THE DEFINITION OF ENGINEERING DEVELOPMENT AND RESEARCH PROBLEMS RELATING TO THE USE OF GEOTHERMAL FLUIDS FOR ELECTRIC POWER GENERATION AND NONELECTRIC HEATING

Apps, J.A.

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J. A. Apps

November 1977

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THE DEFINITION OF ENGINEERING DEVELOPMENT AND RESEARCH PROBLEMS RELATING TO THE USE OF GEOTHERMAL FLUIDS FOR ELECTRIC POWER GENERATION AND NONELECTRIC HEATING

J. A. Apps

I. INTRODUCTION

A. Background and Scope

The use of geothermal fluids for electric power generation and nonelectric purposes causes problems not normally encountered when pure water is used for similar purposes. These problems must be identified and means developed to overcome them before geothermal energy resources can become an important source of electric power or thermal energy in the United States.

The purpose of this report is to list research and development projects aimed at solving those problems arising from the use of geothermal fluids from known sources in the United States.

Problem areas covered are:

- Impact on engineering design caused by chemical, thermodynamic, and transport properties of geothermal fluids;
- Scaling and sludge formation;
- Gases, volatile brine constituents, condensate chemistry;
- Environmental problems.

Other areas such as the corrosion and erosion of materials and the development of new materials for plant and well construction are not discussed in this report.

The research projects identified are general in nature and are not site specific. The development of geothermal resources in the United States is still at a preliminary stage, and available information about the resources is insufficient to predict site specific problems with certainty.

B. Objectives

This report forms the basis of the organization of a national program plan. Its goal is to quicken the exploitation of domestic sources of geothermal energy. The goals of the program would be:

- Definition of potential problems and reduction of risk;
- Determination of the best design for any given field;
- Reduction of capital costs for plant and ancillary equipment and the extension of plant life;
- Improvement of plant reliability and reduction of routine maintenance;
- Reduction of environmental problems.

Secondary goals would include:

- Effective use of waste heat;
- Generation of revenue from geothermal fluid by-products (e.g., salt, potash, nonferrous metals, etc.) and from the production of fresh water.

This report may be used to develop and implement a national plan as outlined in Section V. However, other strategies may be adopted which would lead to an equally effective outcome.

C. Acknowledgments

This report is essentially one person's view of the subject matter. It is not without unconscious bias. In order to ensure that the areas specified are adequately covered, it is advisable to seek the professional assessment of a team of experts whose collective judgment would

minimize bias, inconsistencies, errors, and omissions. The writer would like to acknowledge the critical reviews of drafts of this report and constructive suggestions made by Drs. A. J. Jelacic, R. E. Oliver, R. R. Reeber, and L. B. Werner, all of DOE/DGE; Dr. O. Weres of LBL; and Dr. O. Vetter of Vetter Associates. However, responsibility for the contents of the report rests with the author.

II. ORGANIZATION OF THE REPORT

The task of identifying pertinent research and development projects addressing the problem areas specified in the Introduction requires consideration of many factors. A flow chart is presented in Figure 1 showing the impact of each factor in a logical sequence.

The task is accomplished in three Stages, discussed in Sections III, IV, and V.

Stage 1: Characterization of Geothermal Fluids (Section III)

- Identification of geothermal resource types and classification of geothermal fluids. (Section IIIA)
- Identification of geothermal fields most likely to be exploited in the near term, and the characterization of geothermal fluids from these fields. (Section IIIB)

Stage 2: Program Definition (Section IV)

- Identification of engineering problems resulting from the use of geothermal fluids in each fluid class. (Section IVA)
- Categorization of research and development projects relating to the four problem areas considering the energy conversion systems most likely to be used for each class of geothermal fluid. (Sections IVB and C)

Stage 3: Program Implementation (Section V)

- Development of a program plan. (Section VA)
- Implementation of the program. (Section VB)

The various factors included in each Stage are indicated by a series of matrix charts, the output of one chart serving partly as the input for the next. The first part of Stage 1 (Sections IIIA1-2) involves the classifi-

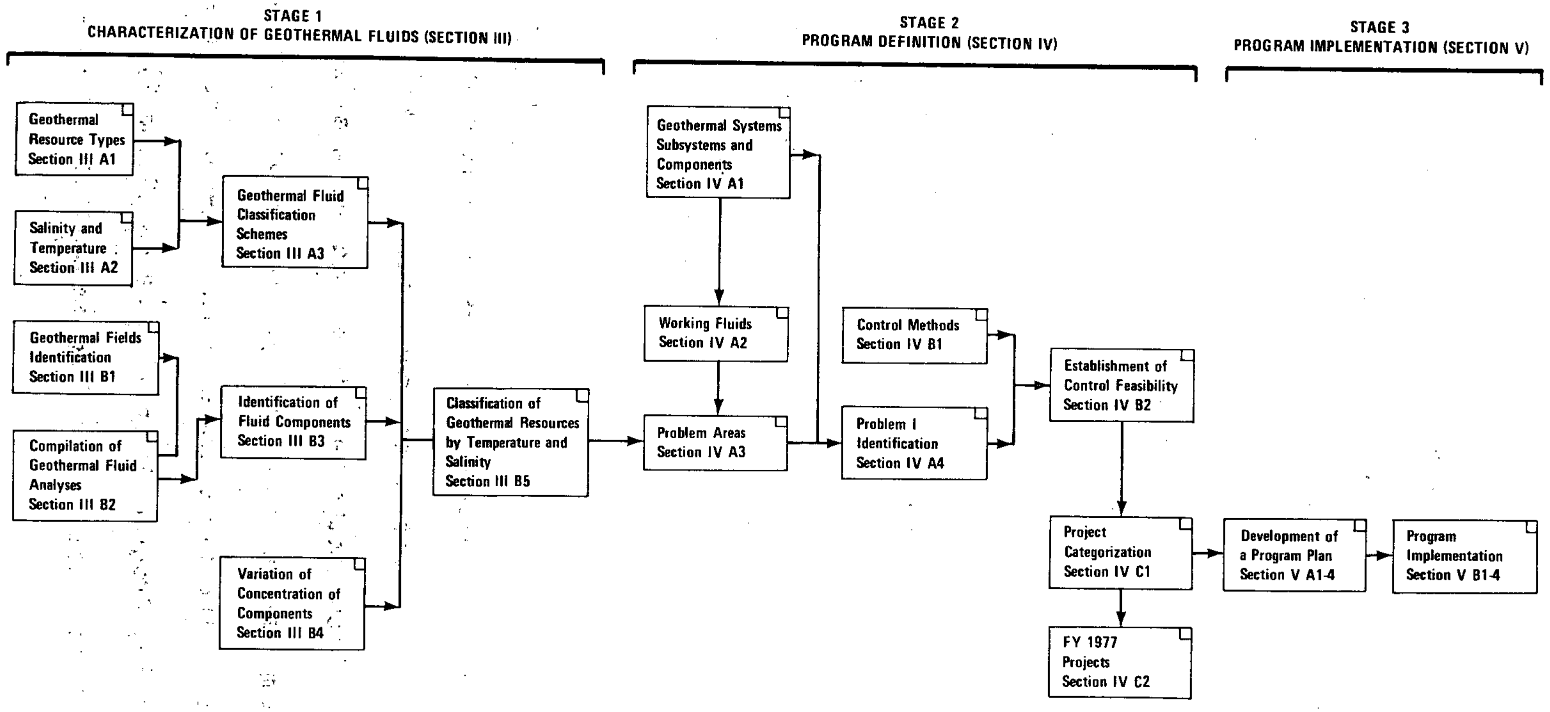

FIGURE 1. FLOW CHART TO SHOW THE ORGANIZATION OF THIS REPORT.

XBL 783-498

cation of geothermal fluids on the basis of geothermal resource types, salinity, and temperature. In the absence of more definitive studies, a professional assessment had to be made as to which geothermal resource types would be most likely to be exploited in the near term (~ 10 years). The next part (Section IIIB1), the identification of geothermal sites, is based primarily on a selection from the listing given by White and Williams (1975). Sites from the listing are restricted to a minimum size of 10^{18} calories and a minimum temperature of 90°C. Other criteria, limiting the choice of sites still further, such as distance from population centers, chemistry, the impact of temperature on well costs, etc., are discussed but not investigated because of the need for extensive study of each site.

The remaining parts (Sections IIIA3 and IIIB2-5), involving the characterization and classification of geothermal fluid compositions from the sites selected previously, are also incomplete. However, preliminary estimates of the distribution of critical components have been made. A separate project (Section IIIB2) has been completed in which geothermal fluid data from the selected sites has been compiled in a computer file. A report tabulating all data compiled will be released shortly (Cosner and Apps, 1978). Further evaluation of these data is continuing, and an LBL report on the characterization of geothermal fluids will be released early in 1978. Sites for which geothermal fluid data are available are classified according to temperature and salinity. This classification, when combined with a knowledge of the fluid composition range of that class, serves as input for the following Program Definition Stage (Stage 2).

The first part of the Program Definition Stage (Sections IVA1-3) compares the geothermal fluid composition range for each class with the geothermal plant system components in order to identify specific problems which would arise from the use of such geothermal fluids. Analogous problems are collected together and used as input for the next part (Section IVA4) which involves verification of research projects. Here (Section IVA4) the output from the previous part (Section IVA3) is compared with control methods (Section IVB1) in a matrix chart in order to determine control feasibility (Section IVB2). The output from this chart (Section IVB2) forms the basis for defining research projects (Section IVC1) needed to solve problems relating to the use of geothermal fluids at selected sites in the Unites States. The proposed research projects (Section IVC1) are tabulated together with FY 1977 projects (Section IVC2) already addressing some of the problems identified.

Although the work organization results in a comprehensive list of potential projects, it is not without problems of its own. These are listed here so that the reader might appreciate the reasons behind the decisions made in compiling this report.

(1) The information on geothermal sites in the United States is currently sufficient to determine neither the order in which they will be exploited nor their relative importance to the attainment of significant exploitation of geothermal energy. However, a recent study by Reitzel (1976) has been made of the economics of exploiting for power generation those geothermal resources listed by White and Williams (1975). Reitzel's study does allow some intelligent guesses to be made as to which resources show most promise at this time.

The implementation of projects proposed in this report may result in significant technical advances which may alter the order in which the resources will be developed. In order to provide the best estimate of the relative importance of geothermal sites, a research effort is required that is beyond the scope of this report and inconsistent with the time restrictions imposed for its completion.

(2) Information on the composition of geothermal fluids at sites in the United States is difficult to obtain and of variable quality. As indicated on page 5, a separate project has been completed in which currently available information has been compiled. Much of the data from geothermal sites which have been drilled is proprietary and usually confidential. Without such information, it is difficult to implement research projects which address site specific problems. Hence the reason for a general approach.

