.
- . Early understanding of the production problems associated with low salinity hydrothermal sources is necessary to assess their market penetration potential.
- . By performing impact analyses and technical and economic requirements definition studies, the electric utilities can help shape the course of federally sponsored programs.
- . It provides the electric utility industry an informed position on the potential and prospects for geothermal energy utilization including inputs to environmental reports for nuclear or fossil powerplant siting permits and data for public hearings.

These factors indicate that EPRI should initiate its geothermal energy research and development program at a level commensurate with certain major issues defined in II. D.

2. General Relationship to Federal Program

The EPRI Geothermal Energy R&D program has been defined to complement the program planned by the Federal Government. The Federal geothermal R&D 5-year plan (FY 75-79) was submitted to the Office of Management and Budget by the Interagency Geothermal Task Force

on 25 July 1974. This plan proposes a 5-year geothermal energy budget of 314.4 million dollars of which federal monies would be 259.0 million dollars and the remainder university or industry cost sharing. The program breakdown includes 78.2 million dollars for Resource Exploration and Assessment, 20.9 million dollars for Environmental, Legal and Institutional Analysis, 74.9 million dollars for Resource Utilization Projects, and 140.4 million dollars for Advanced Research and Technology. The plan further defines that these monies will be expended nearly equally by the National Science Foundation, the Atomic Energy Commission and the Department of Interior. The FY 75 budget request is 45.2 million dollars, with NSF being authorized 22.7 million dollars, the AEC, 11.7 million dollars, and DOI 11.2 million dollars. In addition to the authorization, the President has recently signed the Geothermal Development Act of 1974 which authorizes the National Aeronautics and Space Administration to develop an integrated federal government geothermal energy R&D plan as well as contains provisions for geothermal project loan guarantees. In light of this expressed interest on the part of Congress and the administration to support geothermal energy R&D, it is extremely important that EPRI and the electric utilities develop and maintain a well defined position.

The federal R&D program projects geothermal electrical generation levels of 7900-35,400 Mwe on line by 1985, primarily from "brine" hydrothermal sources (Their estimates are far in excess of those projected by EPRI in II. B.). In general, the federal geothermal resource utilization subprogram emphasizes the design, construction and operation of a number of 5 to 10 Mwe experimental

research facilities (pilot plants). These include one high temperature, high salinity facility, one high temperature, low salinity facility, and two moderate temperature, low salinity facilities. Specific sites for these facilities are presently being defined.

The EPRI geothermal program has been structured to a) provide a basis for obtaining production, operating, and maintenance data for large scale (25-50Mwe) powerplants including powerplant heat exchanger scaling, cold fluid reinjection, and cooling tower performance, b) provide information to the electric utilities on current state-of-the-art geothermal assessment techniques, environmental, legal and institutional requirements, and projected geothermal electric power generation potential, and c) an advanced research and technology effort oriented toward advanced heat exchanger techniques and alternative geothermal resource assessment. This program should provide a basis for electric utility assessment of the potential of geothermal energy development.

What is lacking from both the EPRI and federal program is a major drilling effort to quantitatively define the capacity and characteristics of hydrothermal resources on a regional basis. Such a drilling program should be sponsored by the federal government.

F. Glossary of Terms - Abbreviations

A = Award of Contract
CD = Conceptual Design
CO = Check-out
DD = Detail Design
FA = Fabrication and Assembly
FR = Final Report
ILC = Issue License to Construct
IR = Interim Report
PD = Preliminary Design
RFP = Request for Proposal
S = Ship the Equipment
SOW = Statement of Work

III PROGRAM

A. Broad Objectives

The broad objectives of the EPRI Geothermal Energy Program are to:

1. Increase electric utility awareness and knowledge of present and planned R&D programs by others, with emphasis on the electric power generation potential of geothermal energy obtainable from hydrothermal resources.
2. Provide a point of focus for electric utility policy through which the direction and pace of the Federal Geothermal R&D Program can be influenced.
3. Provide a unified approach by the electric utilities in solving the technical, economic and institutional problems which continue to inhibit commercial development of hydrothermal resources, and in establishing priorities for sponsorship of related R&D programs.
4. Develop an EPRI geothermal program which leads to the commercial development of at least one new hydrothermal resource within the next five years.

5. Provide technical, economic, environmental and legal guidance to EPRI constituents to assist them in formulating and executing their own independent geothermal resource development programs.

6. Provide resource and conversion process state-of-art review for determining the necessity for, and orientation of, future EPRI geothermal activities if such is warranted.

B. Criteria and Philosophy

1. Criteria for the EPRI Geothermal Program

Specific criteria used to define the content of the EPRI programs are:

a) Develop strong electric utility interest and support

b) Produce a significant impact on electric power generation by 1990

c) Have identifiable market penetration potential beyond 1990

d) Provide the framework to focus electric utility policy and requirements to impact Federal R&D program

e) Sponsor key projects, which complement the Federal R&D Program, to prove the technical, economic, institutional, and environmental viability of using new geothermal resource types and/or new power cycles

f) Provide a limited application basis independent of federal R&D programs

2. Philosophy of the EPRI Geothermal Program

The underlying philosophy for the program includes:

a) Acceptance by utility and financial communities will require demonstration plants for new geothermal resources at unit capacities sufficient to define production, maintenance, and operational problems and costs

b) Hydrothermal sources are expected to represent the best candidates for near-term large scale

development in the United States.

c) The capability must be developed to generalize results from reservoir-to-reservoir and to assess reservoir potential

d) An increase in electric utility knowledge and awareness of existing and projected technology for exploration and development of geothermal resources is necessary to enhance geothermal energy utilization

e) A limited, flexible budget should be provided for sponsoring longer term development of exploration techniques or advanced conversion systems

C. Program Content

1. Subprograms and Interrelationships

As a result of an intense and comprehensive planning effort, strongly supported by a three-day Geothermal Planning Workshop, a five-year geothermal program was evolved which is organized into five distinct subprograms. These subprograms consist of the following:

- . Low Salinity, Hydrothermal Demonstration Plant^{(1)*}
- . Guidelines Manuals
- . Geothermal System and Data Analysis
- . Supporting Research and Technology
- . Advanced Reserach and Technology

a) The low salinity, hydrothermal demonstration power plant (capacity: 25-50MWe) is intended to conclusively demonstrate the technical and economical viability and environmental acceptability of generating commercially competitive electrical energy employing low salinity hydrothermal resources.

b) The Guidelines Manuals are intended to serve as a practical, educational tool in supporting electric utility management and engineers in independently planning and executing their own geothermal programs.

c) The Geothermal System and Data Analysis subprogram is intended to assist the utilities management in assessing the potential and requirements of commercially developing hydrothermal resources, to analyze the economics and performance characteristics of geothermal power systems, and to contribute financially and technically to the National Geothermal Data Exchange Center.

(1)* Low Salinity (15,000 ppm dissolved solids)

Power System Design Manual will be practically applied during the design, construction, and commissioning of the demonstration plant. Also, the results of the investigations to be performed in the SRT subprogram will very directly support the work to be performed in planning, designing, and constructing the demonstration plant. Many additional interrelationships exist, and these are presented in graphical form in the simplified flow diagram, Figure III-1.

2. Cost Estimate Summary

The Cost Estimate Summary is presented in Tables III-1, III-2, and III-3. Table III-1 presents the recommended expenditure over the five-year period 1975 thru 1979 with a five-year total of \$16,530,000 by EPRI with an additional \$18,000,000 expected from the electric utilities for the demonstration plant. Table III-2 shows an alternative schedule which would be necessary if it is determined that inadequate reservoir or heat exchanger test data exist at the selected site for the demonstration plant. In this case, the demonstration plant schedule will be delayed some six months from that possible in the preferred schedule. The five year total cost estimate for this option is \$17,160,000 for EPRI and \$17,720,000 from the electric utility(ies) for the demonstration plant.

A minimum program is shown in Table III-3 with an estimated total expenditure of \$13,020,000 by EPRI and an additional \$18,000,000 by electric utility(ies). It should be noted that all estimated expenditures in this report are expressed in thousands of 1975 dollars.

(thousands of 1975 dollars)						
<u>Subprograms</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Low Salinity, Hydrothermal Demonstration Plant (1)	1390 (0) <u>1390</u>	1650 (2500) <u>4150</u>	2800 (5000) <u>7800</u>	1850 (6500) <u>8350</u>	700 (4000) <u>4700</u>	8,390 (18,000) <u>26,390</u>
2. Guidelines Manuals	175	295	300	130	130	1,030
3. Geothermal System and Data Analysis	140	970	820	520	120	2,570
4. Supporting Research and Technology	155	365	730	630	430	2,310
5. Advanced Research and Technology	200	380	450	500	700	2,230
ANNUAL TOTALS:	<u>2060</u>	<u>6160</u>	<u>10,100</u>	<u>10,130</u>	<u>6080</u>	<u>34,530</u>
EPRI CONTRIBUTION:	2060	3660	5100	3630	2080	16,530
UTILITY CONTRIBUTION:	(0)	(2500)	(5000)	(6500)	(4000)	(18,000)

(1) Cost Estimates Based on 50MWe Plant Rating

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

PROGRAM SUMMARY (RECOMMENDED)

(Preferred Schedule)

(thousands of 1975 dollars)							
<u>Subprograms</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>Five Year Total</u>
1. Low Salinity, Hydrothermal Demonstration Plant (1)	1520 (0) <u>1520</u>	1500 (150) <u>1650</u>	2000 (3600) <u>5600</u>	2000 (5970) <u>7970</u>	2000 (6000) <u>8000</u>	-- <u>2000</u>	9,020 (17,720) <u>26,740</u>
2. Guidelines Manuals	175	295	300	130	130	--	1,030
3. Geothermal System and Data Analysis	140	970	820	520	120	--	2,570
4. Supporting Research and Technology	155	365	730	630	430	---	2,310
5. Advanced Research and Technology	200	380	450	500	700	--	2,230
	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
ANNUAL TOTALS:	2190	3660	7900	9750	9380	2000	34,880
	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>
EPRI CONTRIBUTION:	2190	3510	4300	3780	3380	(0)	17,160
UTILITY CONTRIBUTION:	(0)	(150)	(3600)	(5970)	(6000)	(2000)	(17,720)

(1) Cost Estimates Based on 50MWe Plant Rating

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

PROGRAM SUMMARY (RECOMMENDED)

(Alternative Schedule)

TABLE III-2

(thousands of 1975 dollars)						
<u>Subprograms</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Low Salinity, Hydrothermal Demonstration Plant (1)	1390 (0) <u>1390</u>	1650 (2500) <u>4150</u>	2800 (5000) <u>7800</u>	1850 (6500) <u>8350</u>	700 (4000) <u>4700</u>	8,390 (18,000) <u>26,390</u>
2. Guidelines Manuals	175	295	300	130	130	1,030
3. Geothermal System and Data Analysis	90	620	520	320	20	1,570
4. Supporting Research and Technology	155	175	150	150	150	780
5. Advanced Research and Technology	150	200	300	300	300	1,250
ANNUAL TOTALS:	<u>1960</u>	<u>5440</u>	<u>9070</u>	<u>9250</u>	<u>5300</u>	<u>31,020</u>
EPRI CONTRIBUTION:	1960	2940	4070	2750	1300	13,020
UTILITY CONTRIBUTION:	(0)	(2500)	(5000)	(6500)	(4000)	(18,000)

(1) Cost Estimates Based on 50 Mwe Plant Rating.

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

PROGRAM SUMMARY (MINIMUM)

(Preferred Schedule)

D. Subprograms

1. Low Salinity, Hydrothermal Demonstration Plant Subprogram

a) Background

(1) Existing Commercial Plants

A number of geothermal power plants employing hydrothermal resources are in commercial operation in several parts of the world. The most prominent of these is the 193 MWe installation at Wairakei, New Zealand. Recently commissioned was the 75 MWe plant at Cerro Prieto, Mexico. There are also several operating commercial plants in Japan that employ hydrothermal resources; their aggregate capacity is approximately 35 MWe. Of course, there is the Pacific Gas & Electric Company's 396 MWe plant at The Geysers, California, as well as the 384 MWe capacity plant at Lardarello, Italy. However, these latter two are dry-steam plants and are not typical of the type of installations being considered in this five-year program.

(2) Existing Experimental Facilities

The USSR has constructed a number of geothermal power plants employing hydrothermal resources which aggregate approximately 12.5 MWe. One of these, which is located on the Paratunka River (Kamchatka Peninsula), is a 0.44 MWe (net) experimental binary plant. Experimentation relating to the development of plant components is underway at San Diego Gas and Electric Company's heat exchanger test sites at Niland and at Heber, California. These facilities do not generate electric power, but are component development test-stands only.

(3) Need for Demonstration

All existing operational hydrothermal power plants are located outside of the United States (i.e. New Zealand, Mexico, Japan, and the USSR), and all of them (except one) employ the flashed-steam process. Although a fair amount of capital cost data and operational data (technical and economic) is available on certain of these plants, most of it is not convertible into a valid American equivalent, and therefore it is of very limited usefulness. In addition, none of these plants must meet the

the stringent environmental requirements which are attendant with US geothermal plants.

The need for a commercial-scale electric power demonstration plant using a hydrothermal resource, is based to a large degree on the fact that it is virtually impossible to develop credible capital and operating cost estimates in the USA context from available cost information derived from either the Wairakei or the Cerro Prieto installations. It is self-evident that credible cost data is a primary output of any demonstration facility. The selection of the power cycle which will be employed in the demonstration plant has not yet been made. The binary cycle may be chosen because it is the most desirable site which is finally selected. If this is the case, it will be the first and only commercial power plant employing that particular cycle anywhere in the world, and therefore will be the only source of economic and operational data for this type of plant. Also, access to the foreign plants by EPRI or other American interests, for the purpose of developing or testing new processes, components, or technology, is extremely limited if available

at all. Therefore, use of these foreign plants to "demonstrate" to the American utility industry the generalized feasibility of power generation from low salinity hydrothermal resources in the United States is not practical.

(4) Justification for 25 to 50 MWe Capacity
Justification for a plant of 25 to 50 MWe capacity can be established on several different bases, including economic and technical considerations, as well as functionality when integrating the plant into a commercial electrical network.

With respect to economic considerations, the actual capital and operating costs of a 25 to 50 MWe capacity unit will have inherently far higher credibility for the electric utility industry than those data which could be scaled-up from an 8 to 10 MWe pilot plant. It will be nearly impossible to obtain credible operating and maintenance costs except through a commercial-scale demonstration plant of at least 25 to 50 MWe capacity. This scale demonstration plant will be in a far stronger position to demonstrate market competitiveness or non-competitiveness than would be possible for a small scale pilot facility.

Availability of financial resources from the private sector for such a pioneering effort will certainly be more conclusively demonstrated by an EPRI-utility(ies) sponsored demonstration plant than by a unit of subcommercial capacity, such as 8 to 10 MWe. In regard to the technical considerations, a 50 MWe unit will require over five times the mass-flow rate from the reservoir as would be required by an 8 to 10 MWe unit and would thus provide far more hard data on reservoir behavior (wells interaction) over a variety of operating modes in the short term, and reservoir degradation rates over the long term. Operational stability of a 50 MWe unit during steady-load operation, and response characteristics during load-following swings cannot be scaled-up from an 8 to 10 MWe test bed or pilot plant. This information can be obtained only from a commercial scale demonstration plant. Also, development of startup and shutdown procedures, both routine and emergency, can only be done on a full-scale plant. With respect to the functional integration of the demonstration unit into a commercial network, possible sites for the plant include, the Heber region of Imperial Valley, Calif. or Valles Caldera, New Mexico. In each of these settings, 25 to 50 MWe capacity would represent a substantial fraction of the total local

generation capacity, and would permit operation of the demonstration plant alternately in the base, intermediate, and possibly peaking modes. Because of its commercial-scale capacity, the 50 MWe demonstration plant could also be turned-up to an overload condition in response to an emergency outage of another major generating unit in the local network. However, the long-term service effects and attendant problems such as corrosion, erosion, scaling, materials selection, etc., will probably be essentially the same for either a 50 MWe capacity demonstration plant or for a smaller capacity pilot unit. It is possible that over a protracted period of time after the demonstration plant goes into commercial operation, the mean chemical composition (constituents and concentration) of the geothermal fluid could shift from that originally determined during the reservoir verification tests. Such a shift could be beneficial or detrimental, i.e., greater or less total-dissolved-solids or reactivity. If the shift is unfavorable, it could cause a gradual increase in the rate at which plant process equipment deteriorates, and an increase in the rate at which primary heat exchanger surfaces become scaled and their performance degrades. This brine chemistry

shift effect would not be induced nearly as readily with a pilot-scale plant as with a 25 to 50 MWe commercial plant. Justification for a 25 to 50 MWe capacity demonstration power plant is also related to some primary environmental constraints. The effluent disposal requirements of a 50 MWe demonstration plant will be at least five times greater than that of a unit of say 10 MWe capacity, because of the five times greater mass flow rate from the production wells and, therefore, will require a fluid reinjection system or other liquid waste disposal system having sufficient capacity to meet this requirement. Because of the far higher volumetric flow-rate from a reservoir supporting a 50 MWe plant, a much greater opportunity will exist to study the land surface subsidence effect, aquifer drawdown, and possible aquifer cross-contamination. The probability of inducing a seismic slip is so remote in either case that comparison of a demonstration scale unit with a pilot unit on this basis is unwarranted. Noise generation during well drilling and testing operations will be approximately five times more extensive, or of five times greater duration for the 50 MWe plant than for an 8 to 10 MWe pilot plant,

because of the correspondingly greater number of wells. However, noise generation from routine plant operation will be only slightly greater for the 50 MWe unit, and in either case will be no greater than for fossil-fueled units of the same capacity.