(3) It is questionable whether the chemical analysis of a geothermal fluid is sufficient to identify the problems resulting from the use of that fluid. Persuasive arguments might be advanced in support of direct implementation of tests in the field to identify problems associated with a particular geothermal fluid, rather than attempt to predict problems on the basis of brine composition ranges in any particular class.

(4) The matrixing process used in this study is difficult to implement because of the numerous options which result. Many decisions must be made which are necessarily based upon insufficient background information. Therefore, the bases for the decisions are professional assessments rather than in depth evaluations.

(5) The method used does not permit easy incorporation of problems intrinsic to the use of geothermal fluids in geothermal plants (i.e., problems relating to the need to design for the use of a fluid which differs from pure water in its physical, thermodynamic, and transport properties.

In spite of these difficulties, research and development projects tabulated in this report should serve as a useful basis for the formulation of research plans to solve problems relating to the use of geothermal fluids in geothermal plants.

III. CHARACTERIZATION OF GEOTHERMAL FLUIDS

The objective of this Section is to define the concentration ranges of components in geothermal fluids which are most likely to cause operating problems in geothermal plants. Resources considered are those which should be exploited for geothermal energy within the next ten years. The objective is accomplished through:

(A) A geothermal fluid classification scheme based on resource type, salinity, and temperature.

(B) Characterization of the geothermal fluids as a function of temperature and salinity through:

1. Identification of geothermal hot water resources most likely to be exploited.
2. Compilation of analyses of geothermal fluids.
3. Identification of deleterious geothermal fluid components.
4. Establishing the variation of concentrations of geothermal fluid components as a function of temperature and salinity
5. Classification of geothermal resources by temperature and salinity.

A decision chart leading to the characterization of geothermal fluids in relation to their use in geothermal systems is shown in Figure 2. This chart serves as a ready reference to the detailed description which follows.

A. Geothermal Fluid Classification

1. Resource types

Five types of geothermal resources have been identified and are being considered as potential sources of energy or heat. These five types are listed below in decreasing order of probable exploitation:

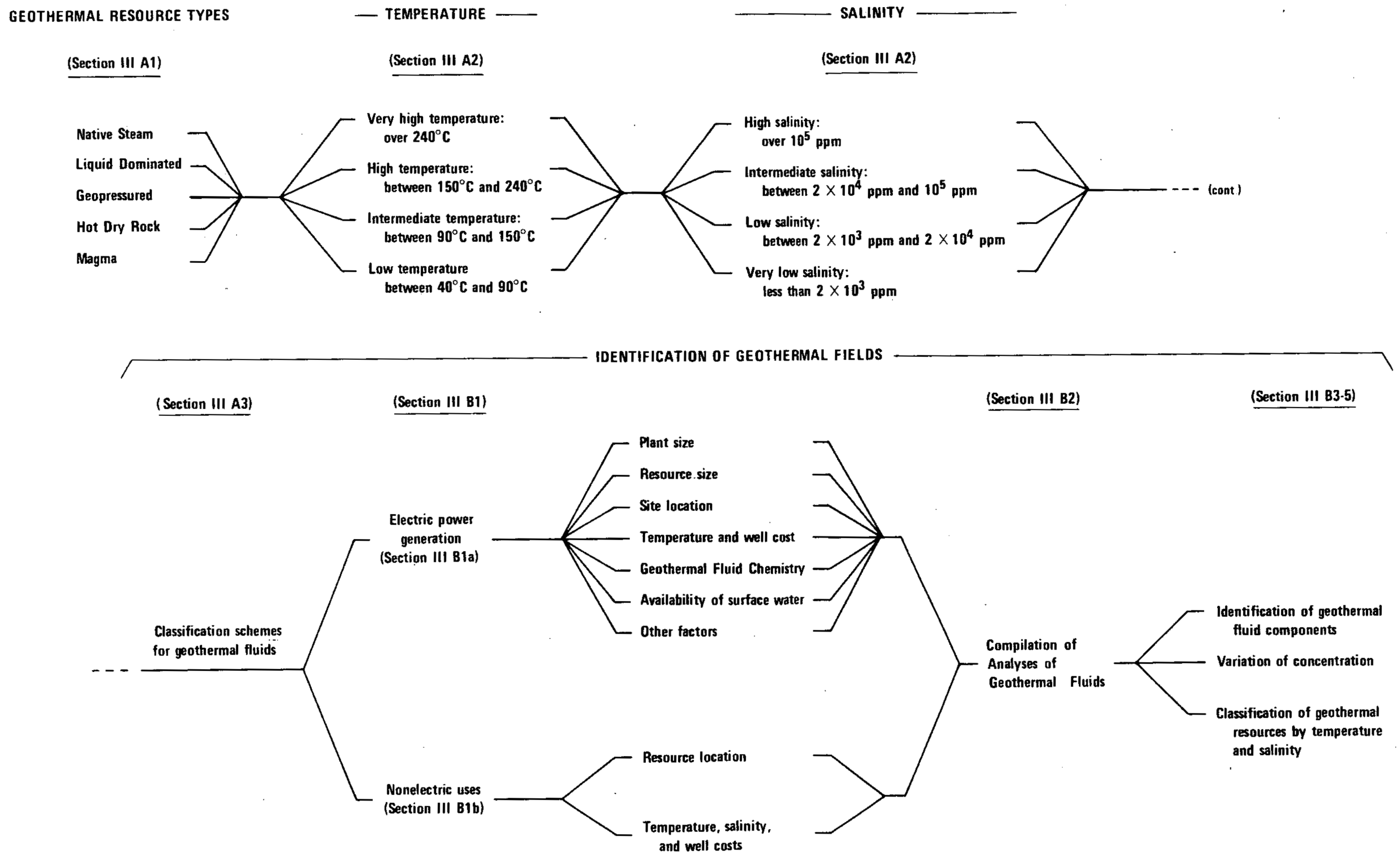

FIGURE 2. DECISION CHART LEADING TO THE CLASSIFICATION OF GEOTHERMAL FLUIDS IN RELATION TO THEIR USE IN GEOTHERMAL SYSTEMS.

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- Native steam
- Liquid dominated
- Geopressured brine
- Hot dry rock
- Magma

No consideration is given to normal gradient resources in this report.

Native steam resources are rare but simple to exploit. The Geysers in California is the sole known representative of this class in the United States not located in national parks.

Liquid dominated resources have been identified and explored in many locations in the western United States. Although no domestic liquid-dominated resources have been exploited, the geothermal field at Cerro Prieto in Baja California, Mexico, is producing electric power and expanded production is planned. Fluids from liquid-dominated resources vary widely in temperature and salinity; hence further classification of such resources on the basis of these two parameters is necessary.

Geopressured resources are found primarily in the Gulf Coast. Brines from such resources usually have moderately high salinity and contain dissolved methane. Geopressured brines are under consideration as a geothermal resource but are not yet ready for commercial exploitation.

Hot dry rock and magma sources of geothermal energy have long-range potential. Commercial exploitation of such resources is not being considered at this time, although research and development projects relating to these sources are being actively pursued at the Los Alamos Scientific Laboratory and at Sandia Laboratories. Because of the short range nature of this program, this report will henceforth be concerned primarily with liquid dominated resources.

2. Salinity and temperature

Geothermal fluids contain dissolved solids ranging from less than 1000 ppm to over 250,000 ppm. Salinity affects both the thermodynamic and the chemical properties of the fluid. Salinity is therefore an important variable in considering the problems associated with the use of geothermal fluids in both electric power generation and nonelectric applications.

Geothermal fluids are subdivided into four salinity ranges. These ranges approximate the commonly used salinity classifications of geothermal fluids, such as those used by the Jet Propulsion Laboratory (1975):

- High salinity; more than 10^5 ppm
- Intermediate salinity; between 2×10^4 ppm and 10^5 ppm
- Low salinity; between 2×10^3 ppm and 2×10^4 ppm
- Very low salinity; up to 2×10^3 ppm

The following temperature classifications are based on White and Williams (1975) and apply to liquid dominated resources only:

- Very high temperature; over 240°C
- High temperature; between 150°C and 240°C
- Intermediate temperature; between 90°C and 150°C
- Low temperature; between 40°C and 90°C

3. Classification Schemes for Geothermal Fluids

Geothermal fluid classification schemes can be based upon a number of variables. One of the best would correlate the fluid composition with temperature and the thermodynamic, or kinetic, relations of the dissolved constituents and the rock-forming and accessory minerals. However, such an approach would be difficult to implement because the current thermodynamic data are inadequate and the chemical processes involved are incompletely understood. Instead, the classification scheme used in this report is based on resource type, temperature, and total salinity.

B. Geothermal Fluid Composition

1. Identification of geothermal fields

The two matrix charts in Table 1 show the probability of exploitation, of different resource types, as a function of salinity and temperature. Exploitation depends also upon a number of factors relating to the brine composition in addition to temperature and salinity. While high temperature-low salinity resources are favored, many compositional factors (e.g., the presence of large amounts of CO_2, CH_4, or H_2S, or the tendency to precipitate large quantities of calcium carbonate or silica) may affect decisions to proceed with development of a particular resource. The probability assignments given in Table 1 are based on assessments of current knowledge of each category. This evaluation indicates that first priority should be given to native steam and liquid dominated resources.

Hot water resources in the United States with a thermal capacity of more than 10^{18} calories and temperatures greater than 90°C were selected from White and Williams (1975) as being the most likely to be exploited during the next ten years. A tabulation of these sites is given in Tables IIA and B.

Development of geothermal resource also depends upon factors other than temperature and salinity. These factors can be divided into the two broad categories based on potential use:

a. Geothermal resources for electric power generation

i. Plant size. Geothermal power plants are expected to range in size from 5MWe to 200MWe. The optimum size will be dependent upon the areal extent of the geothermal reservoir, the need to avoid well interference, potential problems of reinjection of the spent fluid, and

TABLE I

PROBABILITY OF EXPLOITATION OF GEOTHERMAL FLUID CLASSES

A. ELECTRIC SYSTEMS

GEOTHERMAL RESOURCE TYPE	Very low salinity ($0-2 \times 10^3$ ppm)	Low Salinity ($2 \times 10^3-2 \times 10^4$ ppm)	Intermediate Salinity ($2 \times 10^4-10^5$ ppm)	High Salinity ($> 10^5$ ppm)
Native Steam	High	High	Not applicable	Not applicable
Very High Temperature (> 240°C)	Not applicable	Not applicable	High	Intermediate
High Temperature (150°C — 240°C)	High	High	Intermediate	Intermediate
Intermediate Temperature (90°C — 150°C)	Low	Low	Low	Low
Low Temperature (40°C — 90°C)	Not applicable	Not applicable	Not applicable	Not applicable
Geopressured Brine	Not applicable	Not applicable	Not applicable	Intermediate
Hot Dry Rock	Low	Low	Low	Not applicable
Magma	Not known	Not known	Not known	Not known

B. NONELECTRIC SYSTEMS

GEOTHERMAL RESOURCE TYPE	Very low salinity ($0-2 \times 10^3$ ppm)	Low Salinity ($2 \times 10^3-2 \times 10^4$ ppm)	Intermediate Salinity ($2 \times 10^4-10^5$ ppm)	High Salinity ($> 10^5$ ppm)
Native Steam	High	High	Not applicable	Not applicable
Very High Temperature (> 240°C)	High	High	High	High
High Temperature (150°C — 240°C)	High	High	Intermediate	Low
Intermediate Temperature (90°C — 150°C)	High	High	Intermediate	Low
Low Temperature (40°C — 90°C)	High	High	Intermediate	Not applicable
Geopressured Brine	Not applicable	Not applicable	Not applicable	Intermediate
Hot Dry Rock	Not applicable	Not applicable	Not applicable	Not applicable
Magma	Not applicable	Not applicable	Not applicable	Not applicable

TABLE II

GEOTHERMAL HOT WATER RESOURCES

A. TEMPERATURES > 150°C AND TOTAL HEAT CONTENT > 1×10^{18} CALORIES

KGRA or Geothermal Field	∇ Temp. °C	Heat Content $\times 10^{18}$ Cal. ‡		WELLS	Well Data ¶	Brine Data §	Salinity ppm
		Q_T	Q_N				
California							
Brawley	200	3		5	yes	yes	60,000
Coso Hot Springs	220	41	8.5				
East Mesa	180	5.5		8	yes	yes	2,000—32,000
Heber	190	11	2.0	11	yes	yes	12,000—13,000
Mono-Long Valley	220	55	11.5	13	yes	yes	800— 1,100
*Morgan Springs	210	1.2					
Salton Sea	340	21	6.5	26	yes	yes	260,000
*Surprise Valley	175	24	3.9	9	yes		
†The Geysers	240	18.9		numerous wells			
Hawaii							
Puna Geothermal Field	280			2	yes	yes	1,300
Idaho							
Crane Creek	180	5.9		2 wells	yes		
*Weiser	160	6.1					
Nevada							
Beowawe Hot Springs	240	5.7		6 wells to 600 meters	yes	yes	1,200
Brady Hot Springs	214	3.6		13	yes	yes	2,600
*Great Boiling Springs	170	2.3		well			
Soda Lake	165	1.1		1	yes		
Steamboat Springs	210	1.0		20	yes	yes	2,600
Stillwater	160	2.2		1	yes		
*Sulfur Hot Springs	190	1.1					
New Mexico							
*Valles Caldera	240	18	4.1	6, no data		yes	
Oregon							
Crumps Spring	180	1.4		2	yes		
*Hot Lake	180	1.2					
Lakeview	160	1.4		2	yes		
*Mickey Hot Springs	210	1.4					
Vale Hot Springs	160	8.7					
Utah							
Cove-Fort-Sulfurdale	200	2.5		1	yes		
Roosevelt (McKeon) Hot Springs	230	1.0		8	yes		
Wyoming							
*Yellowstone	250	133		15	yes	yes	500—2,000
Mexico							
*Cerro Prieto				numerous wells	yes	yes	13,000—25,000

* Not listed by USGS as KGRA
† Steam field
¶ Includes well owner and drilling date
§ Includes chemical analyses, temperature, pH, total dissolved solids, etc.
‡ Considering 323°K sink temperature (50°C)
∇ From White and Williams (1975)

TABLE II (continued)

GEOTHERMAL HOT WATER RESOURCES

B. TEMPERATURES BETWEEN 90°C and 150°C AND TOTAL HEAT CONTENT > 1×10^{18} CALORIES

KGRA or Geothermal Field	∇ Temp. °C	Heat Content $\times 10^{18}$ Cal. ‡		WELLS	Well Data¶	Brine Data §	Salinity ppm
		Q_T	Q_N				
California							
Wendell-Amedee	140	1.1		6 wells to 338 meters	yes		
*Wilbur Hot Springs	145	2.5		2 wells to 1100 meters	yes		
Idaho							
Bruneau-Grandview	145	263	33.7	Numerous wells			
*Raft River	140	2.3		2	yes	yes	1,200—1,800
Nevada							
Double Hot Springs	145	1.6					
Fly Ranch Hot Springs	130	1.1		2	yes	yes	1,200
Oregon							
Klamath Falls	120	30		Numerous wells	yes	yes	500

* Not listed by USGS as KGRA
¶ Includes well owner and drilling date
§ Includes chemical analyses, temperatures, pH, total dissolved solids, etc.
‡ Considering 323°K sink temperature (50°C)
∇ From White and Williams (1975)

trade-offs expected through balancing the cost of electric power transmission lines and small power plant capacity against the more costly steam or geothermal fluid collection lines and larger power plant capacity.

ii. Resource size. The resource size may have a significant impact on development. In general, potentially larger resources will be developed before smaller ones. However, exceptions are possible when, for example, a small resource is conveniently located, the risks involved in its development are very small, and technical problems are minimal.

iii. Site location. It is not known what effect the cost of transmitting electricity would have on the economics of geothermal power plants. Small units of less than 15 MWe may not be economically justified if the communities served are more than 50 miles away. The possibility also exists that an otherwise attractive site, remote from any point of utilization, may stimulate development in the region. These considerations should be investigated further.

Other sites have obvious limitations which would, in most cases, rule out resource development (e.g., national parks, residential areas, military reservations, and some offshore locations).

iv. Temperature and well cost. These two factors are interrelated. According to Nathensen and Muffler (in White and Williams, 1975), the return needed to pay for a well is approximately 0.8 mil/kilowatt-hour in 1974 dollars. Using the conservative assumption, that 1.5 mil/kilowatt-hour is available for drilling costs, the authors point out that a $300,000 well must produce 2.7 MWe for a particular geothermal resource to be competitive. A well can produce this power output if it has sufficient flow and the geothermal fluid has sufficient temperature. Because the electric energy capable of being produced per kilogram of fluid declines rapidly as the temperature falls, the volume of fluid necessary to produce a given power output becomes excessive (e.g., at 150°C, a mass flow of 80 kg/s, or 1270 gal/min is required whereas at 100°C, a mass flow of 200 kg/s, or 3170 gal/min is required). Furthermore, the plant costs per installed kilowatt of capacity increase rapidly with decreasing fluid temperature. On the other hand, the opportunity to use waste heat for non-electric uses or for the production of by-products from the geothermal fluid (i.e., minerals and potable or agricultural water) might improve the otherwise unfavorable economic conditions for the generation of electric power. For this evaluation, only temperature is considered a restraint for site selection. The other factors which influence production rate depend essentially on knowledge obtained through development of the resource (see Section vii, Other factors, below).

v. Geothermal fluid chemistry. Geothermal fluids which have unusual chemical properties (high salinity, significant quantities of toxic metals, boron, large quantities of noncondensable gases, etc.) will be utilized with difficulty. Suitable and cheap pretreatment methods must be devised for such resources. This may require a costly research and development effort.

vi. Availability of surface water. The availability of water for cooling can be an important requirement for any geothermal plant. For thermodynamic reasons, the quantity of heat rejected per MWe output from a geothermal plant is much larger than from fossil fuel or nuclear power plants of the same size. In regions where high ambient temperatures prevail (e.g., the Imperial Valley, California) evaporative cooling is necessary to improve plant operating efficiency. However, this also leads to a very large loss of water. If geothermal fluids are to be injected to minimize or prevent subsidence, make-up water must be supplied to compensate for water losses due to evaporative cooling. It is also conceivable though questionable that scaling in injection wells and disposal lines can be minimized by diluting geothermal fluids with fresh water.

vii. Other factors. Several other factors could be influential in the development of a hot water geothermal resource. These relate to reservoir characteristics which may, or may not, be anticipated prior to development. Included are:

(1) Bad ground which escalates drilling costs to prohibitive levels or significantly reduces well life. Active fault movements, severely fractured or friable rock, or incompetent clay horizons may lead to abandonment of development of an otherwise desirable resource.

(2) Erratic distribution of geothermal fluids leading to dry or low production wells and an excessive number of unsuccessful wells.

(3) Low producing formation thickness or permeability.

b. Geothermal resources for nonelectric uses.

Many factors which influence the development of geothermal resources for electric power generation also affect the development of geothermal resources for nonelectric uses. In addition, there are other factors which apply particularly to nonelectric uses.

i. Resource location. Geothermal resources for heating will be critically dependent on location. Hot water can be transported only for limited distances (approximately 30 to 50 miles) before heat losses and transmission costs render such an undertaking uneconomic. Therefore, the utilization of geothermal heat will depend primarily on the fortuitous coincidence of availability and the needs of industrial, agricultural, or community interests. Thus, resources located in remote undeveloped areas are unlikely to be economic unless they are sufficiently large to attract industrial or agricultural enterprises and a supporting population.

ii. Temperature, salinity, and well costs. There is an extensive temperature hierarchy of thermal applications for geothermal fluids. The most likely applications depend on the availability of and the equivalent cost of heating with more conventional fuels. Fluids having low total dissolved solids and relatively high temperatures will be most readily exploitable with extensions of present technology. If analyses indicate economic feasibility, with or without artificial mechanisms of support such as tax incentives, subsidies, etc., these may merit a high priority for early development.

As mentioned under Section III.B.1.a.v. on page 13, geothermal fluids having unusual chemical properties will be utilized with difficulty. Appropriate treatment methods must be found for such resources.

Unlike geothermal electric power development, thermal applications of geothermal fluids can range in size from very small (e.g., the heating of a domestic residence) to large scale industrial applications. Therefore, the size of a geothermal resource is not necessarily a limitation to its exploitation. Deep drilling may be justified if the quantity, quality, and temperature of the water are favorable for the application envisaged.

2. Compilation of analyses of geothermal fluids

Chemical analyses and related data pertaining to the geothermal sites identified as being most likely to be exploited have been collected and filed. The data compiled include:

- Concentrations of chemical components;
- Methods of chemical analysis;
- Physical parameters, e.g., pH, total dissolved solids, specific gravity;
- Sampling information, e.g., methods, location, date;
- Well information, e.g., depths, temperatures, flow rates;
- Sources of data.

The compilation has over fifty categories of storage.

The data have been collected from the literature and from the private sector. A bibliography of all sources of data is included.

The information obtained is stored on the Berkeley Data-base Management System (BDMS), a computer filing system also used by LBL's National Geothermal Information Resources Group. The system allows users to choose data elements tailored to their needs. Data input on BDMS may be edited, updated, and retrieved or manipulated as required.