Capital costs of the piping system, and the energy degradation in terms of heat-loss and pressure-drop, are proportional to the extensiveness of the gathering system. Therefore the economics of the overall plant are tied to the extensiveness of the gathering system, which is obviously determined by the total number of wells, and more importantly, by the well-spacing. Spacing of production and disposal wells is generally determined through well testing, reservoir modeling, predicting the long-term hydraulic and thermal potential of the field, and by allowing for development of future wells whose production will compensate for gradual decline of production of the initial battery of wells over the economic life of the power plant. The distance that the fluids can be economically transported, as well as the mean energy productivity of the wells will effectively

limit the maximum centralized plant capacity, and therefore the maximum unit for a particular field. Reinjection wells for disposal of waste liquids must be as widely dispersed over the field as the production wells themselves, in order to adequately control land surface subsidence. The pumping costs to drive the reinjection system are again a direct function of the extensiveness of the piping system.

b) Current Status

(1) Federal Program for Demo/Pilot Plants

The Lawrence Berkeley Laboratory under the auspices of the Atomic Energy Commission is currently in the process of carrying out exploration and field investigations, as well as a feasibility study with the intent of designing and constructing a pilot plant employing a hydrothermal resource in the State of Nevada. Completion and startup of this facility is presently scheduled for the third quarter of 1978. As a parallel effort, the National Science Foundation has funded two feasibility studies leading to the design and construction respectively of two separate pilot scale generation facilities, each accompanied by test-bed capability. One of these studies is

being carried on by Bechtel Corporation of San Francisco and the other by TRW Corporation of Redondo Beach, California. Additionally, the Lawrence Livermore Laboratory (Livermore, California), under the auspices of the Atomic Energy Commission, has undertaken a research and development program of a so-called total-flow concept in which no phase-separation occurs, the prime mover accepting the total-flow of the mixed phases from the geothermal wells. The time schedule for this program envisions operation of a prototype turbine of approximately 100 kWe by the middle of fiscal year 1976.

(2) Energy Conversion Processes

As has been stated in a previous part of this report, there are two commercially established energy conversion processes, specifically, direct steam expansion (e.g. The Geysers and Lardarello) and the flashed-steam system (e.g. Wairakei and Cerro Prieto). Very little additional research and development are required to improve these processes. In contrast with this, insofar as geothermal applications are concerned, the binary conversion process must be regarded as experimental in that only one small scale pilot

plant has ever been built. Extensive turbine and component development for commercial usage and the construction of the first large scale demonstration plant remain to be accomplished. The various proposed total-flow conversion processes must be regarded as of conceptual maturity only, and no pilot plant has yet been constructed employing any of these concepts. It should be noted that, in addition to Lawrence Livermore Laboratory's so-called total-flow concept, which would employ a yet to be developed turbine, there are also other total-flow concepts that are being advanced. These include the so-called KROV Engine (Keller Corporation, Dallas, Texas), the helical screw expander (Hydrothermal Power Company, Pasadena, California), and the so-called bladeless turbine (U.S. Federal Engineering and Manufacturing Company, San Diego, California).

(3) National Science Foundation Supporting Research With the ultimate aim of supporting the operation of large-scale binary process power generation plants, the National Science Foundation is financially supporting the development of three distinctly different concepts of hot/deep geothermal well pumps. The intended function of these pumps is to suppress

flashing (boiling) of the geothermal fluid along its course from a point of 100% thermally saturated liquid in the well, up through the entire hydraulic system and returning to the formation through the reinjection wells. It is hoped that suppression of the flash will avoid excessive concentration of the brine and consequently the precipitation or deposition of dissolved solids on the surfaces of the mechanical equipment. The present pump development program being funded by NSF is presently scheduled to yield ready-for-test prototype units by the end of August 1975. These pumps are being developed for maximum downhole liquid temperatures of approximately 500°F and total mass flow rates of 500,000 #/hr.

(4) Privately Financed Developments

A number of private organizations have been expending private funds in the development of components, prime movers and conversion processes.

(a) Helical Screw Expander

With respect to prime movers, the Hydrothermal Power Company has, for about 2½ years, been constructing and testing the so-called helical screw expander with the intent of applying it as the prime mover in a total-flow power generation system. This

concept is based on a mechanical arrangement very similar to the Lysholm type gas compressor. Hydrothermal Power Company has built and tested two of these machines at well sites at Cerro Prieto, Mexico and at the U.S. Bureau of Reclamation's wells in East Mesa. The largest of these machines, which is presently being tested at East Mesa, has a nominal capacity of 62 kWe (100 hp). Total accumulated running time for these machines by Hydrothermal Power Company is approximately 1000 hours. Very little substantiated performance data on these units have been published to date. Hydrothermal Power Company intends to continue developmental work and testing of these machines with its own funds and intends to sell and manufacture the first commercial unit. Hydrothermal Power Company, in concert with the Jet Propulsion Lab, at Pasadena, has submitted a proposal to the National science Foundation for a program of development and testing of these machines.

(b) KROV Engine

The Keller Corporation of Dallas, Texas has, for a number of years, been developing a so-called rotating oscillating vane (KROV) heat engine which they are proposing as a prime mover for total-flow application

concept is based on a mechanical arrangement very similar to the Lysholm type gas compressor. Hydrothermal Power Company has built and tested two of these machines at well sites at Cerro Prieta, Mexico and at the U.S. Bureau of Reclamation's well in East Mesa. The largest of these machines, which is presently being tested at East Mesa, has a nominal capacity of 62 kWe (100 hp). Total accumulated running time for these machines by Hydrothermal Power Company is approximately 1000 hours. Very little substantiated performance data on these units have been published to date. Hydrothermal Power Company intends to continue developmental work and testing of these machines with its own funds and intends to sell and manufacture the first commercial unit. Hydrothermal Power Company, in concert with the Jet Propulsion Lab, at Pasadena, has submitted a proposal to the National Science Foundation for a program of development and testing of these machines.

(b) KROV Engine

The Keller Corporation of Dallas, Texas has, for a number of years, been developing a so-called rotating, oscillating vane (KROV) heat engine which they are proposing as a prime mover for total-flow application

to geothermal fluids. One four inch diameter cylinder prototype machine has been constructed and tested on compressed air, steam, water, and mixtures of air and water. The results of these tests are as yet unpublished. A second prototype machine, having an eight inch diameter cylinder, is presently being designed and built by personnel from MIT (not by the Institute itself). The completion schedule for this machine is indefinite. When test data becomes available, the Keller Corporation has stated that it intends to publish same.

(c) Bladeless Turbine

The U.S. Federal Engineering and Manufacturing Company is developing, for geothermal applications, a new type of prime mover which depends upon the boundary-layer drag effect to produce torque. This concept takes the form of a series of concentric discs stacked on and fixed to a single central shaft; and they are spaced apart from each other by approximately 0.090 inch. The discs have holes cut through them on a circular pattern near the shaft hub. The discs and shaft rotate within a wrap-around (scroll) type nozzle arrangement which produces uniformly distributed peripheral in-flow of the mixed phase stream. The

fluid passes between the discs, spiralling inward to the discharge ports at the center of the disc stack. Such machines as this, having small capacities, have been developed and applied in the aerospace industry as both motors and pumps. It is not known at this time what future developmental work is planned.

(d) Binary Process

The Magma Energy Company has developed a proprietary energy conversion process to which they have applied the name "Magamax." This is a straightforward binary conversion process using isobutane as the working fluid. Apparently, the design of this system and several uncompleted attempts to construct a power plant using the Magmamax cycle have been financed solely with private funds, some from utilities, and some from other private interests.

(e) Hydrocarbon Expander Development

Hydrocarbon gas expanders suitable for extraction of mechanical energy from high pressure hydrocarbon gases have been used for many years in the petrochemical industry, and the technology covering the design and application of these machines is highly developed. However, the units themselves are of relatively small

power capacities, the largest presently operating being of the order of 25,000 hp (18.64 MWm). These machines have not been designed to drive electrical alternators which are connected to and synchronized with an electric power transmission and distribution network. Speed governing systems and overload controls suitable for this application must be developed for these machines.

One well-known manufacturer has stated that, although they have not yet done so, they are prepared to build and guarantee a 75 MWm hydrocarbon gas expander. This particular firm has stated that it is their intention to spread the development costs for such a machine over the first eight orders for this type of equipment which they receive.

c) Major Problems

1) Technical/Scientific

(a) Solids Deposition Control

All geothermal fluids contain dissolved solids which occur as a variety of constituents in a wide range of concentrations. Precipitated chloride salts are readily soluble in water, and to a lesser degree so is calcium carbonate (CaCO_3). However, crystalline Silica (SiO_2) can only be

removed chemically or mechanically. Solids deposition by scaling on the internal surfaces of piping systems and other power plant equipment (e.g. heat-exchangers, turbine blades, and casings) significantly impairs the operability, reliability, and economic life of the equipment. Precipitation of these materials, and their adherence to the internal surfaces of piping systems, increases the hydraulic pressure losses even to the extent of rendering the system useless. Deposition on the turbine blades can distort blading configuration leading to loss in turbine efficiency and unbalancing of the turbine rotor. Developing the necessary technology to control solids deposition on the internal surfaces of mechanical equipment is a major problem for power plants operating with the direct flash process, but is also of critical importance to plants operating on the binary cycle. The essential link between the heat transport fluid and the working-fluid in the binary cycle is the heat exchanger. Deposition in even relatively thin layers of foreign material on the heat transfer surfaces will drastically reduce the heat flux and therefore the system power capacity.

(b) Hydrocarbon Expander Development

Low pressure steam turbines for application to geothermal sites in capacities of 50 MWe to 100 MWe exist at the present time. The technology relating to these machines is well developed. However, hydrocarbon gas expanders of 50 MWe to 100 MWe capacities which can be applied in a binary conversion cycle have not yet been developed. In addition to scaling up the capacity of presently available gas expanders, it will be necessary to provide appropriately located extraction points for feed heating and to develop reliable speed governing and overload controls systems. Development of long-lived low-leakage shaft seals, which are compatible with a broad spectrum of working fluids, is essential to turbine expander reliability.

(c) Effluent Reinjection

A major technical problem which relates, directly to the environmental acceptability of hydrothermal power generation installations is the ability to economically dispose of massive flows of well effluent laden with dissolved solids. Since reinjection of these fluids into the formation appears to be one of the most practical means of safe disposal of these fluids, a major problem will be to demonstrate

the technical and economic practicality of large scale reinjection operations.

In a technical sense, the consequences of injecting waste geothermal fluids, laden with dissolved solids, into the formation are almost totally unknown. If the partially cooled geothermal fluid being discharged from the conversion system contains dissolved-solids which are not in kinetic equilibrium, solids could continue precipitating out of solution along the entire reinjection path including the formation. It would then be just a matter of time until the reinjection wells and the surrounding formation become so badly occluded they are uneconomical to operate. An additional potential problem is posed by the possibility of reinjecting fully cooled and chemically stabilized brine into the formation which could cause local cooling of untapped brine in the formation, resulting in localized precipitation surrounding the reinjection well. A third possibility is the obvious risk of relatively cold reinjection brine establishing hydraulic communication with the hot production brine, giving a re-circulation, and effectively reducing the energy content of the fluid at the well-head. Lastly, it should be recognized

that the effect on land surface subsidence of pumping fluids into the geological formation are not fully understood. In certain cases in the petroleum industry, repressurizing the formation by injecting water has not controlled subsidence. It is not understood what parameters determine the most favorable ratio of fluid volumes withdrawn versus fluid volumes injected.

(d) Waste-Heat Rejection

Because of the relatively low temperatures and pressures available at the turbine throttles, geothermal power plants have relatively low overall plant efficiencies of about 4 to 14%. Consequently, the heat rejection rate per unit power for a geothermal plant is from 3 to 10 times greater than for modern fossil plants for instance, which can operate at about 38% overall plant efficiency. Conventional heat-rejection methods are as applicable geothermal power plants as to any other power plant, with the choice between them being based on engineering, economic, and environmental considerations. With respect to evaporative type cooling (towers or ponds), dry-steam and flash-steam geothermal plants can supply all required make-up water, and therefore they are not consumptive

users of water. On the other hand, the binary cycle in which flashing of the geothermal brine is suppressed cannot supply its own make-up water and if evaporative cooling is employed, it will become a consumptive user of water. As is well known, if dry cooling is used, the mean cycle thermodynamic efficiency will be less than that obtainable through evaporative cooling. Once-thru cooling is of course the least expensive and the most efficient, however it is not favored for environmental reasons.

(e) Physically Verified Reservoir Models
At present there are few, if any, mathematical models which truly represent the geological and hydrological characteristics of hydrothermal reservoirs, and those that do exist have not yet been verified against actual performance of geothermal reservoirs. A serious effort will be made to verify such models during actual operation of the reservoir selected for the demonstration plant.

(f) Site-to-Site Transferability
It is essential to the basic purposes of a demonstration facility that it be possible to generalize the demonstrated technology from site-to-site. If

the demonstrated technology is highly site specific, the usefulness of the demonstration facility becomes very restricted. For an expansion of this topic, please refer to Appendix B.

2) Economic

(a) Credible Cost Estimates

A major economic problem which chronically besets the geothermal industry is the lack of credibly established comprehensive estimates of capital and energy costs for commercial hydrothermal electric power plants constructed in the United States. This particular economic problem can ultimately be overcome only by the design, construction and operation of a commercial-scale demonstration plant for which detailed and verified capital and operating cost data are compiled and published. The serious need for this type of information is a primary justification for the recommendation for a commercial-scale demonstration plant. Specific data are needed to define production well separation distances, distances required between production and reinjection wells, primary heat exchanger scaling and maintenance requirements, load performance of turbines, etc.

(b) Coherent Economic Model

At present there is no comprehensive coherent economic model of an electric power generation facility based on a hydrothermal resource. Such a model is an essential tool in projecting the economic operating conditions from a known operating facility to hydrothermal power plants which are only in the planning or conceptual stages.

3) Environmental

(a) Liquid Waste Disposal

From an environmental point of view, the inability of the constructor and operator of hydrothermal power stations to safely and completely dispose of saline or toxic liquid wastes would be sufficient grounds on which to bring injunctive action to halt a project. This fact is probably one of the most severe constraints on large scale commercial development of hydrothermal resources. In a technical sense, the consequences of injecting hot fluids, laden with dissolved solids, into the formation are almost totally unknown.

(b) Land Surface Subsidence

Although the occurrence of land surface subsidence caused by withdrawal of large volumes of fluid is

not universal by any means, the possibility of it occurring in connection with operation of the hydrothermal demonstration plant, must be anticipated and planned for. It should be recognized that even a moderate amount of differential subsidence in an agricultural area which is dependant upon a large-scale gravity-flow irrigation system, would be a serious environmental matter. It will be necessary to establish a network of leveling benchmarks throughout the field being developed, and in the areas adjoining the field, all of which are referenced to control benchmarks located outside the area which may be affected. In certain jurisdictions, such a monitoring network is required by law. In any event, such a network will be essential in determining the effectiveness of the fluid reinjection program as a means of controlling subsidence.