The compilation may be used in numerous ways, e.g., to develop thermodynamic models of geothermal fluids, to construct temperature versus concentration diagrams for major constituents, or as a reference for scientists working on geothermal resources development. The compilation is available as a separate LBL report (Cosner and Apps, 1977).

Caution should be exercised in using unevaluated chemical analyses of geothermal fluids. Attention must be paid to the nature of the sample (i.e., unflashed quenched fluid, residual brine, condensate, reconstructed fluid, etc.), the manner in which it was taken, the history of the sample prior to its analysis, the methods used in chemical analysis, the completeness of the analysis, the units specified, and the internal consistency of the chemistry. It should also be recognized that one analysis need not be representative of a geothermal field. Fluid compositions vary with depth, location, temperature, and time. The limited number of available analyses for some fields may be totally misleading.

3. Identification of geothermal fluid components.

Those fluid components which could adversely affect plant performance and the environment are listed under their respective problem areas:

- Scaling constituents

  Ca, Ba, ΣFe, Cu, Pb, ΣCO_2, Cl^-, ΣSO_4^{--}, H_2S, SiO_2
- Noncondensable constituents

  CO_2, H_2S, CH_4, NH_3, H_2, N_2
- Environmentally hazardous constituents

  H_2S, ^{222}Rn, As, Sb, Se, B, Cd, Hg, NH_3, F, Ag, Tl, Pb, total salinity.

4. Variation of concentration of geothermal fluid components as a function of temperature and salinity.

An evaluation of the variation of the concentration of the chemical components as a function of temperature and salinity is in progress, and a separate report will be prepared on the subject. This information will provide general guidelines for the compositional trends of individual chemical components. In some cases, the compositional variation within a specified range of temperature and salinity, may be two orders of magnitude.

Such variations can be due to chemical differences of the host rock, oxidation potential, the presence of complexing agents, or even to erroneous analytical procedures.

5. Classification of geothermal resources by temperature and salinity.

Available data from fifteen geothermal fields permit their classification as a function of temperature and salinity. This classification is given in Table III in which the geothermal fields are identified by the temperature and salinity ranges established in this report. It is interesting to note the absence of resources below the diagonal from T > 240°C, salinity > 10^5 ppm to T < 90°C, salinity < 2×10^3 ppm. This permits simplification of the geothermal fluid classes into four groups:

1. Temperature over 40°C and salinity less than 2×10^3 ppm
2. Temperature over 90°C and salinity between 2×10^3 ppm and 2×10^4 ppm
3. Temperature over 150°C and salinity between 2×10^4 ppm and 10^5 ppm
4. Temperature over 240°C and salinity over 10^5 ppm

These groups will be used subsequently to simplify the identification of problems relating to scaling and sludge formation.

TABLE III

CLASSIFICATION OF GEOTHERMAL RESOURCES BY TEMPERATURE AND SALINITY

Down Hole Fluid Temperature *	Very Low Salinity 0—2 x 10^3 ppm	Low Salinity 2 x 10^3—2 x 10^4 ppm	Intermediate Salinity 2 x 10^4—10^5ppm	High Salinity > 10^5 ppm
Very High Temperature > 240° C	Yellowstone, Wyoming	Puma, Hawaii Valles Caldera, New Mexico Roosevelt Hot Springs, Utah	Cerro Prieto, Mexico	Salton Sea (Niland) California
High Temperature 150° C — 240° C	Mono-Long Valley, California Beowawe, Nevada	East Mesa, California Heber, California Steamboat Springs, Nevada Roosevelt Hot Springs Utah	Brawley, California	
Intermediate Temperature 90° C — 150° C	Raft River, Idaho Fly Ranch Hot Springs Nevada	Brady Hot Springs, Nevada		
Low Temperature 40° C — 90° C	Klamath Falls, Oregon			

* Temperature is based on actual well measurements.

IV. PROGRAM DEFINITION

This Section determines what projects are required to solve problems relating to the use of geothermal fluids in electric power generation and in nonelectric systems. This objective is accomplished through:

(A) The identification of problems through the listing of components of geothermal systems and subsystems and the working fluids in contact with those components;

(B) The establishment of control feasibility through identification of control methods and comparison with the problems expected in different plant components;

(C) Project identification in which projects relating to fundamental studies and problem definition, control methods, and research and development in support of control methods are listed.

A decision chart leading to the listing of projects and outlining the intermediate steps is shown in Figure 3 and serves as a ready reference to the following text.

A. Problem identification

Problems are identified in two ways: (1) by assessment of the impact of a geothermal fluid on the operation of a geothermal plant; and (2) by discussions with professionals in the field and reference to available literature on geothermal plant operation. The second course of action is taken instead of the first, which cannot always be used for lack of sufficient information on the concentration of given components in geothermal fluids. This subsection discusses geothermal systems, subsystems, and components, and the range of working fluids to be considered. Problems are then identified in the manner described above for the four problem

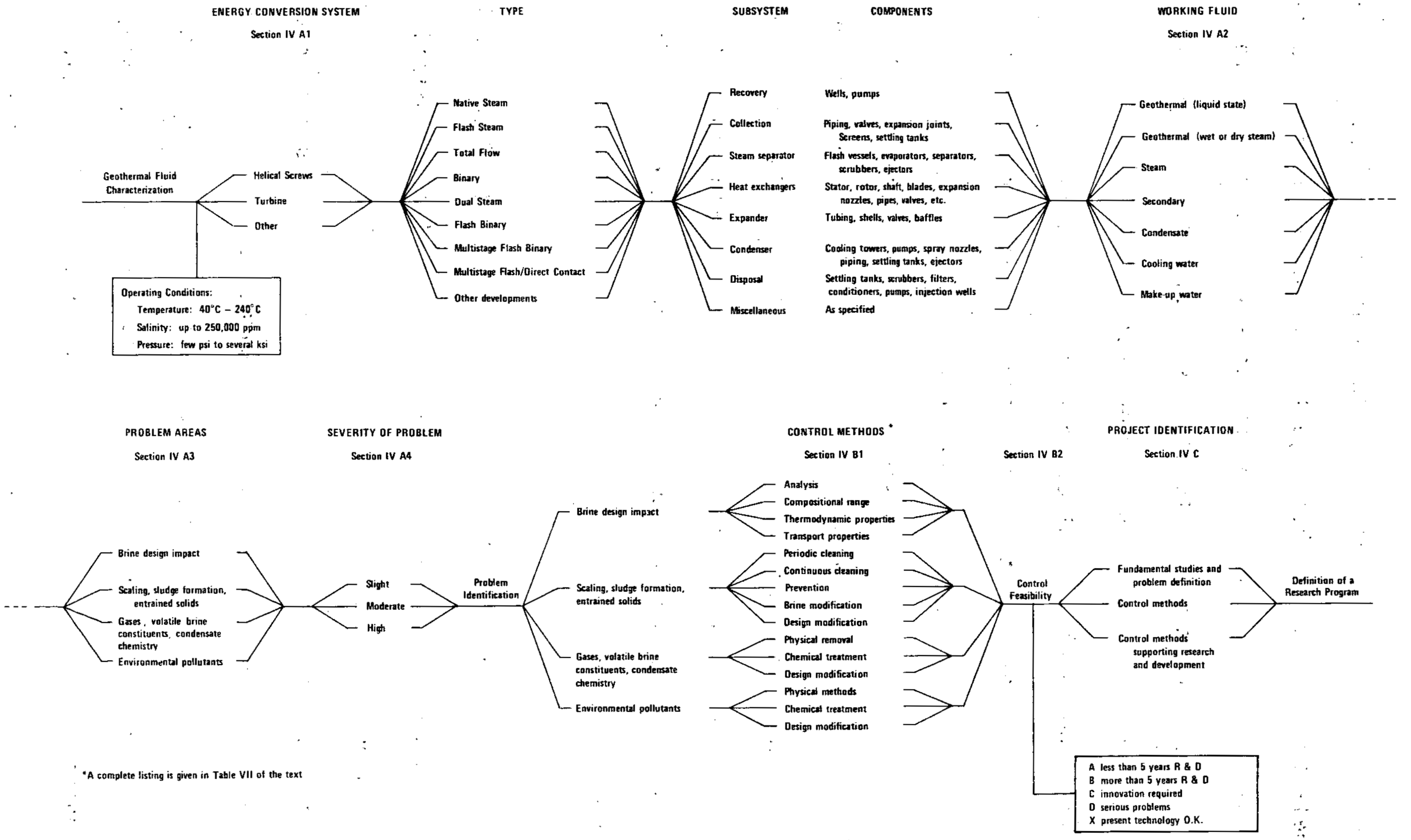

FIGURE 3. DECISION CHART LEADING TO THE DEFINITION OF A RESEARCH PROGRAM FOR PROBLEMS RELATING TO THE USE OF GEOTHERMAL FLUIDS FOR ELECTRIC AND NONELECTRIC PURPOSES.

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areas to which this report is addressed.

1. Geothermal systems

Geothermal systems can be subdivided into two categories:

- Electric power generation
- Nonelectric uses

Tables IVA and B list the types of systems found within each category and associated operating conditions.

The number of possible conversion system configurations for the exploitation of liquid-dominated geothermal resources is substantial and at present there is no clear indication that any preferred system will emerge. The chemical characteristics and temperature of a geothermal fluid at each site rather than system efficiency will probably dictate the choice of system. Each system can be defined in terms of subsystems and components. The principal subsystems of both electric and nonelectric systems are listed together with associated components in Table V. Emphasis is given to those components which are in contact with the geothermal fluid or derived fluid (i.e., steam, condensate, noncondensable gases, etc.).

2. Working fluids

The working fluids in a geothermal system are classified as follows:

- Geothermal fluid, liquid state
- Steam (both wet and dry)
- Secondary (usually a hydrocarbon or mixture of hydrocarbons)
- Condensate
- Cooling water
- Make-up water

The impact of only those fluids which originate from or are compositionally affected by the geothermal fluid are considered in this report.

TABLE IV

TYPES OF GEOTHERMAL SYSTEMS

	Types of Geothermal Systems	Operating Conditions
A.	ELECTRIC POWER GENERATION (1)	
	1. Native Steam	Native Steam 200°C - 300°C
	2. Flash Steam	~150°C and up, any salinity, low noncondensable gas content
	3. Total Flow	
	a. Helical Screw	Any temperature and salinity. Appropriate for geopressured resources.
	b. Turbines	
	4. Binary	
	a. Normal	Preferred for lower temperature resources ($\leq$ 150°C), or where there is a substantial noncondensable gas content
	b. Direct Contact	Preferred for use with fluids where substantial scaling of contact heat exchangers is likely to occur. Not desirable where substantial noncondensable gases are found.
	5. Dual Steam	As for 2 and 3 above (Flash Steam and Total Flow).
	6. Flash Binary	
	a. Normal	Preferred where there are high volatile or noncondensable gas contents.
	b. Direct Contact	Preferred where heat exchanger fouling is particularly troublesome. Preferred where noncondensable gas content is low.
	7. Multistage Flash Binary	Preferred where salinity is very high ($> 10^5$ ppm)
	8. Multistage Flash Direct Contact	Preferred where salinity is very high (> 10 ppm)
B.	NONELECTRIC USES	
	1. Process Steam (Industrial, Agricultural)	Temperatures > 150°C and low concentrations of toxic volatiles desirable
	2. Production of Fresh Water	Temperatures > 90°C with low salinity and low concentrations of toxic volatiles.
	3. Drying (Agricultural, Ice melting)	Temperatures from 40°C - 150°C
	4. Space Heating (Agricultural, Domestic)	Temperatures from 40°C - 150°C
	5. Direct Use (Recreational, Fish Cultivation)	Temperatures up to 40°C with low concentration of toxic constituents

(1) Systems taken in part from Elliott (1975).