(c) Land Use

Dedication of land area to an industrial application such as a geothermal power plant may conflict with other uses to which the land currently is being put, including agricultural and recreational uses. Cooling ponds or canals could occupy fairly substantial land areas. Although gathering systems can

extend over several linear miles, the open spaces on both sides of the pipe-runs can be used for animal grazing or other similar purposes. The individual wells themselves occupy very little land area, however vehicular access to all wells must be maintained. In areas such as the Imperial Valley where agricultural land is of premium value, an industrial facility will have to compete for land on the open market as well as before the local planning commission.

(d) Gaseous Wastes

Disposal of nuisance or toxic, gaseous wastes is an important environmental problem, although it is not as severe a problem as disposal of liquid wastes. The technology for coping with these problems is partially developed, however a complete solution has not yet been achieved.

(e) Soluble Solid Wastes

The disposal of soluble solid wastes (chloride salts) in an environmentally acceptable way is still a serious operational problem. If the particular salt or mixture of salts has little or no economic value, it then must be disposed of in some other

manner. Disposal by dumping in a tailings-heap or by land-fill are not acceptable methods because the soluble salts will be leached into the natural water courses and shallow ground water by meteorological precipitation. This problem is common to desalination operations and to multiple-flash process electric power generation.

(f) Seismic Induction

It is possible to trigger minor earthquakes by injection of fluids into geological formations, under sufficiently high pressure, when the fluids establish hydraulic communication with seismically active faults. Such occurrences have been artificially induced, however they were not in any way associated with geothermal developments. However, the implication is clear that a problem may result from reinjection of liquid wastes to control a land surface subsidence or for recharging of a hydrothermal reservoir. Much excellent experimental field work has been performed by Dr. Barry Raleigh of the USGS at a site near Rangely, Colorado, in connection with artificial earthquake induction, and this has lead to a fairly complete understanding of the physical mechanism. Presently available evidence indicates that triggering earthquakes by

injection of fluids can be avoided by not doing so in close proximity to active seismic faults. Although the probability of triggering a seismic release is fairly remote, the possibility of this occurring should not be overlooked.

(g) Aesthetic Values

The problem of preserving aesthetic values in an area in which an industrial facility is being constructed is essentially the same for a geothermal plant as for any other type of industrial plant. In this respect, problems peculiar to geothermal plants would include the appearance of an extensive serpentine piping system for gathering and returning geothermal fluids. While it is technically feasible to bury these thermally insulated pipes, valving, and expansion loops, this approach would increase the capital costs.

(h) Noise Emissions

Noise emissions from geothermal operations are most prevalent during drilling of vapor-dominated wells, which are usually drilled with compressed air as a drilling fluid. When drilling hydrothermal (liquid-dominated) wells, compounded drilling-muds are used

for cooling and washing out the cuttings, the noise emissions problem is greatly reduced. Noise emissions from the geothermal power plants themselves are no more than from any other steam power plant, and are well within acceptable limits.

4) Institutional

(a) Financial

The present electric utility shortage of capital for investment in conventional electric power plants may very well reduce the electric utilities' priority for investment in geothermal power plants. The recent passage of the Geothermal Development Act of 1974 includes a loan guarantee clause which allows any one organization to obtain a loan guarantee up to 25 million dollars for a given project and a maximum of 50 million dollars if the organization provides 25% of the costs. This legislation dovetails with the proposed demonstration plant and will reduce risks to EPRI and the cooperating electric utility(ies).

(b) Legal and Regulatory

(1) Facility Ownership

For purposes of satisfying taxation requirements and FPC and PUC amortization requirements, the ownership of the facility must be clearly defined.

(2) Licensing Agencies

In the specific areas being considered as potential sites for the demonstration plant, there exists a multiplicity of licensing and regulatory agencies within the various levels of the federal, state, and local governments. It will be necessary to identify and establish initial contact with the responsible agencies during the feasibility study.

(3) Contractual

The specific contractual relationship between EPRI and the electric utility(ies) and the reservoir producers relative to the design, construction and operation of the plant to achieve the stated objectives of this subprogram must be negotiated. These arrangements should allow flexibility in plant design to provide answers to key problems which at the same time allow the utility owner and operator of the power plant to properly integrate the plant into his electric generating system.

d) Specific Objectives

The primary objective of this subprogram is to design, construct, and commission a low salinity, hydrothermal demonstration power plant by the end of 1979. Specific subobjectives include:

1) By the end of 1975 to have completed heat exchanger and reservoir reinjection tests of the selected site and to have defined the EPRI-electric utility(ies) relationship for demonstration plant implementation.

2) By the end of first quarter of 1976 to have completed a Phase 0 Requirements Definition (Feasibility Study) to define the power plant scale, conversion cycle, and conceptual plant design and to have completed the collection of environmental baseline data of the selected site.

3) By the end of the third quarter of 1979, to have completed plant construction and initiated a startup and test program.

The objective of this project beyond 1979 are to:

1) Accumulate and publish long-term performance data derived from the demonstration plant (at least two years of data)

2) Develop and publish credible capital and operating cost data and cost of energy data related to the selected conversion cycle at the demonstration plant site.

3) Conclusively demonstrate the technical and economic feasibility of electric power generation from hydrothermal resources within the United States.

e) Content

1) General

The demonstration plant subprogram consists of a series of interrelated and often complex steps, all intended to be mutually supportive and to culminate in the commercial operation of this proposed facility. In order to achieve the specific objective defined above, a close working relationship must be developed and maintained among EPRI, electric utility(ies), and energy supplier personnel. The major elements of this subprogram are presented below.

2) Phase O - Feasibility Study

A comprehensive Feasibility Study (Phase O) will be undertaken for the purpose of developing sufficient information on which EPRI can base a decision to construct or not to construct a demonstration power generating plant 25 to 50 MWe at a selected geothermal site. One of the primary

objectives of this feasibility study will be to identify the major technical, economic, legal, institutional, and environmental problems associated with the combined selection of a hydrothermal field and a suitable energy conversion cycle. During the feasibility study, a conceptual design will be developed on the basis of which a cost estimate will be generated and a construction time schedule through plant start-up will be prepared. Additionally, the feasibility study team will prepare a detailed procurement specification for the turbine-generator set, and will solicit formal quotations from reputable manufactures for both cost and delivery-time. Also, as part of the feasibility study, the team members will perform a preliminary environmental investigation related to the selected site to identify all relevant local and federal regulatory agencies, potential environmental impacts, and the overall complexity of producing the necessary environmental impact reports. As an integral part of this effort, they will also establish initial contacts with the cognizant regulatory agencies and with responsible public interest groups.

3) Reservoir Verification

In direct support of the feasibility analysis and to give EPRI and its utility associate(s) a high level of assurance that the selected reservoir can support for an extended period of time a power plant of 25 to 50MWe capacity, an investigation will be undertaken to verify the selected reservoir's hydraulic and thermal capacity. This program will augment the energy suppliers well data and will provide independent substantiation of the characteristics and capability of the selected reservoir. This investigation will not only include a determination of the production capacity of the field, but will also verify the capacity of the formation to accept reinjected liquid wastes.

4) Heat Exchanger Scale Test

Also in direct support of the feasibility study, and in anticipation of the possible selection of the binary cycle, it will be necessary to conduct a series of heat exchanger surface scaling tests at the selected geothermal site. The outcome of these tests will determine the technical feasibility of employing the binary cycle at the selected site.

5) Environmental Report

In addition to performing the preliminary environmental investigation, it will be necessary to begin the acquisition of environmental baseline data at the earliest possible date in anticipation of the need for this information in preparing the project environmental reports. Acquisition of this information will extend continuously over a minimum of one year. Therefore, to avoid subsequent delay in licensing the construction, this activity must be started as soon as possible after site selection.

6) Detailed Design

Insofar as the detailed design is concerned, the plant limits will encompass all components of the energy conversion system including the switchyard, but will not include the production and disposal wells, the gathering system, or the electric transmission system. In order to assure timely prosecution of the detailed design, it is assumed that the following information will have been developed in advance of the design effort:

- a) All existing well performance data including chemical definition, thermal defini-

tion, and flow characteristics will be available for the selected reservoir.

b) All reservoir verification information, including reinjection feasibility, resulting from the reservoir verification investigation will be available.

c) All heat exchanger scale - test information resulting from the heat exchanger scale tests will be available.

If the above information is complete and available, the detailed design should proceed smoothly and rapidly.

7) Equipment Procurement

The placement of a firm purchase order for the procurement of the turbine-generator set will be a matter of highest priority because procurement of this item lies on the project critical path. Procurement of all other materials and equipment, with the possible exception of the main high-voltage transformer, should be a fairly routine matter once the proper procurement specifications and documents have been prepared. No other single item of plant equipment will affect the overall duration of the design/construction program.

8) Construction and Startup

Project construction can commence prior to completion of the detailed design, but its completion will be very dependent upon the timely delivery of such critical items as the turbine generator set. A startup and test period of approximately three months duration is anticipated, prior to start of commercial operation.

9) Evaluation, Operation, and Maintenance

The vital function of evaluating the technical and economic performance of this facility shall commence at the end of 1979 and shall be maintained continuously throughout at least a two year test period during the plant's productive life. To a large degree, the credibility of this evaluation will be based upon verified systematic acquisition of definitive operation and maintenance data. The demonstration plant will only be operated in those modes normal to electric power plant operation and will not serve as a test bed for alternative subsystem evaluation.

f) Approach

Because of the minimum time period of one year required to obtain the base line environmental data necessary for the preparation of the environmental report, it is imperative that this acquisition

program be started at the earliest possible date. This should start immediately after a formal agreement has been reached between EPRI and the owners of the selected reservoir.

Throughout this subprogram it will be essential that EPRI and its associates keep available alternative courses of action as hedges against possible failure of particular courses to materialize. It will be necessary for EPRI to make a series of critical decisions before a final full commitment is made to proceed with design and construction of the demonstration plant. In order to provide adequate information on which to base the decisions, a comprehensive feasibility study will be undertaken. As an integral part of the feasibility study, the investigators will prepare complete procurement specifications for the turbine-generator set and any other long-lead items, and will solicit quotations for these items of both price and delivery times. This will permit foreshortening the detailed design and construction period by permitting placement of an order for the turbine generator set immediately after the final decision to go ahead with the project. Very shortly after the final decision is made, an

award must be made of the detailed design and construction contract.

q) Schedules and Cost Estimates

1) Schedules

Two different time schedules have been developed for the demonstration plant subprogram, and these have been designated the Preferred Schedule and the Alternatative Schedule. The details of each of these schedules are presented in the following paragraphs.

(a) Preferred Schedule

The Preferred Schedule is based on the assumption that early designation of a high probability site will be made which will permit almost immediate commencement of preliminary heat exchanger and reservoir verification tests, and shortly thereafter start of acquisition of the environmental baseline data. The overall subprogram schedule which proceeds from this assumption is presented in Figure III-2 details of the first year of the subprogram are presented in Figure III-3. Under this schedule, the critical path passes through: acquisition of the environmental baseline data; filing, review, and approval of the environmental report; issuance of a license to construct; fabrication, assembly,

and delivery of the turbine-generator set; final stage of construction; startup and test. EPRI is scheduled to make the final decision to proceed with design and construction of the plant three months after the feasibility study is issued. It should be noted that final commitment for purchase of the turbine/generator (start fabrication) will occur almost simultaneously with issuance of the license to construct. This is tight scheduling and assumes no delay in obtaining the license to construct. Potential major causes of delay in this subprogram are: an untimely decision by EPRI to proceed with the project; and untimely decision by the responsible regulatory agency to issue a license to construct; an unpredictably long period in developing a 25 to 50 MWe capacity hydrocarbon expander (if binary is used); or labor disputes in the T/G manufacturer's plant or on the construction site. Under the Preferred Schedule, a realistic completion date for placing the plant into commercial operation is the end of 1979.

(b) Alternative Schedule

The Alternative Schedule is based on the assumption that a site is to be chosen for which no previous negotiations have been conducted, for which prelim-

inary heat exchanger tests have not been conducted and for which there is no existing subsidence monitoring network for environmental impact. The overall subprogram schedule resulting from these assumptions is presented in Figure III-4, with details of the first two years being shown in Figure III-5. The critical path through the Alternative Schedule parallels the same items as with the Preferred Schedule. The effect of the above underlying assumptions is to delay commercial operation of the plant by approximately six months beyond that of the Preferred Schedule, i.e. until mid-1980.

The expenditure rate will peak in 1978 with an annual amount of \$8,350,000. It is proposed that EPRI's contribution to the total budget amount will be 31.8% (\$8,390,000). The utility contribution will then be the balance of 68.2% (18,000,000). The cost estimate for the low salinity hydrothermal demonstration plant is based on the following assumption.

- (a) Nominal plant capacity equals 50MWe (net)
- (b) The plant will be constructed in the Imperial Valley
- (c) The downhole saturated well temperature equals 400°F

- (d) A binary conversion process will be used
- (e) Evaporative cooling will be used
- (f) The estimate does not include drilling or construction of the production wells or the disposal wells, the gathering system, or the power transmission system
- (g) An inflation escalation rate of 16% per year occurs from mid-1973 to mid-1975.
- (h) The split between the erection costs and the equipment and materials cost is 40%/60%.

The cost estimate for the alternative schedule is shown in Table III-5. A total of \$26,740,000 is estimated to be expended on this option during the five-year period 1975 through 1979. Similar assumptions as above were utilized in making these cost estimates.

DEMONSTRATION PLANT, LOW-SALINITY HYDROTHERMAL RESOURCE SUBPROGRAM
(PREFERRED SCHEDULE)

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Environmental Baseline and Report	100	100	100	50	--	350
2. Preliminary Heat Exchanger Tests	140	--	--	--	--	140
3. Reservoir Verification	900	200	--	--	--	1,100
4. Feasibility Study	250	50	--	--	--	300
5. Detailed Plant Design	--	800	700	--	--	1,500
6. Hardware Procurement	--	3,000	6,000	3,300	1,200	13,500
7. Construction	--	--	1,000	5,000	3,000	9,000
8. Start-Up and Test	--	--	--	--	500	500
ANNUAL TOTALS:	1,390	4,150	7,800	8,350	4,700	26,390
EPRI CONTRIBUTION:	1,390	1,650	2,800	1,850	700	8,390
UTILITY CONTRIBUTION:	(0)	(2,500)	(5,000)	(6,500)	(4,000)	(18,000)

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

LOW SALINITY, HYDROTHERMAL DEMONSTRATION PLANT

(Preferred Schedule)

DEMONSTRATION PLANT, LOW-SALINITY HYDROTHERMAL RESOURCE SUBPROGRAM
(ALTERNATIVE SCHEDULE)

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>	<u>Five Year Total</u>
1. Environmental Baseline and Report	80	100	100	70	--	--	350
2. Heat Exchanger Tests	490	--	--	--	--	--	490
3. Reservoir Verification	900	200	--	--	--	--	1,100
4. Feasibility Study	50	250	--	--	--	--	300
5. Detailed Plant Design	--	100	1,000	400	--	--	1,500
6. Hardware Procurement	--	1,000	4,500	4,500	3,000	500	13,500
7. Construction	--	--	--	3,000	5,000	1,000	9,000
8. Start-Up and Test	--	--	--	--	--	500	500
ANNUAL TOTALS:	1,520	1,650	5,600	7,970	8,000	2,000	26,740
EPRI CONTRIBUTION:	1,520	1,500	2,000	2,000	2,000	--	9,020
UTILITY CONTRIBUTION:	(0)	(150)	(3,600)	(5,970)	(6,000)	(2,000)	(17,720)

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

LOW SALINITY, HYDROTHERMAL DEMONSTRATION PLANT

(Alternative Schedule)

TABLE III-5

2. Guidelines Manuals

a) Background

Because of the basically embryonic character of the geothermal industry, there are many responsible individuals within the electric utilities' planning organizations who have little familiarity with geothermal energy as an alternative energy source, and who are therefore often confused and misled by the plethora of information and misinformation extant on the subject. During the course of the EPRI Geothermal Workshop (July 16, 17, & 18 1974), the point was repeatedly made by spokesman for the represented utilities that they perceived an urgent need for some type of unbiased, straightforward delineation of all essential steps required to discover and evaluate the resource, finance, design, construct and commission the power plant; and place the entire system into reliable, long-term commercial operation. Such information, compiled in an orderly systematic way would be an invaluable supportive tool for those electric utility engineers and executives responsible for the planning and execution of new generation capacity. Use of such a set of guidelines would enhance knowledgeable decision-making and greatly

reduce the risk of making costly mistakes. Because of the rapidly expanding interest in geothermal energy as an alternative source of energy, the increasingly long delays in bringing conventional generation on line, and the accelerating rise of demand for electric power, the need for such a set of guidelines is urgent and immediate. As a direct outgrowth of the numerous comments, criticisms and suggestions generated during the workshop, the concept has emerged of a comprehensive set of integrated Guideline Manuals spanning the full range of the technology, from exploration through plant start-up.

b) Current Status

At present, no comparable set of documents exists which will fill this need. Additionally, no individual, or public or private agency is known to be engaged in developing such a guideline. If such a set of comprehensive guideline manuals existed today, they would receive immediate and widespread application.

c) Major Problems

1) Technical/Scientific

It is generally recognized that the present

state of knowledge of the location, extent, distribution, and quality of geothermal resources in the U.S. is fragmentary, uncorrelated, and on the whole, undeveloped. This fact is probably the single greatest technical problem impeding the rapid development of an energy industry in the U.S. which is based on geothermal resources. This is due in equal measure to the lack of a coordinated, long-term, well financed exploratory and drilling program, as well as to the experimental and undeveloped nature of the numerous exploration and evaluation techniques.

Only two commercially proven geothermal energy conversion processes exist today, the direct dry-steam expansion process, and the multi-stage flash process. Additionally, there exists a number of conversion processes which are either in the experimental or the conceptual stages. One of these is the binary process, of which only one installation exists today, which is the 440 kWe(net) at the Paratunka experimental power station on the Kamchatka Peninsula in the U.S.S.R. No

full-scale commercial plant, employing this process, has yet been constructed. The binary process has certain advantages and disadvantages when compared to the multi-stage flash process.

Another energy conversion process currently being widely proposed is the so-called total-flow process, in which the entire flow including all phases are passed through the prime mover without separation. This process is currently conceptual only, but a development program is underway at the Lawrence Livermore Laboratory which is intended to bring it to the experimental stage.

Processes other than for energy conversion, which have been proposed but not proven, include combustion of H_2S gas at the well-head as a means of avoiding release to the atmosphere; or injection of CO_2 gas deep into the production wells for the purpose of inhibiting deposition of calcium carbonate in the well casing.

The wide-spread non-standardization of data acquisition and reporting methods has resulted

in much basic geophysical, geochemical, geological, and other technical data being published which is incomplete and often not comparable.

The lack of historical, definitive operational data of long-term reservoir operation and long-term power plant operation inhibits the intelligent planning, design, and optimum operation of reservoirs and generation facilities.

The non-existence of a widely available geothermal data exchange center designed to receive, store, retrieve, and disseminate existing and future reservoir data (geological, geochemical, hydrological, geophysical, etc.) for use in resource exploration and appraisal, inhibits the discovery, assessment, planning, development, and operation of geothermal resources in the U.S.

With respect to the commercially unproven processes such as binary and total-flow, it should be understood that commercial scale prime-movers essential to these processes,

have not yet been developed. For the binary process turbine, this is simply a question of scaling-up capacity from existing designs that are based on well established technology. For the total-flow process, however, this becomes a matter of developing and proving entirely new equipment capable of efficiently extracting energy from a multi-phase stream. This will require the development of highly efficient injection nozzles and appropriately configured and structured turbine blading.

Solids (scale) deposited on the internal surfaces of piping systems and power equipment (e.g. heat exchangers, turbine blades and castings), significantly impair the operability, reliability, and economic life of the equipment.

In the binary cycle, the essential link between the heat-transport fluid and the working-fluid is the heat exchanger. Maintaining the heat transfer surfaces in a clean, unfouled condition is vital to the effective operation of any heat exchanger, and the accumulation of even a relatively

thin deposit of foreign material on the heat transfer surfaces will markedly reduce the effectiveness of the equipmnet.

Finally, the Guidelines Manuals will undertake to define the types of physical data which must be collected and integrated in order to define the actual operating characteristics of the reservoir, the gathering system, and electric power generation plant. This type of information is essential to the determination of the economic viability of the entire system. Specific examples of this type of data may be offered as an instructive aid.

2) Economic

In order to support budget requests for the development of reservoirs and for the construction of energy conversion facilities, it is essential that credible cost estimates of these expenditures to be developed. These type of supportive cost estimates are essential to the request for the necessary funds from the major lending institutions.

3) Environmental

With respect to the acquisition of the essential baseline data necessary for the preparation of the required formal environmental reports, it is essential that the program for acquiring this information be planned and initiated well in advance of actual need. This is necessary to avoid possible loss of vital data which subsequently will be irretrievable. It is necessary to appreciate that gathering the required data is a protracted affair, and this information must be acquired on a consistent, uninterrupted, long-term basis.

It should be recognized that at any time during the course of planning or executing the project, individuals or public interest groups can initiate intervenor action for the purpose of influencing the course of the development, or to stop the project entirely. To minimize the risk of this occurring, it is prudent to establish initial contact with the cognizant regulatory agencies, and with responsible public interest groups during the early planning stages of a project.

Disposal of toxic and saline liquid wastes (arsenic, boron, chloride salts), in an environmentally acceptable manner, is presently the single most severe environmental constraint on the physical development of hydrothermal reservoirs. In most cases, the only practical method presently available is to inject the liquid waste into the geological formation. The technical consequences of reinjecting conversion system effluents, laden with dissolved solids which are not in kinetic equilibrium, is almost totally unknown.

Geothermal fluids (liquids and steam) often carry substantial volumes of dissolved gases which are released upon loss of liquid pressure or when the steam is condensed. Commonly encountered gases are carbon dioxide (CO_2), hydrogen sulfide (H_2S), methane (CH_4), and ammonia (NH_3). CO_2 is relatively harmless when discharged to the atmosphere. Depending on concentration, the effects of H_2S can vary from nuisance to lethal. NH_3 occurs infrequently, and in low concentration, it is only a nuisance. However, CH_4 is odorless, explosive, and in sufficiently high concentration is lethal.

Withdrawal of substantial volumes of fluids from geological formations over relatively long periods of time has caused differential subsidence of extensive land surface areas. This has occurred in a number of instances in the petroleum industry in the U.S. as well as in the Wairakei geothermal field in New Zealand. In the petroleum industry, land subsidence have been controlled by repressurization with water. Differential subsidence is irreversible and can be very damaging to gravity-flow systems such as irrigation works, flood control systems, sewer systems, and natural water courses. Economic structures such as railroad beds, airport runways, and foundation systems can also be adversely affected.

Severe subsurface ground-water contamination can be caused by loss of formation integrity caused by improperly executed drilling and cementing procedures. Loss of formation integrity permits the migration upward around the well casing of high pressure, toxic or saline geothermal fluids which intermix with shallow ground water.

4. Institutional

a) Financial

Major industrial lending institutions appear to have two basic attitudes with respect to developing geothermal resources. The first of these relates to reservoir exploration and development operations, in which there is an inherently high degree of risk. The lending institutions view geothermal exploration as being analogous to petroleum exploration in which they limit risk by writing individual lending contracts to cover three or more prospective fields. Whether this approach can be generally applied to geothermal exploration is an open question. The second basic attitude applies to the development of the above-ground facilities, concerning which lending institutions rely almost entirely upon the sound judgement and credibility of the particular utility requesting the funds. This is to say, the utility requesting the loan must submit its own credit rating as collateral for the loan and must assume full risk with respect to the economic soundness of the project.

The Guidelines Manuals will point out to the utilities potential major hazards in the development of geothermal resources, which could cause substantial financial loss.

The potentially long development time required by the geothermal industry before it can satisfy a significant portion of the available market may operate to discourage participation by otherwise interested investors of venture capital.

The non-existence of a credible demonstration-scale electric power plant, sited on a hydrothermal field, distinctly inhibits utility and lending institutions management from committing funds for hydrothermal developments.

In terms of the necessary financial resources, private investment is nearly always attracted to those ventures which yield the highest rate of return with the least risk. Financial institutions are, and will continue to be, reluctant to commit funds to the development of an essentially unknown natural resource whose location, extent, energy potential, and longevity are all undefined.

b) Legal and Regulatory

Presently, there is a lack of uniform legal definition of the geothermal resource. There is no consistent agreement as to whether it is energy, water, mineral, land, or something else. The legal definitions as they presently exist vary greatly from state to state. A number of crucial questions including ownership rights, taxation, and governmental regulation hinge on the legal definition of the geothermal resource.

At present, the tax structure does not grant a general depletion allowance for geothermal resources and, hence, does not encourage investment of venture capital in exploration, drilling, and field development. This situation cannot be adequately changed until a uniform legal definition of the geothermal resource is developed and adopted. The legal definition must state whether the resource is exhaustible or renewable.

There exists a multiplicity of regulatory agencies within the various levels of federal, state, and local governments; these agencies

often exercise overlapping authority. A complex and protracted series of licensing steps is required, primarily on the local level, in order to initiate and carry out a geothermal exploration, field development, and construction program. These extensive and sometimes duplicative licensing requirements cause undue delay in exploration, development, and utilization of geothermal resources in general.

c) Other Factors

In preparing the Guidelines Manuals, it is planned that real case studies will be presented portraying specific situations in which utilities have been involved in premature or ill-defined geothermal ventures. While such case studies may be educational to the reader, it is recognized they could also prove embarrassing to the source organization. Therefore, such case studies would be sterilized of any references to particular individuals or organizations and would be phrased in general terms in order to preclude embarrassment but at the same time realize whatever educational benefit may be contained therein.

An institutional problem often overlooked is the question of limited availability of competent and skilled personnel, knowledgeable in the disciplines required to commercialize geothermal energy. This problem must be addressed in the overall context of the electric power generation picture and with respect to other industries competing for these same skilled personnel.

Because of their regulated position and their fixed rate of return, utilities traditionally opt for long-term, low-risk amortization of their capital investment. In contrast with this, the geothermal resources development companies (e.g., the oil companies) can accept short-term fast write-off, high risk capital investment. In short, neither group can live with long-term, high-risk investment. Integrating these two sharply differing orientations into a common project has caused fiscal problems in the past.

In general, public utility rate setting regulations do not presently allow inclusion of costs for field exploration and development, and for equipment and process research and development. This being the case with few exceptions, the electric utilities understandably avoid entering into geothermal development activities.

Finally, competitive private interest are often reluctant to share proprietary information and data with each other or with the government. This institutional problem is inherent in the private enterprise system.

d) Specific Objectives

The primary objective of this effort is, by the end of 1977, to provide utility management and engineers with a comprehensive set of manuals, citing all essential types of field data required, and setting forth the step-by-step procedures for designing, cost estimating, procuring, constructing, and commissioning a geothermal power station, including definition of environmental, legal and regulatory requirements.

Specific Subobjectives include:

1) By the end of 1976, to provide utility management and engineers with basic guidelines with which they can evaluate definitive physical data and claims related to prospective reservoirs. This information would include brief descriptions of the available exploration methods, and the geophysical, geochemical, geological, and hydrological measurement techniques. Additionally, the guideline would characterize these methods in terms of the reliability of the data obtained, the corroborative effect of one measurement technique with respect to others, as well as the time, costs, and skills required to carry them out.

2) By the end of 1976, to provide a compilation of existing information concerning environmental, legal and regulatory requirements for geothermal plants. This will include the need for

anticipatory, systematic acquisition of critical environmental, geological, and hydrological baseline data.

3) By the end of 1977, to define methods with which to evaluate hydrothermal reservoirs and to interpret reservoir test data. This information would include brief descriptions of presently employed well and reservoir test procedures, including statements as to the reliability of the data obtained and the inferences that can reasonably be drawn from them.

e) Content

It is planned that initially a set of comprehensive Guidelines Manuals be developed to address four basic general areas:

- 1) Reservoir exploration and assessment
- 2) Reservoir testing procedures
- 3) Baseline data acquisition, including environmental, geological, hydrological, and other required data
- 4) Power systems design

The Reservoir Exploration and Assessment Manual would be prepared for the purpose of acquainting the utility executive and the utility engineer with the methods of resource assessment and verification. This manual would present guidelines which are useful in assessing proposals for "downhole money", joint ventures, and power development schemes, and would include such materials as:

- 1) Guidelines for exploration and assessment equipment calibration, and data presentation and interpretation, with examples
- 2) Guidelines for reservoir test equipment calibration and verification, and data presentation and interpretation, with examples
- 3) Guidelines for assessing the commercial viability of given reservoirs, including data requirements and interpretation, as well as at least one case study

The Environmental Legal, and Regulatory Manual would be prepared for the purpose of informing the utility executive and the utility engineer of the requirements and

reasons for documenting before-the-fact environmental, geological, and hydrological conditions (baseline data) within, and adjacent to, a reservoir development site. This manual would discuss the methods employed and the time required to collect and compile sufficient baseline data. This data includes surveys of fauna, flora, and aquatic life, as well as air quality data, meteorological, geological, hydrological and reservoir chemistry data. This manual would also detail the requirements for systematic data acquisition, presentation, analyses, and interpretation, and would include at least one case study. It will also show how the utility may use this data for purposes other than satisfying the requirements of the environmental reports. The manual will emphasize the prudence of establishing early and amicable contact with the responsible public authorities concerned with environmental regulations and enforcement, as well as with concerned responsible public interest groups.

The Power System Design Manual would address the many diverse questions relating to the detailed design of the overall power system.

This manual would cover the very broad range of necessary design activities, including all physical elements of the power system, such as wells, downhole pumps, gathering systems, fluid processing systems, power conversion systems, environmental protection systems, instrumentation, materials selection, heat rejection systems, and secondary working fluid selection. It would also cover operational aspects of the power system, including chemistry and chemical kinetics peculiar to geothermal systems, scaling, corrosion, erosion, and solids deposition. One section of this manual would present the most recent commercial state-of-art, as well as related currently active R&D efforts.

The Reservoir Testing Procedures Manual would delineate, in general and specific terms, the conventional test procedures for evaluating the hydraulic, chemical, and thermal characteristics of individual wells, and of the reservoir as a whole. It would also include an appraisal of the reliability of the physical data in terms of representing the actual in situ physical situation, and in terms of its dependability in forecasting future performance.

f) Approach

Prior to preparation of the content of any of these manuals, it will first be necessary to establish the internal organization, basic format, system of cross-indexing, standards of draftmanship, etc., of the entire set of manuals. The basic intent is that the individual manuals be internally expandable for the purpose of revising and up-dating. From time to time, additional manuals can be added to the initial set of four in order to cover other topics as deemed appropriate.

The plan is to develop an initial set of four basic documents and to issue them periodically. These manuals will then be sustained by periodic revisions and updating. It is further intended that these instructive manuals be made available to the electric utilities on a timely basis.

g) Schedule and Cost Estimates

1) Schedule

The schedule for this subprogram is presented in Figure III-6. Negotiation for the development of the Reservoir

Exploration and Assessment Manual has begun. It is proposed that the development of the Environmental, Legal, and Regulatory Manual and the Power System Design Manual be started in 1975.

The initiation of the Reservoir Testing Procedures Manual will be deferred until 1976.

2) Cost Estimate

The cost estimate for this subprogram as presented in Table III-6 shows a total proposed expenditure over the next 5-years of \$1,030,000. The expenditure of these funds generally peaks at the outset and is fairly uniformly distributed over the balance of the five year period.