TABLE V

SUBSYSTEMS AND COMPONENTS OF GEOTHERMAL SYSTEMS

Subsystem	Component
1. Recovery	Wells; Downhole pumps
2. Collection	Piping, valves, expansion joints, screens, settling tanks
3. Steam Separation	Flash vessels, evaporators, separators, scrubbers, ejectors
4. Heat Exchanger a. Shell and tube b. Direct contact	Tubing, shells, valves, baffles
5. Expander (energy conversion) a. Turbine (axial or radial flow) b. Impulse turbine (total flow) c. Helical screw (total flow) d. Miscellaneous	Stator, rotor, shaft, blades, expansion nozzle, pipes, valves, etc.
6. Condenser a. Direct contact b. Surface	Cooling towers, pumps (condensate circulation, cooling water), spray nozzles, piping, settlement tanks, ejectors
7. Disposal	Settling tanks, scrubbers, filters, conditioning tanks, pumps (centrifugal, turbine, positive displacement), injection wells, formation adjacent to the injection well
8. Miscellaneous a. Chemical treatment b. Mineral recovery etc.	As specified for the subsystem.

3. Problem areas

The problem areas covered by this report are as specified on page 1 in the Introduction:

- Impact on engineering design caused by chemical, thermodynamic, and transport properties of geothermal fluids;
- Scaling and sludge formation;
- Gases, volatile brine constituents, condensate chemistry;
- Environmental problems.

4. Problem identification

The identification of specific problems with respect to each problem area is presented in tabular form in Table VI. In Table VI B, Scaling and Sludge Formation, geothermal system components are compared with grouped classes of geothermal brines, and the potential problems and their severity are estimated. In the remaining problem areas, the problem is compared only with the system component. Problem severity is not determined because of the potential variability from site to site.

Problem severity is estimated at three levels: (a) Low—the problem is sufficiently minor that neither design modification nor special preventive techniques need be considered. The problem can be overcome through routine maintenance, scheduled shut-down and cleaning, or established preventive measures. Quantification of the rates of scaling or sludge formation would be necessary to establish the level of maintenance or treatment required. (b) Medium—the problem calls for preventive or ameliorative treatment for the geothermal system to function effectively.

TABLE VI

PROBLEM IDENTIFICATION

A. IMPACT ON DESIGN CAUSED BY GEOTHERMAL FLUID THERMODYNAMICS AND TRANSPORT PROPERTIES

Property	System Components Affected
1. Chemistry	
a. Solubility of non-condensables	Steam separators, surface and direct contact condensers, ejectors.
b. Solubility of major dissolved constituents (e.g., NaCl)	Steam separators, affects flashing in wells.
c. Solubility of minor constituents	All system components affected by scaling.
d. pH, Eh	Affects in part the corrosion rate of all system components exposed to geothermal fluid.
2. Density	Well pumps (both recovery and injection). Pumping costs are affected, Steam separators, Helical screw expander.
3. Enthalpy	Steam separator components, heat exchangers, expanders, condensers.
4. Heat Capacity	Steam separator components, heat exchangers, expanders, condensers.
5. Film Coefficients	Surface condensers, heat exchangers.
6. Thermal Conductivity	Heat exchangers. Has impact on scaling rates in plant components.
7. Viscosity	Pumps (affects work required to pump fluid) well bores (affects turbulence and hence scaling rates).
8. Diffusion Coefficients	All system components affected by scaling

TABLE VI (continued)

PROBLEM IDENTIFICATION

B. SCALING AND SLUDGE FORMATION

COMPONENT	ESTIMATED PROBLEM TYPE AND SEVERITY*							
	< 2 x 10^3 ppm, 90°—240°C		2 x 10^3—2 x 10^4 ppm, 90°—240°C		2 x 10^4—10^5 ppm, > 150°C		> 10^5 ppm, > 240°C	
1. Formation adjacent to recovery well	$CaCO_3$	?	$CaCO_3$	?	?	?	?	?
2. Well	$CaCO_3$	L	$CaCO_3$	M-H	$CaCO_3$	M	$CaCO_3$, SiO_2	M-H
3. Downhole pumps	$CaCO_3$	L	$CaCO_3$	L	$CaCO_3$	L	$CaCO_3$	L
4. Collection system (i.e., piping, valves, etc.)	$CaCO_3$	L	$CaCO_3$	M-H	$CaCO_3$	M	$CaCO_3$	M
5. Two-phase expanders	$CaCO_3$, SiO_2	M-H	$CaCO_3$, SiO_2	M-H	$CaCO_3$, SiO_2, sulfides, etc.	H	$CaCO_3$, SiO_2, sulfides, Iron oxides	H
6. Steam separators	$CaCO_3$, SiO_2	L	$CaCO_3$, SiO_2	L	$CaCO_3$, SiO_2	L	$CaCO_3$, SiO_2 sulfides, FeO not serious	L
7. Heat exchanger components a. Shell and Tube	SiO_2		SiO_2				sulfides probably severe	
b. Direct contact	$CaCO_3$	M	$CaCO_3$	M-H	$CaCO_3$, SiO_2	H	$CaCO_3$, SiO_2	H
8. Turbine blades		L		L	$CaCO_3$, SiO_2	M	pptn due to spray carryover	M
9. Condenser components a. Direct contact		L		L		L	minor	L
b. Surface		L		L		L		L
10. Scrubbers		L		L		L		L
11. Pumps (above ground)	SiO_2	M	$CaCO_3$, SiO_2	M	$CaCO_3$, SiO_2	M-H		M
12. Injection wells	SiO_2	H	$CaCO_3$, SiO_2	H	$CaCO_3$, SiO_2	H	$CaCO_3$, SiO_2	H
13. Formation adjacent to well	SiO_2	H	SiO_2	H	$CaCO_3$, SiO_2	H	$CaCO_3$, SiO_2	H
14. Miscellaneous (settling tanks i.e., pre and post stages)		L		L		L		L

* Problem severity: H = High; Technology changes required
M = Medium; Preventive or ameliorative treatment required.
L = Low; Knowledge of rates required

TABLE VI (continued)

PROBLEM IDENTIFICATION

C. GASES, VOLATILE BRINE CONSTITUENTS, CONDENSATE CHEMISTRY

No.	Problem	System Components
1.	Noncondensable gas removal from brines	Separators, ejectors
2.	Noncondensable gas removal from condensers	Condensers, ejectors
3.	H_2S abatement	Condensers and scrubbers
4.	Corrosion by condensate, including additives, catalysts, etc.	Condensers, scrubbers, cooling tower, etc.
5.	Control of condensate chemistry to prevent downhole corrosion, scaling, etc., by O_2 additives and catalysts	Injection wells

D. ENVIRONMENTAL PROBLEMS

No.	Problem	System Components
1.	Preplant emissions (e.g., venting during plant downtime, malfunctions, etc.).	Recovery wells
2.	H_2S disposal or elimination	Ejectors, cooling tower drift, spills
3.	Emission of trace volatiles (H_3BO_3, Hg, As, etc.).	As above.
4.	Formation damage due to scaling or dissolution and collapse	Injection wells.

(c) High—a solution to the scaling or sludging problem is necessary to permit exploitation of the geothermal resource. This classification presupposes the current state of technological development. The impact of research and engineering development will result in changes in the estimated level of problem severity.

B. Control Feasibility

The initial phase of the strategy for defining an engineering development program requires:

- Identification of control methods;
- The grouping of problems having similar causes under comparable conditions, and establishment of control feasibility.

1. Control methods

The control methods are based on the problem areas identified in Section IV.A.3, on page 21. The control methods for each problem area are listed in Table VII. The lists are comprehensive and include some methods which may eventually prove to have limited or no application in geothermal energy systems. The last two problem areas overlap strongly as hydrogen sulfide emission is the chief environmental problem associated with geothermal development. Experience at The Geysers has amply demonstrated that finding a working solution to the problem of hydrogen sulfide emission is of importance in gaining public acceptance of geothermal energy and, for that matter, in obtaining permission from the relevant regulatory agencies to expand capacity.

Condensate chemistry must be specifically included since a substantial part of the fluid flow in a flash steam cycle plant is condensate rather than the primary geothermal fluid. The practical importance of condensate chemistry is that H_2S emission is largely determined by the complex chemical interactions between steam, condensate, and off-gas.

2. Establishment of control feasibility

The first step in establishing control feasibility is the grouping of problems having similar causes under comparable conditions. Thus, for example, scaling in recovery wells, downhole pumps, and collection systems is similar for certain brine types. This is accomplished through review of Table VII. Comparison of problem groups with control methods establishes whether or not the feasibility of the given control method is effective and some indication is given of the amount of research and development effort involved in implementing such a method.

Control feasibility is classified according to the four levels of research and development effort involved.

(A) Intermediate R&D effort required ($\leq$ 5 years)
(B) Long-range R&D effort (> 5 years)
(C) Uncertain that technology can be developed. Innovation is required.
(D) Serious drawbacks because of technology, cost, or irrelevance.
(X) None required. Technology available.

Level A is of immediate concern since it represents research efforts with less significant risk and a potentially short time limit for problem solution. It covers projects that can be accomplished in the time necessary to insure that the DOE goals in geothermal energy are met. Levels B, C, and D require longer range or high risk research which is incompatible with the proposed program.

Table VIII summarizes the control feasibility respectively for the impact of geothermal fluid on plant design; scaling and sludge formation;

TABLE VII

GEOTHERMAL FLUID CONTROL METHODS

A. Impact on Design Caused by Geothermal Fluid Thermodynamics and Transport Properties.

1. Develop standardized and reliable procedures for geothermal sampling and chemical analysis.
2. Define compositional ranges of geothermal fluid classes.
3. Define chemical thermodynamic properties of geothermal fluids to predict conditions which require system modification.
4. Define rates of scaling, precipitation, gas partition, oxidation, etc., from geothermal fluid and derivative fluids under various geothermal system operating conditions to establish system design requirements.
5. Specify the thermodynamic properties of geothermal fluids (e.g. density, enthalpy, heat capacity, etc.).
6. Specify transport properties of geothermal fluids (e.g. film coefficients, thermal conductivity, viscosity, diffusion coefficients, etc.).