SUBPROGRAM ELEMENTS		1975			1976			1977			1978			1979		
1.	RESERVOIR EXPLORATION AND ASSESSMENT MANUAL				IR.	UPDATE		F.R.	UPDATE							
2.	ENVIRONMENTAL, LEGAL, REGULATORY MANUAL				IR.			F. R.	UPDATE							
3.	POWER SYSTEM DESIGN MANUAL		RFP		A			UPDATE		F. R.	UPDATE					
4.	RESERVOIR TESTING PROCEDURES MANUAL				RFP		A				UPDATE					

FIGURE III-6

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Reservoir Exploration and Assessment Manual	50	20	20	20	20	130
2. Environmental, Legal, and Regulatory Manual	125	75	30	30	30	290
3. Power System Design Manual	--	150	150	50	50	400
4. Reservoir Testing Procedures Manual	--	50	100	30	30	210
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
ANNUAL TOTALS:	175	295	300	130	130	1,030
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
EPRI CONTRIBUTION:	175	295	300	130	130	1,030

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

GUIDELINES MANUALS SUBPROGRAM

(Recommended Program)

TABLE III-6

3. Geothermal System and Data Analysis

a) Background

Commencing after the publication of the Hickel Report (1972), under sponsorship of the National Science Foundation's RANN program, the Federal Government has issued a series of

projections of the installed capacity for electricity generation using geothermal energy. These projections have been made using little verifiable information on the capacities of individual reservoirs. Further, the projections for individual resource types typically treat those resources such as geopressure and hot-dry rock, the distributions and abundance or the conversion process for which are unknown, as having equal potential compared to developed and/or known resources such as the vapor-dominated and hydrothermal. The most recent government projection, that of the Interagency Panel, predicts 1985 installed capacities of 7,900 to 39,000 MWe.

The practical implications of these projections extend beyond the deliberations of government agency committees. When electric utility companies submit applications for construction of generation facilities, discussion of alternative actions are necessary for environmental impact reports and statements, It is at this juncture that the utility, in defense of its decision, has great difficulty convincing a

technically unqualified public that the federal projections are, at the best, optimistic and, at the worst, unrealistic.

A number of federal and private agencies have developed geothermal research programs. At this time, the federal agency programs are not well coordinated with one another although some progress in this direction is evident. Coordination of federal and private programs is poor.

The only geothermal fluids utilization contract which is associated with ongoing electric power generation establishes the geothermal fluid (fuel) price using a complex formula which involves the cost of nuclear fuel and fossil fuels, excluding coal, plus an effluent disposal fee. The geothermal fuel price is not related to 1) the cost of exploration and development of the geothermal field, 2) the amortization of such cost with adequate profits, and 3) the overall exploration and development risk associated with the geothermal resource industry.

At the time the contract was developed, appropriate data to assess the above three factors did not exist.

Currently only utilization facilities for Electric Power Generation using the vapor-dominated resource exists in the U.S. Thus, performance, economic, and operational data exist only for the vapor-dominated resource. Overseas data of this type is usually not applicable to U.S. conditions so that hydrothermal data from overseas is of limited value. No applicable data exists anywhere for commercial scale binary cycles, or for the utilization of the untested geopressure and hot, dry rocks resources. Some applicable data for hydrothermal resource effluent reinjection systems has been developed but is not publically available.

Data for assessing U.S. geothermal resource distributions and abundance is presently being developed. This data is accumulating within various organizations, many of which are private and treat the data as proprietary.

The Data available is therefore fragmented, uncorrelated, and not reported to a centralized statistical analysis operation.

Performance data for utilization facility components, especially those under development, is generally not available as, until recently, much of this development was proprietary. Systematic or standardized test information is generally unavailable for reinjection tests, steam clean-up units, prime movers, downhole pumps, heat exchanger scale tests, and others.

b) Current Status:

There is interest within the federal government to achieve better coordination of publically-funded geothermal research programs. Recently-signed legislation creates a Geothermal Energy Coordination and Management Project to provide "effective management and coordination with respect to a National Geothermal Research, Development, and Demonstration Program". Instead of reducing the number of federal agencies involved in the federal Geothermal

program, the legislation adds yet another - NASA. NASA has been given responsibility for providing management capability to the project. In addition, the AEC is seeking to develop a commercialization (resource/technology) scenario simulation package for reviewing its own R&D program.

Since the Hickel Report of 1972, little progress is evident for data accumulation in a National Geothermal data exchange. The data exchange is only now being organized at two locations - Lawrence Berkeley Laboratory (Berkeley, Calif.) and USGS (Menlo Park, Calif). No mechanism exists for reporting (and protecting for a limited time) proprietary data.

Development of new utilization facility components continues in a number of proprietary environments. Definitive data is usually not available concerning the stage of development, the tests from which progress is ascertained, the reliability and/or performance achieved, the issues yet to be addressed, the scientific/technical

bases of development, and the schedule for future development. The electric utility companies individually have not the manpower to assess the technological, operational, and economic factors for technologies which are in development or being improved. There is no focal point for electric utility cooperation in utilization technology assessment, each utility currently purchasing information from consultants.

Proprietary resource exploration and assessment is proceeding at a rapid pace. But, as the utilities have no central support for resource assessment, technology assessment, nor economic and operational analysis, utility negotiators are at a distinct disadvantage relative to the resource company. A centrally-funded operation is required which will develop the data and the methodology necessary for utility companies to present a unified approach during contract negotiations. Substantiated data and methods for evaluating alternative utilization technology costs and requirements are essential to developing an equal negotiating

position. In addition, the utilities in their negotiations with resource companies, require a geothermal fuel cost analysis package which takes account of all cost factors relevant to geothermal resource assessment, exploration and development, and geothermal fluid production and effluent disposal.

c) Major Problems:

1) Technical/Scientific

For hydrothermal systems, representative tests and analytical methods do not exist for evaluating the long-term viability of reinjecting utilization facility effluents back into the production interval or an adjacent interval for the reservoir of origin. Furthermore, no known tests of reinjection have evaluated the effects of rapid thermodynamic and chemical equilibria state changes which occur in the reinjection system upon bypass of the power conversion equipment when generation outages occur. A thermodynamics, fluid mechanics, chemical

kinetics, heat transfer, reservoir engineering package is essential for analyzing tests and predicting consequences.

Utilization equipment suffers the effects of solids deposition (scaling), corrosion, erosion, and materials failure due to reactions with dissolved solids and gases. A thermodynamics, fluid mechanics, chemical kinetics, and heat transfer package is needed to analyze deposition, corrosion, and erosion phenomena and to investigate parameters relevant to materials failures.

A continuing technology assessment, which includes thermodynamics, fluid mechanics, mechanisms, vibrations, materials, and control systems analyses of specific utilization system components, is needed to provide utilities with verifiable, updated information. Models are also needed to aid in the generalization of test bed and demonstration plant

experience to proposed commercial installations at other hydrothermal reservoirs. Newly proposed utilization concepts and components need similar analysis for assessing their development potential and what role they could assume in the National Geothermal Development Program.

2) Economic:

Utility companies need a costs analysis package which can evaluate the costs of exploring for and developing a prospective geothermal field, the operations costs for producing the field and for disposal of utilization system effluents, and the overall risk costs to the Geothermal Resource Industry. The package would allow the utility to assess proposed geothermal fluid (fuel) costs with respect to the rate of return to the resource company after overall investment amortization costs.

Considering the increasing costs of electric power generation, optimization of the economics of a generation project

is essential. Economic optimization of geothermal electric power generation projects requires consideration of site topography, land area use, geology, reservoir characteristics, gathering system, effluent disposal, comparative economics of conversion technology alternatives, reliability of and maintenance costs for conversion systems, and fuel costs for various field development alternatives. A general network package is needed for this optimization.

Economic cost/benefit analysis is necessary for environmental impact reports.

Network analysis of those costs and benefits unique to geothermal may be required. Such results should be available from an economic optimization package.

3) Operational

Except for the Geysers dry steam geothermal power plant, there is little or no directly applicable geothermal power system operational data available in the

U.S. Field operational data is difficult to obtain because of the limited number of fields, of field size, and of its generally proprietary nature. Near-future availability of operational data will improve only slowly owing to the slow growth in utilization of resources and continuing proprietary considerations. Nevertheless, a network system is needed to analyze the operations experience of the demonstration plant and other operating plants with particular emphasis on economic impact.

4) Institutional:

Resource companies maintain a proprietary position on their reservoir data and assessment and exploration results. This is natural as assessment and exploration require high-risk investment. However, as the major portion of geothermal exploration in the U.S. is done under proprietary auspices, open determination of resource distributions and abundances becomes very difficult. Obtaining

proprietary data for inclusion in the National Geothermal Data Exchange presents a difficult institutional problem.

5) Environmental

Contributions to the environmental cost/benefit ratio for geothermal activities, originating from both system development and system operation, need to be analyzed qualitatively and quantitatively. Network and/or component analysis of those aspects which are unique to geothermal development require emphasis.

d) Specific Objectives:

1) Initiate an assessment of the commercialization potential and requirements for geothermal resources in 1975, and develop a capability for systematically analyzing national research and development programs by 1977.

2) Contribute annual financial and technical support to the National Geothermal Data Exchange, commencing in 1975.

- 3) By the end of 1978, develop a reinjection system analysis for the performance study of steady-state effluent reinjection and of transient (conversion system bypass) reinjection wells.
- 4) Develop, by 1977, a geothermal fluids (fuel) cost analysis package
- 5) Develop a first-cut thermodynamics/fluid mechanics/chemical kinetics coupled model to produce a dissolved solids distribution and deposition package for analysis of utilization equipment by the end of 1978.
- 6) Develop or adapt methods for an overall system technology assessment, including: thermodynamics, fluid mechanics, vibrations, mechanical, and control system analysis package; individual components and new technology to be analyzed as necessary by mid-1977.

e) Content

The Subprogram contains three elements as follows:

- . Assessment of Commercialization Potential and Requirements, and of National R&D strategies

- . Geothermal Systems Performance, Economic, and Operational Analysis
- . National Geothermal Data Exchange Support

1) Assessment of Commercialization Potential and Requirements, and of National R&D Strategies.

A network study, probably based on the GERT III algorithm, will be undertaken, the objective of which is to model all of the factors necessary for the commercialization of all types of geothermal resources. These will include economic, technical, institutional, legal, environmental, and financial factors. The model will be used to study the various scenarios, cash flows, and research emphases which may lead to achievement of a particular development goal. Additionally, the model will be used to study the sensitivity of development goals to particular strategies and scenarios, and to determine the impact of competition for materials, manufacturing capacity, technical and management personnel, and financial resources. This study will be useful for developing a rational "national" geothermal development plan, and for reviewing both the Federal and EPRI geothermal plans in relation to the "national" geothermal plan.

2) Geothermal Systems Performance, Economic, and Operational Analysis

This program element consists of four basic tasks:

- a) Reinjection system analysis package, consisting of a comprehensive analysis of geothermal system effluent reinjection in both the steady-state (utilization system operating) and transient (utilization system bypassed) modes. The package will model: fluid mechanics, thermodynamics and heat transfer, chemical kinetics, and reservoir response.
- b) Geothermal fluids (fuel) cost package - a comprehensive analysis of the factors which identify the cost of geothermal fluids (fuel), including: resource exploration and assessments, reservoir development, field operation and maintenance, utilization system effluent reinjection, apportioned losses for unsuccessful exploration efforts, capital charges, amortization of investment, and profit on investment.
- c) Thermodynamics, fluid mechanics, chemical kinetics analysis package - an analysis of the behavior of geothermal fluids in various process and hardware environments with emphasis

on deposition (scaling), corrosion, erosion, and materials failure. Thermodynamics, heat transfer, fluid mechanics, and chemical kinetics must be integrated in this system. Cycle and process performance of utilization system components is an important adjunct activity which is necessary for generalization demonstration plant and test bed experience.

d) Overall system performance package - A network analysis of overall geothermal system performance including thermodynamic, mechanical, vibrations, and control with reliability analysis and operational data analysis subtasks; useful for demonstration plant experience analysis and generalization.

3) National Geothermal Data Exchange Support
EPRI proposes to provide annual grants in support of the National Geothermal Data Exchange Center. The Data Exchange Center will receive, store, retrieve, and disseminate a comprehensive array of data including geological, hydrological, engineering, financial, regulatory, and environmental matters, relevant to the commercial development of geothermal resources. EPRI will also contribute significant technical data to the Data Exchange Center and

will draw useful information from the Exchange on a reciprocal basis.

f) Schedule and Cost Estimates

1) Schedule

The time schedule for this subprogram, under the recommended program, is presented in Figure III-7. It is intended that subprogram elements 1 and 2 be initiated through the mechanism of RFP's and that both of these elements will be started in the latter part of 1975 with the intent of issuing final reports by the end of 1977. EPRI's contribution to the National Geothermal Data Exchange is scheduled to begin by the end of the first quarter 1975 and to extend indefinitely thereafter.

2) Cost Estimates

a) Recommended Program

The cost estimate for this subprogram, under the recommended program, is presented in Table III-7 which projects an expenditure of \$2,570,000 over the next five years, all of which will be contributed by EPRI.

b) Minimum Program

The cost estimate for this subprogram, under the minimum program, is \$1,570,000 presented in Table III-8 which projects a total expenditure over the next five years of all of which will be contributed to EPRI.

c) The essential difference between these two cost estimates is that the Element 2 budget was reduced by approximately 50%.

GEOTHERMAL SYSTEM AND DATA ANALYSIS
 SUBPROGRAM SCHEDULE
 (RECOMMENDED PROGRAM)

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Assessment of Commercial- ization Requirements, Potential and National R&D Strategies	50	300	200	100	100	750
2. Geothermal Systems Performance, Economic, and Operational Analyses	50	650	600	400	0	1700
3. National Geothermal Data Exchange Support	40	20	20	20	20	120
	—	—	—	—	—	—
ANNAUL TOTALS:	140	970	820	520	120	2570
	—	—	—	—	—	—
EPRI CONTRIBUTION:	140	970	820	520	120	2570

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

GEOTHERMAL SYSTEM AND DATA ANALYSIS SUBPROGRAM

(Recommended Program)

TABLE III-7

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Assessment of Commercial- ization, Potential, Requirements, and National R&D Strategies	50	300	200	100	--	650
2. Geothermal Systems Performance, Economic, and Operational Analyses	--	300	300	200	--	800
3. National Geothermal Data Bank Support	40	20	20	20	20	120
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
ANNUAL TOTALS:	<u>90</u>	<u>620</u>	<u>520</u>	<u>320</u>	<u>20</u>	<u>1,570</u>
EPRI CONTRIBUTION:	90	620	520	320	20	1,570

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

GEOTHERMAL SYSTEM AND DATA ANALYSIS SUBPROGRAM

(Minimum Program)

TABLE III-8

4. Supporting Research and Technology

a) Background

Selection of materials of construction which are compatible with the wide range of geothermal fluids which will be encountered in the commercial development of these resources, requires the testing of materials over extended time periods in the geothermal environment. Obtaining and publishing consistent, credible performance data, and consistent evaluation and interpretation of that data is essential to the selection of materials having long-term compatibility with reactive geothermal fluids.

As indicated in earlier portions of this report, deposition of dissolved solids in the producing formation, the wells, and the mechanical equipment, is a serious operational problem.

Off-the-shelf industrial instruments and electrical equipment are often inadequate when applied to dry steam or hydrothermal systems. This is usually the case because of the incompatibility of the instruments, wiring, contacts, etc. with an H_2S corrosive atmosphere, or the inadequacy of the primary sensing devices when applied to multiphase fluids.

At present, flow-testing hydrothermal wells is restricted to the use of phase separation techniques, which are inherently cumbersome and expensive. Alternatively, the New Zealanders have for some years relied entirely upon the so-called "lip method" (conceived by Mr. Russel James) and which they consider to be adequate for their purposes. In order to conserve both time and cost, it would be desirable to

develop a multiphase, portable fluid flow-meter of sufficient capacity and accuracy to satisfy the requirements of hydrothermal well testing.

Although a considerable amount of theoretical brine chemistry work has been performed, there remain many areas of critical importance to geothermal process work such as brine kinetics, which have not yet been properly investigated or documented. This situation also applies to the thermodynamic properties of complex brine mixtures.

b) Current Status

San Diego Gas and Electric Company, in conjunction with their heat exchanger test facility at Niland (Imperial Valley), has for some time been conducting static material compatibility tests on the brine being emitted from the Niland wells. None of these tests include static stressing or cyclical loading of the material specimens. The general practice has been to insert an array of unstressed specimens in

the geothermal flow stream for an extended period of time, and simply observe the macro or micro effect on these various specimens. This type of test, however, does not reveal in any way the response of the material to a statically stressed condition, and even less so to a dynamically stressed condition.

Presently, industrial instrument manufacturers do not perceive a sufficiently broad and continuing market in the geothermal field to prompt them to undertake a development program aimed at solving the instrumentation problems inherent in geothermal power plant work. This situation is not unique to the instrument manufacturers; such a perception of the geothermal industry has also been expressed by major component manufacturers as well.

Apart from pressure, temperature, and single-phase flow rate, primary sensing elements for other parameters do not have the necessary reliability required in commercial power plant operation.

Presently, very little reliable and sufficiently extensive physical data exist which are definitive of the thermodynamic, dynamic and kinetic properties of complex brines.

c) Major problems

1) Technical/Scientific

To achieve accurate and reliable results in determining the chemical constituents and concentrations of geothermal fluids, it is necessary to rigorously control the sampling methods employed, as well as the analytical techniques applied to the samples. Obviously, obtaining representative samples of fluid from the gross flow stream is essential. Additionally, because of the complex and dynamic nature of the chemical solution, it is necessary to carry out the analytical work as soon as possible after the sample has been obtained. This cannot be achieved unless the analytical equipment and personnel are in close proximity to the wells. This problem immediately suggests the advantages of having a mobile, analytical laboratory designed for this specific purpose.

Investigating the fundamental nature of the kinetics of geothermal fluids, which are simultaneously undergoing phase changes and heat extraction, can also only be achieved in a practical sense in close proximity to the wells. Again, this strongly suggests the need for a mobile analytical facility. Such a facility could be readily moved from well-to-well and field-to-field with minimum expenditure of dollars and set-up time.

The lack of adequately developed and designed industrial instruments for application in geothermal power systems will inevitably inhibit the reliable operation of these plants.

Carry-over of dissolved solids from flashing brines into the turbine casings and other down-stream equipment, impairs the operability, reliability, and economic life of the equipment.

The acquisition of consistent and verified physical data definitive of the compatibility of materials of construction under statically and dynamically stressed conditions is essential in supporting the large scale design of geothermal power plants. At present, methods for obtaining such consistent and verified data have not been standardized.

2) Economic

Not Applicable

3) Environmental

Not Applicable

4) Institutional

Unless the industrial instrument manufacturers can be convinced that there is an extensive and long-term market, or that the developmental risk will be assumed by others, it is unlikely that they will undertake the instrument development program required for geothermal electric power generation.

d) Specific Objectives

This subprogram has been organized for the purpose of achieving the specific objectives cited below:

- 1) In 1975, initiate a continuing program in brine chemistry to obtain chemical kinetics and thermodynamic properties of hydrothermal fluids.
- 2) By the end of the first quarter of 1976, to have completed testing a steam scrubber at the demonstration plant site to provide a backup approach should the heat exchanger scale problem be too severe to permit use of a binary cycle.
- 3) By the middle of 1978, to have a mobile material and fluid test laboratory unit checked out and in operation for conduct of consistent, real time sampling and analyzing of geothermal fluids.

e) Content

This subprogram consists of the following four specific elements:

- 1) Brine Chemistry.
- 2) Flash-steam scrubbers

3) Instrumentation Requirements and Development.

4) Mobile Materials and Fluid Test Laboratory, and Field Test Data Analyses

Brine Chemistry

The Brine Chemistry element of this subprogram will consist of a "level of effort" activity supporting investigations of the fundamental nature of the chemical kinetics and thermodynamics of complex brines. This activity will be conducted in close cooperation with other such studies being carried on by public and private agencies.

Flash Steam Scrubbers

In anticipation of the possible use of a flashsteam energy conversion process in the demonstration power plant, EPRI will undertake a program to design and develop flash-steam scrubbers which are adequate to protect the steam from excessive carry-over of dissolved solids and to enhance the long-term reliability of a power plant employing the flash steam cycle. This investigation will include the

evaluation of various steam separation and steam clean-up methods as applied to the selected field.

Instrumentation Requirements and Development
As an additional element of this subprogram, EPRI will undertake a "level of effort" activity to identify instrumentation requirements, and development needs in the general area of power plant industrial instrumentation, and will provide "seed money" to reputable instrument manufacturers for investigation of one or more key instrumentation problems.

Mobile Materials and Fluid Test Laboratory
EPRI plans to sponsor a project to design, construct, and operate a trailer-mounted mobile test laboratory which will be equipped to conduct the necessary brine chemical analyses, and material compatibility tests on a variety of geothermal fluids. This laboratory would be owned, managed and operated by EPRI. The field services and data analyses which could be processed through it would be paid for by the using utilities on a fee basis.

In addition to providing test and analytical services in the field, the laboratory would provide a consistent data collection service for EPRI's internal use. This latter activity would necessarily have to be negotiated on a case-by-case basis with the using utility. Included in the laboratory management activity will be the development of standard data reporting and analytical procedures. These procedures would be published in the Guidelines Manuals, which would provide leadership to the utility industry in the development of related standards. The types of physical data which would be gathered in the field and analyzed either at the site or at a central point, would include geothermal fluid temperature, pressure, enthalpy, chemical composition and concentration, flow rate, compatibility of materials, and environmental baseline data. As an essential part of this element, EPRI will specify and procure the necessary computer hardware and software to be integrated with the operation of the mobile test laboratory.

f) Schedule and Cost Estimates

1) Schedule

a) Recommended Program

The time schedule for the recommended program is presented in Figure III-8. The flash-steam scrubber investigation will be initiated early in 1975 and completed in 1976, in support of the design activity for the demonstration plant in the event that the flash-steam cycle is selected. Start of the instrumentation development effort and the mobile test laboratory will be deferred until 1976.

b) Minimum Program

The time schedule for the minimum program will be essentially the same as that for the recommended program, except for the deletion of Elements 3 and 4.

2) Cost Estimates

a) Recommended Program

The cost estimate for this subprogram, within the recommended program, is presented in Table III-9, and it

anticipates a total expenditure over the next five years of \$2,310,000, all of which will be contributed by EPRI.

b) Minimum Program

The cost estimate for this subprogram, under the minimum program, is presented in Table III-10, and it anticipates the expenditure over the next five years of \$780,000, which is 34% of that proposed under the recommended program. It will be noted that under the minimum program, the instrumentation development effort, and the mobile materials and fluid test laboratory, have been deleted entirely.

SUPPORTING RESEARCH AND TECHNOLOGY SUBPROGRAM SCHEDULE
(RECOMMENDED PROGRAM)

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Brine Chemistry	75	150	150	150	150	675
2. Flash Steam Scrubbers	80	25	--	--	--	105
3. Instrumentation Requirements and Development	--	50	150	150	100	450
4. Mobile Materials and Fluid Test Laboratory, and Field Test Data Analyses	--	140	430	330	180	1,080
	---	---	---	---	---	---
ANNUAL TOTALS:	155	365	730	630	430	2,310
	---	---	---	---	---	---
EPRI CONTRIBUTION:	155	365	730	630	430	2,310

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

SUPPORTING RESEARCH AND TECHNOLOGY SUBPROGRAM

(Recommended Program)

TABLE III-9

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Brine Chemistry	75	150	150	150	150	675
2. Flash Steam Scrubbers	80	25	---	---	---	105
3. Instrumentation Requirements and Development	---	---	---	---	---	---
4. Mobile Materials and Fluid Test Laboratory, and Field Test Data Analyses	---	---	---	---	---	---
	---	---	---	---	---	---
ANNUAL TOTALS:	155	175	150	150	150	780
	---	---	---	---	---	---
EPRI CONTRIBUTION:	155	175	150	150	150	780

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

SUPPORTING RESEARCH AND TECHNOLOGY SUBPROGRAM

(Minimum Program)

TABLE III-10

5. Advanced Research and Technology

a) Background

With the intent of achieving cooperation and coordination with the federal geothermal R&D program, EPRI is planning to provide both financial and technical support to certain selected federally sponsored projects, which

are or may be undertaken by the National Science Foundation, Atomic Energy Commission, Department of Interior, National Aeronautics and Space Administration, or other federal agency. Potential areas include geopressure field assessment and other advanced concepts.

1) Geopressure

Hydrothermal resources are regarded as the one class of geothermal resource which holds the greatest immediate promise for large-scale, commercial development. The next ranked class of geothermal resource for this purpose is the geopressured zones which are predominantly located along an onshore and offshore belt, roughly paralleling the coast line of the Gulf of Mexico. Other geopressured zones of lesser extent exist in the Anadarko Basin (Oklahoma and Texas), the Rocky Mountain Basin, and the Los Angeles Basin.

2) Direct Contact Heat Exchangers

As a possible means of transferring heat from the raw geothermal brine to a secondary working-fluid on a zero terminal-

temperature-difference basis, the method has been proposed of intimately mixing an immiscible secondary fluids with the geothermal brine. Direct contact of the two fluids gives efficient heat transfer, and natural separation of the two fluids is achieved through the immiscibility. This permits both fluids to exit the heat exchanger at the same terminal temperature, effecting a higher thermodynamic efficiency.

3) Total Flow Concepts

A number of public and privately financed agencies are pursuing the development of several distinctly different total-flow concepts. All of these concepts are of conceptual maturity only. Development of one or more of these concepts to a prototype level may permit possible application to the hydrothermal fluids or fluids from the geopressure zones along the gulf Coast.

b) Current Status

1) Geopressure

To date, a great deal of exploratory and

production drilling has been carried out both on-shore and off-shore along the periphery of the Gulf of Mexico by the oil and gas industry. As a result, there exists a large mass of definitive geological data related to this region, and with it a moderate amount of hydrological information. However, much of this information has not been released publicly.

2) Direct Contact Heat Exchangers

Direct contact heat exchangers have been successfully applied in certain chemical processes but have never been attempted in conjunction with geothermal fluids. Currently, the University of Utah is carrying on an experimental program to evaluate the practicality of this method of heat-transfer, as applied to geothermal brines. The principal investigators in this program are H. R. Jacobs, R. F. Boehm, and W. W. Coates.

3) Total Flow Concepts

The most well defined program currently underway to develop a total-flow method of converting thermal energy to electrical

energy, is being carried on by the Lawrence Livermore Laboratory (Livermore, Calif.) and is funded by the Atomic Energy Commission. Additionally, at least three other distinctly different concepts of total-flow power generation are being developed through undisclosed levels of private funding.

c) Major Problems

1) Technical/Scientific

a) Geopressure

The extent, location, distribution, and long-term energy potential of the Gulf Coast geopressured zones has never been definitively established. An energy conversion process to convert the available energy in geopressured fluids in an efficient, economical way has not yet been developed.

Based on publicly available well data, the predominant energy component within the geopressured fluids is represented by substantial concentrations

of dissolved methane. Therefore, the economic value of these fluids, in terms of generating electric energy, is determined by the concentration of methane. Geopressured reservoirs, having none or only minor amount of methane in solution, will be of doubtful economic value for power production.

b) Direct Contact Heat Exchanger
Obvious technical problems of major importance with respect to direct contact heat exchangers is the possibility of brine salts being absorbed into the secondary working fluids and, thereafter transferred into the rotating mechanical equipment. Also, possible emulsification of the brine and working-fluid would greatly complicate final separation of the two fluids at the end of the heat-exchanger process.

c) Total Flow Concepts

A myriad of developmental problems exists in connection with the practical development of the total-

flow concepts, including the development of reliable and efficient prime movers, and the scaling of these machines up to commercial capacities.

2) Economic, Environmental, and Institutional
Demonstrating the economic viability of commercially developing the geopressured zones must await demonstration of practical total-flow energy conversion processes and equipment.

Development of the geopressured zones on a commercial scale will pose nearly all of the same environmental problems as will be experienced during the commercial development of the hydrothermal resources. The most basic of these environmental problems will undoubtedly be the disposal of massive flows of geothermal liquid waste. Lack of a uniform legal definition of the geopressured resource from state-to-state along the Gulf Coast will inhibit large-scale commercial development of the geopressured zones.

d) Specific Objectives

Since this subprogram is oriented toward advanced technology development, objectives must necessarily be more general than in the other subprograms. Specific Objectives include:

- 1) Completion of a preliminary assessment of the potential of geopressure resources by the end of 1976.
- 2) Complete initial testing of a bench-scale direct contact heat exchanger using hydrothermal brines by the end of 1976.
- 3) Complete development of one promising total flow energy conversion concept at a bench-scale by the end of 1978.

e) Content

This subprogram consists of the following three distinct elements.

- 1) Joint Projects with Federal R&D.
 - a) Geopressure Resource Assessment.
 - b) Others, to be defined.

- 2) Direct Contact Heat Exchangers.
- 3) Total-Flow Concepts

Brief Descriptions of the Subprogram elements follow.

- 1) Joint Projects with Federal R&D

- a) Geopressure Resource Assessment

This subprogram element is a "level of effort" activity designed to augment and accelerate regional reconnaissance studies for the Gulf Coast geopressured resource.

Facies studies will be performed using oil and gas well logs to identify the top of the geopressured zone, to map growth faults and sand formations, to develop cross-section maps of shale and sand formations, to plot subsurface temperature profiles, and to study porosity, permeability, water salinity, and gases in solution.

In addition, detailed geological studies may be performed to further develop knowledge of prospective

well sites in preparation for selecting a specific site for drilling a well to test the resource.

b) Other Joint Projects

Other "level of effort" programs will be defined to provide a direct interface with the Federal Geothermal R&D program by supplying financial and technical support to projects jointly sponsored by EPRI in cooperation with the NSF, AEC, Department of Interior, or other Federal agency.

2) Direct Contact Heat Exchangers

EPRI proposes to support field tests of the heat transfer concept based on direct contact between the geothermal brine and a designer-selected working-fluid, for the purpose of evaluating the potential problems of:

- a) Brine carry-over to the working-fluid,
- b) dissolved salts carry-over to the working-fluid,
- c) brine/working-fluid emulsification,

- d) inadequate separation of the brine from the working-fluid,
- e) fluid flow and heat transfer behavior on a gross basis.

3) Total-Flow Concepts

This element consists of a "level of effort" program designed to monitor, evaluate and directly support the development of one promising total-flow concept during 1976 and 1977, and to support research and development of a second distinct and promising concept during the 1977 and through 1979 period. A possible resource application will be the Gulf Coast geopressured zones.

f) Schedule and Cost Estimates

1) Schedule

The schedule for this subprogram, under the recommended program, is presented in Figure III-9. The geopressured resources assessment element and the direct contact heat exchanger element are scheduled for initiation at the beginning of the

second quarter 1975, and completion by the end of 1976. The total-flow concept element is scheduled to begin with the first quarter of 1976 and continue indefinitely and successively beyond 1979.

2) Cost Estimates

a) Recommended Program

The cost estimate for this subprogram, within the recommended program, is presented in Table III-11. It projects the expenditure over the next five years of \$2,230,000, all of which will be contributed by EPRI.

b) Minimum Program

Similarly, the cost estimate for this subprogram, within the minimum program, is presented in Table III-12 which proposes the expenditure over the next five years of a total of \$1,250,000, all of which will be contributed by EPRI. The recommended subprogram is distinguished from

the minimum subprogram by the deletion of the direct contact heat exchanger element, and the reduction by 50% of the joint projects with the Federal R&D.