B. Scaling and Sludge Formation

1. Periodic Cleaning
    - a. Physical removal, e.g. scraping, physical shocking
    - b. Thermal shocking
    - c. Ultrasonic cleaning
    - d. Cavitation techniques
    - e. Strippable coatings
    - f. Dissolution with chemical agents
2. Continuous Cleaning
    - a. Physical removal, e.g. scraping, scouring, deformable units, etc.
    - b. Ultrasonic cleaning
    - c. Erosion
    - d. Suspended solids removal by
        - i. Filtration (conventional, sand bed, or membrane)
        - ii. Cyclones
        - iii. Centrifuges
        - iv. Settling
        - v. Flocculation
3. Prevention
    - a. Geothermal fluid modification
        - i. Chemical (flotation, coprecipitation, sol formation, complexing or chelating
        - ii. Surface-fluid interactions (plastics, precipitation, sol formation, and complexing), inhibition of scale attachment or growth by proprietary chemicals
        - iii. Homogeneous nucleation control by catalysts
        - iv. Pre and post precipitation and filtration
        - v. *Dilution*
    - b. Electrostatic and magnetic fields
    - c. Other methods
        - i. Downhole pumping
        - ii. Operation at minimal efficiency
4. Design Modification
    - a. Design modifications to minimize turbulent flow
    - b. Design modifications to minimize the effects of scaling (e.g. direct contact, or fluidized bed heat exchangers, helical screw, converters, etc.).

TABLE VII (continued)

GEOTHERMAL FLUID CONTROL METHODS

C. Gases, Volatiles, and Condensate Chemistry
1. Physical Removal a. Rejection of initial flash steam b. Native steam condensation followed by (a). c. Air stripping or steam stripping the condensate d. Periodic blowdown of the condensate
2. Chemical Treatment a. Preplant treatment by oxidation or other means b. Steam scrubbing (with or without regeneration) c. Absorption from steam (with or without regeneration) d. Rejection in off-gases through pH adjustment of circulating condensate (especially for H_2S), by adsorption of SO_2, CO_2, or externally supplied chemical reagents e. Catalytic oxidation in the condensate (especially for H_2S) f. Catalytic oxidation of gas (especially for H_2S) g. Other chemical treatments including burning off h. Reabsorption in spent geothermal fluid prior to reinjection, with or without burning.
3. Design Modification a. Rejection in off-gases through use of surface condensers b. The use of binary power cycles or other closed systems c. Other
D. Environmental Problems (other than in C).
1. Chemical Treatment a. Coprecipitation of pollutants with silica or other additives b. Removal of toxic constituents through ion exchange c. Other chemical treatment
2. Physical Methods a. Distillation for the production of clean water b. Safe disposal of toxic scale and sludge c. Full reinjection of the residual brine

TABLE VIII

CONTROL FEASIBILITY

A. IMPACT ON DESIGN CAUSED BY GEOTHERMAL FLUID THERMODYNAMICS AND TRANSPORT PROPERTIES

Control Method	Control Feasibility
1. Develop standardized and reliable procedures for geothermal fluid sampling and chemical analysis.	A
2. Define compositional ranges of geothermal fluid classes.	A
3. Define chemical thermodynamic properties of geothermal fluids to predict conditions which require system modification.	A
4. Define rates of scaling, precipitation, gas partition, oxidation, etc., from geothermal fluid and derivative fluids under various geothermal system operating conditions to establish system design requirements.	A
5. Specify the thermodynamic properties of geothermal fluids (e.g. density, enthalpy, heat capacity, etc.).	A
6. Specify transport properties of geothermal fluids (e.g. film coefficients, thermal conductivity, viscosity, diffusion coefficients, etc.).	A

R & D Effort:
A—Intermediate R & D effort required (≤ 5 years)
B—Long-range R & D effort (> 5 years)
C—Uncertain that technology can be developed. Innovation is required.
D—Serious drawbacks because of technology, cost, or irrelevance.
X—Technology available.

TABLE VIII

CONTROL FEASIBILITY

B. SCALING AND SLUDGE FORMATION

CONTROL METHOD	Severe Problem Salinity > 2 x 10^4 ppm, t > 90°C					Moderate Problem Salinity < 2 x 10^4 ppm, t > 90°C			
	SiO_2 and $CaCO_3$ formation in well bores	SiO_2+$CaCO_3$ formation in 2-phase expanders	SiO_2+$CaCO_3$ + sulfide formation in heat ex-changers	Pumps (above ground)	Injection Wells and adjacent formations	$CaCO_3$ formation collection system	pptn in turbine	pptn in pumps (above ground)	Injection Wells and adjacent formation
1. Periodic Cleaning									
a. Physical removal (scraping, physical shocking)	C	C	C	C	D	C	C	C	D
b. Thermal shocking	D	C	C	C	D	D	C	C	D
c. Ultrasonic cleaning	C	C	C	C	D	C	C	C	D
d. Cavitation techniques	A	A	A	C	C	A	C	C	C
e. Strippable coatings	C	C	C	D	C	C	D	D	C
f. Dissolution with chemical agents	A	A	A	A	A	A	A	A	A
2. Continuous Cleaning									
a. Physical removal (scraping, scouring, deformable units, etc.)	C	C	C	C	D	C	C	C	D
b. Ultrasonic cleaning	C	C	C	C	C	C	C	C	C
c. Erosion	C	C	C	C	D	C	C	C	D
d. Suspended solids removal by filtration (conventional, sandbed, or membrane), cyclones, centrifuges, settling, flocculation	D	D	A	A	A	D	D	A	A
3. Prevention									
a. Geothermal fluid modification									
i. Chemical (flotation, precipitation, sol formation, complexing or chelating	A	A	A	A	A	A	A	A	A
ii. Surface-fluid interactions (plastics, precipitation, sol formation complexing, inhibition of scale attachment or growth by proprietary chemicals	C	C	C	C	C	C	C	C	C
iii. Homogeneous nucleation control by catalysts	C	C	C	C	C	C	C	C	C
iv. Pre and post precipitation	D	C	C	C	A	D	C	C	A
v. Dilution	D	D	D	X	X	X	X	X	X
b. Electrostatic and magnetic fields	D	C	C	C	D	D	C	C	D
c. Other methods									
i. Downhole pumping	A	D	D	D	D	A	D	D	D
ii. Operation at minimal efficiency	A	A	A	A	A	A	A	A	A
4. Design Modification									
a. Design modification to minimize turbulent flow	A	A	A	D	A	A	D	D	A
b. Design modifications to minize the effects of scaling (direct contact or fluidized bed heat exchangers, helical screw, converters, etc.)	D	D	A	D	D	D	A	D	D

NOTE: A—*Intermediate R&D effort required* ($\leq$5 years)
B—Long range R&D effort (> 5 years)
C—Uncertain that technology can be developed. Innovation is required.
D—Serious drawbacks because of technology, cost, or irrelevance
X—Technology available

TABLE VIII (continued)

CONTROL FEASIBILITY

C. GASES, VOLATILES, AND CONDENSATE CHEMISTRY

CONTROL METHOD	Reservoir	Recovery Well/ Collection System	System Component Steam Separators	Ejectors	Condensers and Scrubbers	Cooling Towers	Injection wells
1. Physical Removal							
a. By rejection of initial flash steam		A	A	A			
b. Native steam condensation followed by (a)		D	A	A			
c. Air stripping or steam stripping the condensate					A		
d. Periodic blowdown of condensate					X	X	A
2. Chemical Treatment							
a. Preplant treatment by oxidation or other means	D	A	A		A		
b. Steam scrubbing (with or without regeneration)		A	A		A		
c. Absorption from steam (with or without regeneration)		A	A		A		
d. Rejection in off-gases through pH adjustment of circulating condensate (especially for H_2S) by adsorption of SO_2, CO_2, or externally supplied chemical reagents				A	A	A	
e. Catalytic oxidation in the condensate (especially for H_2S)					A		
f. Catalytic oxidation of gas (especially for H_2S)				A			
g. Other chemical treatments including burning off				A			
h. Reabsorption in spent geothermal fluid prior to reinjection, with or without burning				A			
3. Design Modification							
a. Rejection in off-gases through use of surface condensers					A		
b. The use of binary power cycles or other closed systems		X	A		A		A
c. Other							

NOTE: A—Intermediate R&D effort required (≤ 5 years)
B—Long-range R&D effort (> 5 years)
C—Uncertain that technology can be developed. Innovation is required
D—Serious drawbacks because of technology, cost, or irrelevance
X—Technology available

TABLE VIII (continued)

CONTROL FEASIBILITY

D. ENVIRONMENTAL PROBLEMS (other than included in Table C).

Control Method	Control Feasibility
1. Chemical Treatment	
a. Coprecipitation of pollutants with silica or other additives	A
b. Removal of toxic constituents through ion exchange	A
c. Other chemical treatment	A
2. Physical Methods	
a. Distillation for the production of clean water	D
b. Safe disposal of toxic scale and sludge	A
c. Full reinjection of the residual brine	X

R & D Effort:
A—Intermediate R & D effort required ($\leq$ 5 years)
B—Long-range R & D effort (> 5 years)
C—Uncertain that technology can be developed. Innovation is required.
D—Serious drawbacks because of technology, cost, or irrelevance.
X—Technology available.

gases, volatile geothermal fluid constituents, and condensate chemistry; and environmental problems.

C. Project Identification

1. Categorization of projects

Specific projects are identified by review of all A and B research and development levels from Table VIII. The projects fall into three groups:

(a) Fundamental studies and problem definition

This group includes studies relating to the determination of parameters affecting the composition of geothermal fluids as well as measurement of their thermodynamic and transport properties. It also includes research into problems not clearly defined at this time.

(b) Control methods

This group is the most important of the three. It includes all research and engineering development projects addressing well-defined problems. The goal of all these projects is to find solutions or means of circumventing problems.

(c) Research and development in support of control methods

Research and engineering development projects frequently require supporting research and development. This last group incorporates projects which have as their primary role the support of engineering projects specified in group (b).

All projects are listed in tabular form in Table IX. The table is subdivided according to problem areas as well as project groups. The table also includes investigators and their affiliations where related projects are funded in FY 1977 by government or private institutions. More complete descriptions of FY 1977 projects can be found by reference to Table X.