ADVANCED RESEARCH AND TECHNOLOGY SUBPROGRAM SCHEDULE
(RECOMMENDED PROGRAM)

(thousands of 1975 dollars)

<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Joint Projects with Federal R&D	150	200	250	300	500	1,400
a) Geopressure Resource Assessment						
b) Others to be defined						
2. Direct Contact Heat Exchangers	50	80	--	--	--	130
3. Total Flow Concepts	--	100	200	200	200	700
	---	---	---	---	---	---
ANNUAL TOTALS:	200	380	450	500	700	2,230
	---	---	---	---	---	---
EPRI CONTRIBUTION:	200	380	450	500	700	2,230

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

ADVANCED RESEARCH AND TECHNOLOGY SUBPROGRAM

(Recommended Program)

TABLE III-11

(thousands of 1975 dollars)						
<u>Subprogram Elements</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>Five Year Total</u>
1. Joint Projects with Federal R&D	150	200	200	100	100	750
a) Geopressure Resource Assessment						
b) Others to be defined						
2. Direct-Contact Heat Exchanger	--	--	--	--	--	--
3. Total Flow Concepts	--	--	100	200	200	500
	---	---	---	---	---	---
ANNUAL TOTALS:	150	200	300	300	300	1,250
	---	---	---	---	---	---
EPRI CONTRIBUTION:	150	200	300	300	300	1,250

EPRI GEOTHERMAL PROGRAM PLAN
FIVE YEAR COST ESTIMATE

ADVANCED RESEARCH AND TECHNOLOGY SUBPROGRAM

(Minimum Program)

TABLE III-12

IV MANAGEMENT PLAN

A. Program Implementation

The scope of the EPRI Geothermal Research and Development Program includes:

1. Design, development, construction, and test of a low salinity, hydrothermal demonstration plant (power level of 25 to 50 Mwe).
 2. Assessment of the potential, requirements and impacts of geothermal development, particularly hydrothermal systems.
 3. A Supporting Research and Technology effort to address key problems in generalizing hydrothermal results from one resource area to another.
 4. An Advanced Research and Technology effort consisting of an orderly program which builds on the present state-of-the-art in hydrothermal resource utilization and carries this through the development of a demonstration plant.
- The demonstration project will be conducted utilizing a phased project implementation approach.

Phase O: Requirements Definition/Preliminary Design.

Phase O is structured to define the specific functional/performance and operational requirements (Feasibility Study) for the demonstration plant, to perform a preliminary design of the demonstration system or system test facility, and to develop specific implementation plans for subsequent phases. The analysis efforts will include, a) detailed site selection, b) conceptual and preliminary design of the demonstration plant, c) identification of key subsystem requirements, policies, or data necessary for detailed plant design and

development, and d) identification of critical procurement long lead-time items. In parallel, environmental baseline data will be collected for preparation of environmental reports for the demonstration plant. In addition, a test program to evaluate reservoir characteristics and heat exchanger performance will be conducted during Phase 0 to establish the feasibility of utilizing the selected hydrothermal resource.

Phase 1: Criteria, Documentation, Specifications.

During Phase 1 criteria for detailed design, fabrication, assembly, and check-out will be written for all hardware and software systems. Experimental demonstration of critical subsystem performance shall be established prior to freezing the demonstration plant detailed design. Sufficient documentation of all hardware and software shall exist to establish the "as fabricated" configuration. A reliability and quality assurance program on all parts, components, materials, and testing shall be in effect. In addition, detailed demonstration plant test plans, including test conditions, procedures, and operations, shall be defined for Phase 2.

Phase 2: Architect/Engineering, Construction, Check-out, Testing

The first portion of Phase 2 shall be initiated in parallel with the Phase 1 system development. This first effort will include architect and engineering for the demonstration plant, site preparation, and construction of permanent facilities. The second portion of Phase 2 includes integration of systems hardware on site, system check-out, and testing. After an

appropriate debugging time, system energy will be delivered to meet load requirements. A test program of at least 1 year shall be included to verify system operating and maintenance performance.

Subsequent phases of commercial implementation beyond the scope of this program include Phase 3, preproduction planning; Phase 4, full scale commercial system design, development, and test; and Phase 5, wide-scale commercialization of system.

B. Organization.

The EPRI Geothermal Energy Research and Development Program will be managed by the Program Manager, Solar and Geothermal Energy. The Program Manager shall have complete authority to implement the program consistent with the policies of EPRI.

The EPRI Program Manager will obtain electric utility inputs and guidance directly through the Solar and Geothermal Program Committee and through direct contact with interested electric utility personnel.

If projects are jointly sponsored by EPRI and an electric utility or electric utility consortium, the specific project management arrangement shall be negotiated between the interested parties and appropriate approvals shall be obtained for such agreements from upper managements of the participating organizations.

C. Major Technical/Programmatic Interfaces.

It is necessary to identify the significant interfaces between the EPRI Geothermal Energy R&D Program and those technical efforts which provide support to various program elements, but which are not administered within the scope of the program. The majority of these program interrelationships will be with the federal R&D program. The definition of these interfaces will allow the identification of a) possible benefits from external R&D efforts, b) information required from sources outside the scope of the program, and c) possible problems arising from modification of these external programs.

These support interfaces necessitate close planning and interfacing to contribute to the successful completion of the affected subprogram elements. It is essential to the EPRI Geothermal Energy R&D Program that related efforts outside the program be quately planned and managed.

1. External

a. Federal Geothermal Program

The Federal Government geothermal program consists of activities underway in three departments or agencies: Recent legislation has authorized participation of a fourth agency and creation of a fifth entity. The following federal agencies are currently active:

- 1) Atomic Energy Commission - The Commission is working through six of its laboratories: Pacific Northwest Laboratory, Los Alamos Scientific Laboratory, Lawrence Berkeley Laboratory, Lawrence Livermore

Laboratory, Idaho National Engineering Laboratory, and Oak Ridge National Laboratory. These efforts range from development of new technology such as total flow energy conversion units to design and development of test beds and 10 Mwe pilot plants to operate with specific hydrothermal resources, particularly Raft River, Idaho; and Buffalo Valley, Nevada.

- 2) Department of the Interior - The Department has geothermal activities in three groups: Bureau of Mines, Bureau of Reclamation, and United States Geological Survey. These efforts range in scope from broad assessment of the geothermal resource potential to specific drilling programs in the East Mesa area of Imperial Valley, California.
- 3) National Science Foundation - The Foundation, through its Research Applied to National Needs Program (RANN) is supporting research in universities, non-profit research organizations, and industry. The Foundation plans to develop regional laboratory facilities at selected geothermal resource sites which will probably include 10 Mwe pilot plants as well as test beds. In addition, they are sponsoring technology development in down-hole pumps for hydrothermal sources as well as exploratory efforts of other geothermal resource types.

In addition to the above active agencies, the Geothermal Energy Research, Development, and Demonstration Act of 1974 authorized:

- 1) Participation of the National Aeronautics and Space Administration in geothermal energy development.
- 2) Creation of a Geothermal Energy Coordination and Management Project.

Interfaces with these two agencies are unknown as the role they will play in geothermal development is undetermined.

b. Electric Utility Programs

To date, the electric utilities in concert with private companies have sponsored or conducted most of the research and development on geothermal resources. The Geysers dry steam field remains the only commercially developed geothermal source in this country, jointly developed by Magma, Thermal Power, Union, and P.G. & E. Research programs are also being sponsored by San Diego Gas and Electric and Southern California Edison at sites in the Imperial Valley, California, by Utah Power and Light, Arizona Public Service, Sierra Pacific, and other electric utilities. In addition, West Associates, the Public Geothermal Resources Development Group, and the Northwest Public Power Council have all sponsored geothermal development efforts or assessed the potential of these resources.

2. Internal

The Geothermal Program will closely interface with the EPRI Advanced Power Generation Group in the areas of organic vapor cycle turbine development and waste heat rejection requirements. The geothermal program will also interface with the efforts in The Energy Systems, Environment and Conservation Division relative to economic analysis and environmental impacts of geothermal plants.

D. Special Boards and Committees.

The EPRI Solar and Geothermal Program Manager will rely on all levels of the EPRI Utility Industry Committee structure to provide guidance toward meeting the specific objectives of the Geothermal Energy R&D Program. In particular, the Solar and Geothermal Program Committee of the Task Force on Advanced Systems will make direct inputs to the EPRI Technical Staff responsible for Geothermal Energy R&D. This advisory function will be performed through the regular committee meetings, through regular, informal contact between the EPRI Technical Staff and the Subcommittee members, and through workshops specifically oriented towards various geothermal energy technology areas.

E. Reviews.

1. Management Reviews

- a) Progress Reviews - Semi-annual progress reviews shall be held on each contract or grant awarded by the EPRI Geothermal Energy Program. The purpose of these

reviews is to 1) define progress and problems encountered in the conduct of each effort relative to planned milestones and cost estimates, 2) establish guidelines for future efforts, and 3) disseminate the results of each effort on a timely basis to the EPRI Geothermal Energy staff and management and to other contractor/grantees. EPRI personnel shall be responsible for scheduling and chairing these reviews; however, EPRI shall invite electric utility representatives and other appropriate individuals to these reviews to assure the technical adequacy of the progress. The EPRI Geothermal Program staff may deem it appropriate to require quarterly or even monthly progress review meetings covering specific topics and involving appropriate contractors or grantees. These provisions will be negotiated with contractors/grantees prior to final award of those specific contracts/grants.

- b) Program Reviews - EPRI may require key contractors/grantees to participate in semi-annual program reviews to discuss overall program status, progress, problems and future plans. These provisions will be negotiated with contractors/grantees prior to final award of these specific contracts/grants.
- c) Major Program Reviews - Major program reviews will be scheduled prior to initiation of any large scale (greater than 5 Mwe) powerplant, pilot or demonstration

project. The low salinity, hydrothermal demonstration plant project is the only project of this type planned in the 1975-1979 time period. Major program reviews shall include at least EPRI and electric utility representatives.

2. Technical Reviews

- a) Design Reviews - The purpose of design reviews is to obtain the independent judgement and recommendations of a senior technical board composed of at least EPRI and electric utility representatives, with regard to preliminary and detailed design of systems and subsystems prior to the commitment of major resources for the procurement, fabrication and assembly of the system/subsystems. The reviews will cover all aspects of the effort, including
 - 1) functional, performance, and operational requirements and specifications,
 - 2) status of critical bench model hardware results,
 - 3) details of the design concept,
 - 4) quality assurance and reliability status and plans,
 - and 5) procurement, fabrication, and assembly planning.

These design reviews shall be applicable to 1) all pacing subsystem research and development efforts which are critical to the design of demonstration powerplants or system test facilities, and 2) demonstration projects.

- b) Preshipment or Acceptance Reviews - The purpose of the preshipment or acceptance review is to obtain the independent judgement and recommendations of a senior technical board composed of at least EPRI and electric utility representatives, with regard to the readiness of a system or subsystem for commitment to a major test program. These reviews will cover all aspects of the system readiness, including
- 1) subsystem/system test results to verify performance and compliance with requirements and specifications,
 - 2) major problems encountered in system testing and associated "fixes" required,
 - 3) status of problem failure reports, with particular attention on any "open" failure reports,
 - 4) reliability and quality assurance program including assessment of the conformance of hardware and testing with requirements and procedures,
 - 5) documentation of the hardware configuration, and
 - 6) details of test plans including test objectives, problem failure reporting system, engineering change control, and field test logistics requirements.

These preshipment and acceptance reviews shall be applicable to systems or subsystems to be integrated into demonstration projects,

- c) Failure Reviews - In the event that failure of a major component, subsystem, or system occurs during the test program, a formal failure review shall be

held. The purpose of failure reviews is to obtain an independent assessment and review of the causes of a system/subsystem failure. The reviews will cover 1) the immediate causes of failure, 2) the proposed corrective action, 3) the impact on the overall system performance, and 4) the impact on the overall EPRI Geothermal Energy R&D Program.

These failure reviews shall be applicable to systems/subsystems which have been integrated into demonstration projects. If, during the research and development effort, key subsystems should become subject to repeated failures of such a fundamental nature that a significant impact on the schedule, cost estimates or feasibility of the system is experienced, failure reviews may also be called to investigate and assess these failures at a subsystem or subassembly level.

F. Documentation

1. Program Plans.

The EPRI Geothermal Energy R&D Program Plan shall be reviewed and updated on an annual basis to incorporate key accomplishments and assess the impact of these accomplishments or problems on future planned efforts, schedules, and cost estimates. This updating shall be conducted by the EPRI staff and reviewed by the Solar and Geothermal Committee of the Advanced Systems Task Force.

2. Reports.

- a) Quarterly - Each contractor/grantee shall be required to submit formal quarterly progress reports summarizing progress, status, and any changes in plans for future work.
- b) Monthly - Informal monthly progress reports shall be submitted, summarizing progress, status, and any major problems.
- c) Technical Completion - Technical Completion reports shall be written and submitted to the EPRI Geothermal staff whenever a major accomplishment has been achieved. Publication of these major accomplishments in the open technical literature is encouraged. These reports should define the objective of the effort, the research and development approach, the specific accomplishment and associated verification data, and the importance or impact to the field.

3. Engineering Data Management.

- a) Hardware - An Engineering Data Management System shall be established to verify and document plant, system, subsystem, and subassembly configurations. The scope of this system shall include at least the following "family of documents":
 - 1) Requirement documents including system functional, performance, and operational requirements, system design requirements, and subsystem design requirements.

- 2) Specifications including subsystem, system and plant detail specifications, system test specifications, and environmental test specifications.
- 3) Standards, including drafting and specification standards.
- 4) Configuration control, including interface control drawings, circuit data sheets, engineering change control procedures and system critical (or indentured) parts lists.
- 5) Test plans and procedures, including system test plan, system test procedures, system test logs, and environmental test specifications, procedures, qualification, and acceptance.
- 6) Safety plans, including analysis, results and procedures.
- 7) Training plans for assembly, handling and operating personnel.

This Engineering Data Management requirement shall be applicable to all hardware systems/subsystems/subassemblies which will be integrated into powerplant demonstration projects. All or any of these requirements may be deemed appropriate for key subsystems, during the research and development program. Should that be deemed necessary, appropriate provisions shall be specified in contractual agreements.

- b) Software - A Software Data Management Control System shall be established to verify and document computer

program design, check-out, and maintenance. The scope of this system shall include at least the following documents: 1) computer program flow sheets, 2) log of computer program verification, 3) punched card and magnetic tape indexing and inventory procedures, and 4) computer program change control procedures and approvals.

This Software Data Management Control requirement shall be applicable to all software, generated under the EPRI Geothermal Program. Prospective contractors/grantees shall demonstrate their ability to meet this requirement in proposals and shall be responsible for verifying that these controls have been utilized.

G. Quality Assurance and Reliability (QA&R)

Quality assurance and reliability assurance plans shall be prepared in accordance with specific project requirements. These plans shall include a) the identification of major reliability/quality aspects of the hardware and rationale for the particular QA&R approach taken, b) a list of all governing documents to be utilized in design on controlling the system configuration, c) the specific QA&R activities to be undertaken, and definition of the levels of inspection, workmanship standards, and worst case analysis to be utilized, d) failure mode analysis requirements and approach, and e) the procedures to be utilized in inspection and reliability assurance programs.

H. Procurement

The primary procurement mode to be utilized in the EPRI Geothermal Energy R&D Program will be competitive procurements in response to EPRI generated Request for Proposals or Program Solicitations. This approach will assure that qualified contractors are given an opportunity to bid on major project activities. If it is deemed in the best interest of EPRI, or if an outstanding capability exists with a single contractor, EPRI may award contracts on a sole-source basis. Unsolicited proposals will be considered only in limited cases, and these proposals should be in areas consistent with the EPRI Geothermal Energy R&D Program Plan.

V COMMUNICATION/DISSEMINATION OF RESULTS

A. Within the Geothermal Community

The federal government has been sponsoring an increasing number of ad hoc symposia or workshops in geothermal energy. EPRI participation in these meetings has been welcomed and serves as a means to publically exchange viewpoints on geothermal development.

In addition, EPRI has been requested to serve on a Federal Government-Industry Geothermal Liaison Group to increase communications between the federal and private sectors.

Information is also exchanged within the geothermal community by exchange of the periodic progress reports required of each contractor by the sponsoring agency.

B. To Utility Industry

Formal communication with the utility industry is maintained by regular contact between the EPRI staff and its Utility Industry Committee structure. One Geothermal Energy Workshop has been held under EPRI sponsorship, and others may be planned as the need arises. Some individual contractors also maintain working agreements with individual utilities (or groups of utilities) outside the EPRI structure.

Informal communication between the EPRI staff and utilities occurs continuously through telephone contact, letters, and personal contacts at a variety of industry-oriented meetings.

C. With Other R&D Programs.

At present, no formal means of communication exists between the geothermal energy field and the research and development efforts in other supporting disciplines. This situation is due primarily to the fact that geothermal energy applications development has only begun to grow rapidly in the past 2 to 3 years. However, the interdisciplinary nature of the current effort practically guarantees that individual workers maintain a cross-flow of information between their respective fields and geothermal energy and EPRI can provide a common meeting ground for such exchanges.

APPENDIX A

Key Issues to be Considered in the Development of Geothermal Resources and Power Systems

I. Operational Issues

A. Function

1. Electrical Load
 - a. Base
 - b. Intermediate
 - c. Peaking
 - d. Emergency
2. Non-electrical Uses
 - a. Industrial process heat
 - b. District Heating
 - c. Miscellaneous Uses

B. Performance

1. Economic
 - a. Capital costs
 - b. Operating and maintenance costs
2. Technical
 - a. Resource
 - b. Electrical and thermodynamic
 - c. Operational
 - i. cycling
 - ii. partial load
 - iii. load factor
 - iv. startup and shutdown
 - 1.) routine
 - 2.) emergency
 - d. Long-term service
 - i. corrosion and scaling
 - ii. materials
 - iii. deterioration of electrically-actuated systems
 - 1.) control
 - 2.) monitoring
 - 3.) protection
3. Environmental
 - a. Effluent Release
 - b. Subsurface Alteration
 - i. seismic induction
 - ii. subsidence
 - iii. aquifer drawdown & contamination
 - c. Noise
4. Institutional (manufacturing industry)
 - a. Critical materials availability
 - b. Fabrication capacity
 - c. Critical equipment availability
 - d. Personnel availability
5. Major External Interfaces
 - a. Integration into grid
 - b. Integration into water and/or gas distribution systems
 - c. Margin requirements and reliability

6. Safety
7. Training
 - a. Simulation
 - b. On-site

II. Institutional Issues

- A. Legal/Regulatory
 1. Uniform definition of resource
 2. Multiplicity of Regulatory Agencies
 3. Multiplicity of permits required
 4. Resource rights and ownership
 5. Tax policy
 6. Enforcement and Compliance
- B. Economic
 1. Market competitiveness
 2. Net energetics of total system
 3. Financial resources availability
 4. Federal financing provisions
 - a. Loan guarantees
 - b. Subsidies
 5. Cost/benefit analysis
- C. Environmental
 1. Aesthetic values
 2. Intervention by environmentalists
 3. Cost/benefit analysis
 4. Standards
 5. Public Safety
- D. Miscellaneous
 1. Geographic distribution of resources
 2. Fragmentation of geothermal R & D efforts
 3. Skilled personnel availability
 4. Centralized Data Bank

III. System Issues

- A. Resource Types and Distributions
 1. Vapor-dominated hydrothermal
 2. Liquid-dominated hydrothermal
 3. Hot-dry rock
 4. Geopressured
 5. Magma chambers
 6. Salt domes
 7. Normal gradient
- B. Reservoir Prediction and Production
 1. Geological exploration and assessment
 2. Geological models
 3. Reservoir engineering
 4. Reservoir development and production

- C. Gathering system
 - 1. Fluid State
 - a. Single-phase
 - b. Multiple-phase
 - 2. Aesthetic Design
 - a. Surface
 - b. Buried
- D. Power Conversion Systems
 - 1. Flashed steam process
 - 2. Bi-fluid process
 - 3. Total flow process
- E. By-product recovery
 - 1. Solids in solution
 - 2. Non-condensable gases
 - 3. Potable water
- F. Waste Disposal Systems
 - 1. Liquids
 - 2. Solids
 - 3. Non-condensable gases
- G. Major internal system interfaces
 - 1. System protection
 - 2. System control
 - 3. System performance
- H. Major external system interfaces
 - 1. System protection
 - 2. System control
 - 3. System performance

I Operating Modes

IV. Subsystem Issues

- A. Exploration Subsystems
 - 1. Exploration product packages
 - a. Standardized designs
 - b. Standardized input/output formats
 - 2. Improved and standardized methods
 - 3. Data interpretation
 - a. Interpretation and evaluation of individual methods
 - b. Weighted consensus of individual methods
- B. Reservoir Development Subsystems
 - 1. Drilling technology
 - a. Rotary methods
 - i. production drilling bits
 - ii. coring bits
 - b. Advanced methods
 - i. erosion
 - ii. melting

- c. Lubricant, coolants, and chip-removal media
 - i. muds
 - 1.) natural
 - 2.) synthetic
 - ii. fluids
 - 1.) water
 - 2.) air
 - 3.) synthetic
- d. Pack-off seals, valves
- e. Well logging methods, formation sampling
- f. Fluid sampling, metering, and separation
- g. Heat shields and lubricant cooling
- h. Drilling and blowdown silencers

2. Well systems

- a. Reservoir formations
 - i. deposition plugging
 - ii. siltation plugging
- b. Casings
 - i. materials selection
 - ii. corrosion and scaling
- c. Cements
 - i. high temperature setting
 - ii. chemical breakdown
- d. Completion technology
- e. Reservoir monitoring
 - i. downhole and formation
 - ii. data analysis

3. Well stimulation

- a. Hydrofracturing
- b. Leaching
- c. Thermal fracturing
- d. Explosive fracturing

C. Gathering Subsystems

1. Pipeline Systems

- a. Hardware
 - i. bends
 - ii. valves
 - iii. traps
 - iv. expansion loops
- b. Critical flow performance
- c. Protection systems
- d. Corrosion and scaling
- e. Optimization
- f. Energy conservation

2. Downhole pumps

- a. Corrosion, scaling, and cavitation
- b. Design criteria
 - i. seals
 - ii. bearings
 - iii. lubricants
 - iv. insulation
- c. Downhole power transmission

- D. Flash/Separator Units
 - 1. Physical principles
 - a. Nozzle
 - b. Chamber
 - 2. Mechanical design
 - a. Materials Selection
 - b. Number of stages
 - 3. Solids deposition control
 - 4. Separation of fluid phases
- E. Steam Cleanup Units
 - 1. Physical principles
 - 2. Materials selection and design
 - 3. Energy losses
- F. Heat Exchangers
 - 1. Performance degradation by solids deposition
 - 2. Corrosion
 - 3. Materials selection
 - 4. Design configurations--self-cleaning
- G. Prime Movers
 - 1. Mechanical configurations
 - a. Reaction turbines
 - b. Impulse turbines
 - c. Bladeless turbines
 - d. Positive displacement machines
 - 2. Design considerations
 - a. Sealing and corrosion
 - b. Self-cleaning functions
 - c. Materials specification
 - d. Subcomponents
 - i. blades
 - ii. seals
 - iii. bearings
 - e. vibration, wear control
 - 3. Auxiliary subsystems
 - a. Speed/frequency regulation
 - b. Overload control
- H. Condensers
 - 1. Corrosion, sealing control
 - 2. Thermal performance
 - 3. Non-condensable gases and vacuum state
- I. Effluent Control Systems
 - 1. Non-condensable Gases
 - a. Condenser exhaust, condensate
 - b. Well blowdown, cleanout, and bleed-out
 - c. By-product recovery
 - i. methane
 - ii. helium
 - 2. In-solution Solids
 - a. Condenser condensate
 - b. Cooling tower blowdown bitters
 - c. Well blowdown, cleanout, and bleed-out
 - d. By-product recovery
 - e. Desalination of water

3. Radioactivity
 - a. Non-condensable gases
 - b. Solids
4. Physical Principles for separation
 - a. Precipitation
 - b. Pond settling
 - c. Scrubbing
 - d. Electrolytic
 - e. Catalytic
 - f. Flocculation
5. Effluent Disposal Methods
 - a. Burial
 - b. Reinjection
 - c. Industrial utilization
 - d. Burning

J. Instrumentation

1. Control, Monitoring, and Protection
 - a. Sensors, probes
 - i. fluid flow rate
 - ii. fluid composition (chemical)
 - iii. fluid enthalpy
 - iv. solids deposition
 - b. Interfaces (between sensors, probes and controllers, monitors, protectors)
 - i. digital
 - ii. analogue
2. Calibration and Standards

V. Testing

- A. Resource Exploration and Assessment Methods
 1. Calibration of existing methods using known reservoirs
 2. Testing new methods during development
 3. Comparison of newly-developed methods with proven methods
 4. Development of methods to evaluate a resource consensus based on individual exploration methods.
- B. Wells
 1. Production Wells
 - a. Fluid production rates (flow-rate vs. well-head pressure; initial tests plus long term monitoring)
 - b. Thermal characteristics (bottom-hole & well-head temperature; mean specific enthalpy; initial test plus long-term monitoring)
 - c. Chemical properties (liquid and gas sampling with chemical analysis)
 - d. Intra-field wells flow correlation tests.
 2. Reinjection Wells
 - a. Inflow rate as a function of pump power (initial test plus long term monitoring)
 - b. Tracer injection to prove flow course.

- C. Down-hole pumps (high temp.)
 - 1. Electrical component durability
(Cable insulation, motor windings)
 - 2. Mechanical component durability
(Seals, bearings, lubricants, impellers)
 - 3. Performance (Pump efficiency, cavitation, head vs. flow-rate)
- D. Heat Exchangers
 - 1. Scale deposition (scale build-up rate, i.e. mean thickness as a function of time for fixed T,P,Q)
 - 2. Scale removal (by mechanical, hydraulic, and chemical means)
 - 3. Scale prevention (by additives, special non-adherence surfaces, etc.)
 - 4. Scale composition (sample and analyze)
- E. New Prime-movers
 - 1. Proto-type testing (component durability & engine efficiency; wide range of geoth. fluids.
 - 2. Production units (engine efficiency by std. ASME engine performance tests)
 - 3. Reliability (long-term runs, performance tests & tear-down)
- F. Novel Processes
 - 1. CaCO_3 deposit suppression by CO_2 injection
 - 2. H_2S removal by combustion
 - 3. H_2S control by chemical additives
- G. Materials Compatability
 - 1. Corrosion coupons installation & monitoring
 - 2. Vessel and Pipe walls corrosion rates (long-term measurements)
 - 3. Testing for H_2 embrittlement and intergranular corrosion of turbine blades
- H. Phase separation
 - 1. Steam scrubbing versus energy degradation
 - 2. Liquid & particulate carry-over prevention versus energy degradation
- I. Multiphase Flow
 - 1. Development of gathering system design criteria
 - 2. Calibration of methods for measuring and monitoring multiphase fluid flow rates and contents.
 - 3. Behavior of multiphase fluids in prime-mover systems
- J. Instrumentation
 - 1. Development of standards for calibration of instrumentation
 - 2. Calibration of new and existing instrumentation
 - 3. Testing of proposed instrumentation principles and techniques.

VI. Materials and Component Selection and Qualification

A. Components

1. Well casings
 - a. Linings
 - b. Protective coatings
2. Valves
 - a. Seats
 - b. Cases
 - c. Trims and Controllers
3. Gathering and Piping Systems
 - a. Flow indicators
 - b. Traps
4. Downhole pumps
 - a. Impellers
 - b. Casings
 - c. Seals
5. Flasher/Separator
 - a. Vessels
 - b. Internals
 - i. metals & alloys
 - ii. ceramics
6. Steam Cleanup Units
 - a. Vessels
 - b. Internals
 - i. metals & alloys
 - ii. ceramics
7. Heat Exchanger Tubes
 - a. Alloy selection after coupon tests
 - b. High thermal conductivity coatings
8. Turbines
 - a. Blades
 - b. Casings
 - c. Bearings
 - d. Seals
9. Pumps
 - a. Casings
 - b. Impellers
 - c. Trim
 - d. Drivers
10. Flow Sensing (measurement) Elements
11. Electrical Contactors & Conductors
 - a. Contact surfaces
 - b. Actuators
 - c. Insulators
12. Secondary Working Fluids

B. Materials

1. Selection

- a. Lifetime and replacement frequency
- b. Economics

2. Degradation Control
 - a. Corrosion
 - i. alloy usage
 - ii. design configuration
 - iii. isolation
 - b. Erosion
 - c. Cavitation
3. Secondary Working-Fluid Specification
 - a. Cost
 - b. Toxicity
 - c. Transport/Transfer
 - d. Thermo-chemical stability

APPENDIX B

ON THE GENERALIZATION OF THE TOTAL EXPERIENCE OF A 50 MWe HYDROTHERMAL RESOURCE DEMONSTRATION PLANT TO COMMERCIAL UNITS OF 100-200 MWe

Geothermal energy resources occur with a wide range of properties which, at a particular site, are dependent on the geology, hydrology, and mineralogy of that particular reservoir. Even for the hydrothermal (or hot water) subcategory of the resource there exists a wide range of resource properties. It is natural, then, to ask the question - "How can the experience obtained from a 50MWe hydrothermal resource demonstration plant at a particular site be generalized to provide the design basis for commercial units of 100-200 MWe capacity to be installed at other sites?" The answer to this question obtains from a systems analysis of a hydrothermal resource power plant.

For the purposes of discussing the generalization of demonstration plant experience, the geothermal power facility can be divided, Figure B-1, into two major subsystems - the "Site-Sensitive," the "Reservoir Sensitive," and the "Site-Insensitive" subsystems. In what follows, "reservoir sensitive" means that the principles of fluid mechanics, thermodynamics, chemical kinetics, and mechanics alone cannot be used to scale-up the site of the subsystem or to adjust for different reservoir fluid property input data. Instead, experiments need be conducted to account for effects arising from the changed reservoir fluid properties.

FIGURE B-1: SKETCH OF SIMPLIFIED GEOTHERMAL POWER FACILITY

The Reservoir Sensitive subsystem can be further subdivided into those components which belong to the power plant and those which are part of the fuel system. This division line is part of the plant boundary; the fuel (steam, hot water, or a mixture of the two) is delivered at the boundary by the gathering system. Each reservoir sensitive component is discussed below:

A. Fuel Side of Plant Boundary:

1. Reinjection System

- a. Disposal - The demonstrated process for disposal of fluids in shallow levels of sedimentary basins can be generalized using brine chemistry, chemical kinetics, reservoir engineering, and test bed experience at the particular reservoir under consideration. Porosity, rather than rock hardness, will be the controlling rock mechanics parameter.
- b. Subsidence Control - The demonstration of subsidence control in shallow levels of sedimentary basins will only be transferable to similar geologic regimes; demonstration for hard, fractured rock regimes will require further experimentation.

2. Down-hole pumping to suppress deposition in heat exchanger (binary process plant) - Demonstrated deposition suppression technique will be transferable using brine chemistry, chemical kinetics, and test bed results providing a down-hole pump suitable for operation at depths greater than 1000 feet is developed.

B. Plant Side of Plant Boundary:

Energy Extraction Interface

1. Flash-Steam System

- a. Flash units - Demonstrate the economics of applying this technology in the U. S.
- b. Steam Scrubbers - Demonstrate the technology of removing carry-over material contained in flash-steam and the losses of available energy in the scrubbing process. Knowledge of brine chemistry, chemical kinetics, and aerosol technology combined with test bed experience should allow transfer to other hydrothermal resources.

2. Hydrocarbon Working Fluid Process

- a. Heat Exchanger
 - i. Scaling (deposition) - demonstrate solution to the scaling problem by pumping the fluid and using the pressure variable to control the chemical kinetics (see down-hole pumps); transfer using chemical kinetics, brine chemistry, and test bed results.
 - ii. Corrosion - Demonstrate solution to corrosion problem using materials selection, etc. Corrosion effects are sensitive to fluid composition and must be solved using a test bed operation at each site.
- b. Secondary Fluid - Demonstrate the application of hydrocarbon turbines in scaled-up sizes. This "site-sensitive" technology is readily transferable using the heat exchanger primary side fluid entrance state, primary and secondary fluid properties, and the principles of thermodynamics and mechanics to design the working fluid cycle.

One of the most important "site-sensitive" components of the powerplant are those associated with the condenser and cooling

water systems. Many geothermal systems will be located in arid areas so that make-up water for the condenser may have to come from the reservoir fluids or from flash-steam condensate. However, these considerations can be generalized using engineering principles and physical laws. The "site-sensitive" components may well have environmental impacts that only study of a specific site can solve.

Conclusion:

The demonstration plant experience should allow the design of commercial hydrothermal powerplants for various hydrothermal resources. Reservoir-sensitive and Site-sensitive components will be designed using engineering principles plus the results of test bed experiments investigating deposition, pumping, and corrosion phenomena. Engineering principles alone should allow design of site-sensitive components. The latter components represent the major portion of the capital investment in the powerplant. The well-field costs must be taken as fuel costs; the technology adaptation cost necessary to produce the well-field and gather the fluid also appears as a fuel cost. Demonstration plant economics experience, appropriately adjusted, allows making an informed decision concerning hydrothermal resource commercialization.