TABLE IX

PROJECT IDENTIFICATION

A. FUNDAMENTAL STUDIES AND PROBLEM DEFINITION

No.	Project Title	Comments	Investigators
1.	ANALYTICAL METHODS FOR GEOTHERMAL FLUIDS		
	Development of standardized procedures for geothermal fluid sampling and chemical analysis	Geothermal fluid chemical analyses currently available are often sampled and analyzed by a variety of techniques making intercomparisons difficult.	**D. W. Shannon, BPNL (2)**
2.	CHEMICAL COMPOSITION OF GEOTHERMAL FLUIDS		
	Compositional range of geothermal fluids	Brine composition as a function of temperature and salinity need to be more clearly defined	J. A. Apps, LBL D. E. White, USGS
	Characterization of gases and other volatile geothermal fluid constituents	Determination of identity and concentration of various chemically and/or environmentally important volatile (H_2S, NH_3, CO_2, Rn, HF) and potentially volatile (HCl, SO_3, H_3BO_3, Hg, As) constituents of geothermal fluids and native steam from various sources, including vapor-dominated reservoirs, high and low salinity liquid-dominated reservoirs, hot dry rock leaching fluids, and magma leaching fluids. Should include determination of chemical species where relevant.	J. A. Apps, LBL D. E. White, USGS
	Characterization of toxic geothermal fluid constituents	Identification and quantitative determination of potentially environmentally harmful geothermal fluid and hot rock leach water constituents; determination of their chemical forms. The potential toxic pollutants in low temperature, low salinity fluids which might be developed as water resources should be addressed specifically.	S. R. Cosner LBL (in part)
3.	CHEMICAL THERMODYNAMIC PROPERTIES OF SCALE AND SLUDGE		
	Thermodynamic properties of amorphous silicates	No information is currently available.	
4.	CHEMICAL THERMODYNAMIC PROPERTIES OF GEOTHERMAL FLUIDS		
	Factors controlling geothermal fluid composition	A basic understanding of geothermal fluid chemistry and compositional controls is required to identify potential problems with specific brines. An understanding of the thermodynamic relation of rock forming minerals with the coexisting fluid is also required.	J. A. Apps, LBL F. A. Cafasso, ANL L. Blatz, LASL C.C. Herrick, LASL C. Holley, LASL J. Balagna, et al., LASL R. O. Fournier, USGS R. A. Robie, USGS A. H. Truesdell, USGS

TABLE IX (continued)

PROJECT IDENTIFICATION

A. FUNDAMENTAL STUDIES AND PROBLEM DEFINITION (continued)

No.	Project Title	Comments	Investigators
4.	CHEMICAL THERMODYNAMIC PROPERTIES OF GEOTHERMAL FLUIDS (Continued)		
	Thermodynamic Data Compilations	Supports previous project	J. Haas, USGS
	Prediction of volatile constituents in geothermal fluids	Geochemical and thermodynamic interpretation and prediction of volatiles and potential volatiles in various geothermal fluids. This work will be particularly important in regard to hot dry rock and magma technologies, as relevant experiments may be difficult to perform in these cases	J. L. Haas, USGS
	Gas partition between brines and steam	Experimental determination and physio-chemical interpretation of partition ratios of volatiles and potential volatiles in flash steam systems, upstream condenser-reboiler and scrubber systems, and in postcondenser condensate scrubbers. Should also include consideration of gas reabsorption in residual geothermal fluids as a means of off-gas treatment.	
	Condensate chemistry of minor volatiles	Field and laboratory studies and interpretation of the chemistry of the major potential volatiles of environmental interest (Hg, As, H_3BO_3) under geothermal plant conditions	
	Prediction of potentially harmful geothermal fluid constituents	Geochemical and thermodynamic interpretation and prediction of potentially environmentally harmful geothermal fluid and hot rock leach water constituents. This kind of theoretical examination will be particularly useful in the cases of hot dry rock and magma schemes, as suitable experiments will be difficult to perform.	
	Geothermal fluid scale partition of trace pollutants	This study involves the characterization of probable toxic constituents of geothermal plant scale and the partition of these substances between the geothermal fluid and scale. Coprecipitation kinetics should be studied also.	G. E. Tardiff, LLL (in part)

TABLE IX (continued)

PROJECT IDENTIFICATION

A. FUNDAMENTAL STUDIES AND PROBLEM DEFINITION (continued)

No.	Project Title	Comments	Investigators
5.	KINETICS OF SCALING, GAS PARTITION, OXIDATION, ETC.		
	Scaling mechanisms—basic thermodynamics and kinetics	Relative importance of different scaling mechanisms needs to be defined, particularly with respect to precipitation, dissolution, polymerization and flocculation of silicates, carbonates, and sulfides.	O. Weres, LBL E. G. Bohlmann, ORNL P. W. Shannon, BPNL
	Scaling rates and characteristics in plant components	Scaling characteristics in geothermal plant components must be determined and reconciled with scaling mechanisms.	E. G. Bohlmann, ORNL R. Feber, LASL J. Samaniego, Ben Holt Co. T. Springer, Rockwell Internat. G. E. Tardiff, LLL J. S. Wilson, Dow Chemical USA
	Impact of injected geothermal fluids on formation permeability	A potentially important area which has not been clearly defined. Project should include the effect of geothermal fluid reheating, mixing of the injected brine with the formation fluid, and chemical interactions between the formation rocks and the injected brine.	
	Injected geothermal fluid—rock interactions	There is a distinct possibility that spent geothermal fluids which have been altered chemically in going through a power plant will chemically attack or partially dissolve the reservoir rock into which they are injected. A decrease in permeability or mechanical strength of the reservoir matrix could render further injection impossible or increase the subsidence risk, respectively. The possibility of such phenomena should be examined both experimentally and theoretically.	
	Carbon dioxide desorption and absorption kinetics	Field and laboratory studies of the kinetics of CO_2 desorption and absorption under geothermal plant cycle conditions. There appear to be no kinetic data at all about these reactions at high temperature, and very little is known about possible catalytic effects at any temperature. This reaction is an important one in geothermal practice, as CO_2 has the dominant role in determining geothermal fluid and condensate pH and thereby the partition of H_2S and the rate of precipitation of silica.	

TABLE IX (continued)

PROJECT IDENTIFICATION

A. FUNDAMENTAL STUDIES AND PROBLEM DEFINITION (continued)

No.	Project Title	Comments	Investigators
6.	THERMODYNAMIC PROPERTIES OF GEOTHERMAL FLUIDS		
	Thermodynamic properties of geothermal fluids	Information needed for general power plant design and prediction of geothermal fluid behavior	C. F. Ball, ORNL R. E. Mesmer, ORNL R. H. Busey, ORNL S. L. Phillips, LBL K. S. Pitzer, LBL R. W. Potter, USGS
7.	TRANSPORT PROPERTIES OF GEOTHERMAL FLUIDS		
	Geothermal fluid transport properties	Information needed for general power plant design and prediction of geothermal fluid behavior	

B. CONTROL METHODS

No.	Project Title	Comments	Investigators
1.	SCALING AND SLUDGE FORMATION		
	Cavitation cleaning in well bores, heat exchangers, etc.	Technology needs to be evaluated with respect to specific applications.	A. A. Hochrein, Jr., Daedalean Associates, Inc.
	Periodic cleaning with chemical agents.	More effective cleaning techniques for given scales need to be identified. This effort should be site specific.	
	Geothermal fluid modification to prevent scaling in well bores, expanders, heat exchangers, and pumps.	Effort should be concentrated on solving problems with geothermal fluids in the field. EPRI mobile lab and LLL efforts could support this problem. NOTE: A basic research effort is needed to clarify mechanisms to support valid solutions	G. E. Tardiff, LLL
	Pre and post-filtration and precipitation of scale formers	Techniques may lead to secondary problems resulting from additives. Precipitation, once initiated, may be slow to go to completion and thereby result in problems for which the technique was proposed to avoid. Project could be combined with above.	
	Downhole pumping to inhibit flashing and carbonate scale formation.	Technique needs to be demonstrated in the field to prove out the concept.	W. D. McBee, Sperry Res. Ctr. L. Ross, U. Denver Res. Ins. (in part)

TABLE IX (continued)

PROJECT IDENTIFICATION

B. CONTROL METHODS (Continued)

No.	Project Title	Comments	Investigators
1.	SCALING AND SLUDGE FORMATION (continued)		
	Operation at minimal efficiency	Some operations might function at less than optimum, but be free of scaling problems. Site-specific studies need to be implemented to establish feasibility.	
	Design modifications to minimize turbulent flow in wells, collection system, 2-phase expanders and heat exchangers	Modifications should be based upon a sound understanding of the interaction between the hydrodynamics and precipitation of scale.	
	Design modifications to minimize scaling in heat exchangers helical screw expanders, etc.	Projects depend upon the testing of specific engineering concepts.	H. R. Jacobs, Univ. Utah R. A. McKay, NASA-JPL (in part) W. Suratt, DSS Engineers E. Wahl, Occidental Res. Corp.
	Physical removal of scale through scraping and physical or thermal shocking	Techniques already exist for such methods of scale removal. However, there is some question whether they would be economic or feasible in all cases. Innovative new procedures should be developed. However, they would probably be both site and plant specific. Thermal shocking of wells is not considered advisable.	
	Ultrasonic cleaning of all power cycle components except injection wells.	Modest test program suggested to establish feasibility.	
	The use of strippable coatings on static surfaces	A modest exploratory program might be initiated to investigate the feasibility of such an approach.	B. Breindel, Aerojet
	Continuous cleaning by scraping, scouring, or deformable units	Possible applications might be in heat exchangers, or in helical screw expanders. Exploratory program should be initiated to establish feasibility and practicality.	B. C. Musgrave, INEL
	Continuous removal of suspended solids by filtration, cyclones, centrifuges, or settling tanks	Feasibility of alternative processes needs to be evaluated.	
	Surface modification to prevent scaling in well bores, expanders, heat exchangers, and pumps	Efforts to date have not been very successful. Risk is high therefore effort should be exploratory. Work should be done in the field. Basic supporting R & D effort is needed.	Interest expressed by Pfizer

TABLE IX (continued)

PROJECT IDENTIFICATION

B. CONTROL METHODS

No.	Project Title	Comments	Investigators
1.	SCALING AND SLUDGE FORMATION (continued)		
	Nucleation control in geothermal plants	The possibility of scaling control by this effort needs to be defined. LLL has had success in controlling silica nucleation through scale control.	G. E. Tardiff, LLL
2.	GASES, VOLATILES, AND CONDENSATE CHEMISTRY		
	Removal of noncondensable gases by rejection of the initial flashed steam at the testing well, collection system, or in the steam separators.	Field studies using prototype designs should be tested.	
	Steam condensation and re-evaporation with rejection of noncondensables.	Technique has been used successfully at Lardarello, but tends to be inefficient. Limited field testing of new concepts might be initiated where reservoirs have high volatile or noncondensable gas content.	
	Air or steam stripping of the condensate to remove volatiles	Testing and evaluation of concepts should be carried out at sites where volatile absorption in the condensate proves to be troublesome.	
	Preplant removal of volatile and noncondensable gases (esp. H_2S) by chemical treatment: execution of scrubbing, absorption, oxidation techniques	Field testing of suitable methods should be carried out at sites where this appears to be a problem.	W. H. Harvey, EIC Corp. P. C. Walkup, BPNL J. S. Wilson, Dow Chemical USA
	Removal of H_2S by catalytic oxidation in the condensate, or in the noncondensible gases	Field testing where the gas emissions might be a problem.	Various tests performed by PG&E at The Geysers with mixed success
	Removal of H_2S by burning off with the noncondensable gases	The technique has proved troublesome at The Geysers. An improved method of dealing with the problem should be worked out.	

TABLE IX (continued)

PROJECT IDENTIFICATION

B. CONTROL METHODS (continued)

No.	Project Title	Comments	Investigators
2.	GASES, VOLATILES, AND CONDENSATE CHEMISTRY (continued)		
	Reabsorption of CO_2, H_2S, and other volatiles in the cooled geothermal fluid, prior to reinjection, with or without burning	Field testing should be done where this approach appears both possible and economic.	
	Rejection of volatiles in off-gases through use of surface condensers in flash steam plants	As above.	
	Use of burning cycles where high volatile or noncondensable gas condensates might preclude operation.	As above.	
3.	ENVIRONMENTAL PROBLEMS (other than included in B-2).		
	Coprecipitation of toxic metals and other pollutants with silica through the use of lime.	Technique has been used at Wairakei, N. Z. Such an approach would only be suitable if the treated geothermal fluids were of low salinity and surface discharge was contemplated.	
	Removal of toxic metals and other pollutants by ion exchanger; adsorbtion	Technique would be suitable only where low salinity geothermal fluids were to be discharged into river systems.	
	Safe disposal of toxic scales and sludge	Satisfactory disposal techniques would probably be site specific. Initiation of this project would require identification of the site or sites to be chosen for development.	

TABLE IX (continued)

PROJECT IDENTIFICATION

C. CONTROL METHODS SUPPORTING RESEARCH AND DEVELOPMENT

No.	Project Title	Comments	Investigators
1	SCALING AND SLUDGE FORMATION		
	Characterization of scale in geothermal plants (fabric, structure, chemical composition, mineralogy)	Special attention should be paid to carbonates, silicates, and sulfides.	
	Precipitation mechanisms	A research effort is needed to clarify mechanisms of precipitation so as to provide technical guidance to field programs in geothermal fluid modification to prevent scaling.	J. A. Apps, LBL O. Weres, LBL
	Kinetics of silica carbonate and sulfide precipitation in the presence of added reagents to induce precipitation	This project could support B1(4).	
	The effect of turbulent flow on precipitation kinetics	This is an important area of research required to understand what causes localized precipitation of scale, and how to prevent it.	
	Physical and chemical properties of suspended solids	The origin, rates of formation, size distribution, and physical and chemical properties of suspended solids needs to be undertaken in order to design for their removal.	G. E. Tardiff L. Owen, LLL
	Surface modification to prevent scale attachment	Exploratory program in fundamental mechanisms of scale attachment is needed to provide guidance to development programs in surface modification to prevent scale attachment.	
	Nucleation phenomena	The feasibility of controlling nucleation should be established through an understanding of how it is caused and whether it can be controlled.	J. A. Apps, LBL O. Weres, LBL
	Integral plant chemistry	Experimental determination and physio-chemical interpretation of chemical mass-balances in operating geothermal plants. Effects of added catalysts should also be investigated.	

TABLE IX (continued)

PROJECT IDENTIFICATION

C. CONTROL METHODS SUPPORTING RESEARCH AND DEVELOPMENT (continued)

No.	Project Title	Comments	Investigators
2.	GASES, VOLATILES, AND CONDENSATE CHEMISTRY		
	Sulfur compound chemistry	Field and laboratory studies of aqueous sulfur compound chemistry under operating geothermal plant conditions. Influence of various catalysts, both accidental and added, should also be determined. The importance of this problem is illustrated by the fact that The Geysers condensate is presently known to contain H_2S, S°, SO_2, $SO_4^=$, $S_2O_3^=$, and polysulfides. The distribution of sulfur chemical species ultimately determines the efficacy of liquid phase H_2S oxidation schemes. Effects on flocculants and antiflocculants on elemental sulfur precipitation and sedimentation should also be considered.	
3.	ENVIRONMENTAL PROBLEMS		
	Geothermal fluid chemistry	Study of possible chemical methods of precipitating or otherwise removing potentially environmentally harmful trace constituents from residual geothermal fluids prior to release into environment. This will be particularly important if low salinity fluids are to be considered a water resource.	

2. FY 1977 projects

Efforts are already under way to tackle some of the problems identified in this report. Projects in progress during FY 1977 are listed in Table X together with the principal investigators, their affiliations, and the sponsoring institutions. The latter include the DOE divisions of Geothermal Energy, Basic Energy Sciences, and Biomedical and Environmental Research; the United States Geological Survey; the United States Bureau of Mines; and the Electric Power Research Institute, Palo Alto, California.

TABLE X

RESEARCH PROGRAMS RELATED TO GEOTHERMAL FLUID CONTROL: FY 1977 PROJECTS

A. BRINE CHEMISTRY

No.		Person in Charge or Principal Investigator	Performing Organization	Sponsor
1.	Silica Precipitation and Brine Management a. Brine composition	J. A. Apps S. R. Cosner	LBL	ERDA-DGE
2.	Brine Chemistry and Corrosion/Erosion Studies for Support of Total Flow Turbine Development	A. L. Austin	LLL	ERDA-DGE
3.	Thermochemistry of Geothermal Related Materials	F. A. Cafasso	ANL	ERDA-DPR
4.	Solutions—Minerals Equilibrium	C. L. Christ	USGS, Menlo Park	USGS
5.	Modeling of Geothermal Systems a. Model Geothermal Systems b. Static High Temperature, High Pressure Experiments c. Thermodynamic Modeling of Geochemical Systems	R. B. Duffield L. Blatz et al. L. Blatz, C. Holley C. C. Herrick	LASL LASL LASL LASL	ERDA-DPR ERDA-DPR ERDA-DPR ERDA-DPR
6.	Observational and Analytical Petrology and Geochemistry a. Rock—Solution Equilibria in Agitated Systems b. Single Mineral Alteration in a Static System	R. B. Duffield J. Balagna et al. J. Balagna et al.	LASL LASL LASL	ERDA-DPR ERDA-DPR ERDA-DPR
7.	Rock-Water Interactions	R. O. Fournier	USGS, Menlo Park	USGS
8.	Computer Modeling of Rock-Water Interactions	J. L. Haas	USGS, Reston	USGS
9.	Physical Chemistry of Geothermal Solutions a. Ionization of water in NaCl solution to 300°C b. Ionization and polymerization of silica acid c. Activity coefficients in geothermal solutions	R. E. Mesmer R. E. Mesmer, R. H. Busey R. E. Mesmer, R. H. Busey C. F. Baes et al.	ORNL ORNL ORNL ORNL	ERDA-DPR ERDA-DPR ERDA-DPR ERDA-DPR
10.	A Study of Brine Treatment	S. L. Phillips	LBL	EPRI
11.	Volumetric Properties of Brines	R. W. Potter	USGS, Menlo Park	USGS
12.	Thermodynamic Tables	R. A. Robie	USGS, Reston	USGS
13.	Development of probes for downhole and in-line chemical analysis of high pressure, high temperature geothermal fluids	D. W. Shannon	BPNL	ERDA-DGE

TABLE X (continued)

RESEARCH PROGRAMS RELATED TO GEOTHERMAL FLUID CONTROL: FY 1977 PROJECTS

A. BRINE CHEMISTRY (continued)

No.		Person in Charge, or Principal Investigator	Performing Organization	Sponsor
14.	Develop standard methods and manual for sampling and analysis for geothermal fluids and gases	D. W. Shannon	BPNL	ERDA-DGE
15.	Geochemical Indicators	A. H. Truesdell	USGS, Menlo Park	USGS
16.	Thermal waters	D. E. White	USGS, Menlo Park	USGS
17.	Geosciences relating to geothermal energy	P. A. Witherspoon	LBL	ERDA-DPR
	a. Thermodynamics of high temperature brines	K. S. Pitzer	LBL	ERDA-DPR
	b. Geochemistry and mass transfer in geothermal systems	J. A. Apps	LBL	ERDA-DPR

B. SCALING AND SLUDGE FORMATION

No.		Person in Charge, or Principal Investigator	Performing Organization	Sponsor
1.	Silica Precipitation and Brine Management	J. A. Apps	LBL	ERDA-DGE
	a. Silica and Mass Transport	O. Weres	LBL	ERDA-DGE
2.	Precipitation and scaling in dynamic geothermal systems	E. G. Bohlmann	ORNL	ERDA-DGE
	APEX: An advanced geothermal primary heat exchanger	B. Breindel	Aerojet Liquid Rocket Company	ERDA-DGE
3.	Computer modeling of geothermal energy extraction systems	R. Feber	LASL	ERDA-DGE
4.	Study of silica scaling from geothermal brines	W. H. Harvey	EIC Corp.	ERDA-DGE
	Research and development of cavitation descaling techniques for heat exchanger tubes used in geothermal energy plants	A. A. Hochrein, Jr.	Daedalean Assoc.	ERDA-DGE
	Feasibility study of the application of direct contact heat exchangers to power cycles utilizing geothermal brines	H. R. Jacobs	Univ. of Utah	ERDA-DGE
	Feasibility demonstration of geothermal downwell pumping system	W. D. McBee	Sperry Research Center	ERDA-DGE
	Experimental investigation of a helical rotary screw expander power system using geothermal brine	R. A. McKay	NASA-JPL	ERDA-DGE
	Second generation heat exchanger development	B. C. Musgrave	INEL	ERDA-DGE
	Two-phase flow in geothermal energy systems	L. Ross	Univ. Denver Research Inst.	ERDA-DGE

TABLE X (continued)

RESEARCH PROGRAMS RELATED TO GEOTHERMAL FLUID CONTROL: FY 1977 PROJECTS

B. SCALING AND SLUDGE FORMATION (continued)

No.		Person in Charge, or Principal Investigator	Performing Organization	Sponsor
5.	2000-hour heat exchanger test	Jose Samaniego	Ben Holt Company	EPRI
	Investigate brine chemistry and combined heat/mass transfer, scaling kinetics and develop models to predict geothermal plant degradation	D. W. Shannon	BPNL	EPRI
	Research on direct contact binary process for geothermal hot water	A. Sims	Ben Holt Company	ERDA-DGE
6.	Mobile geothermal fluids, materials, and components test laboratory	T. Springer	Rockwell International	EPRI
	Study and testing of direct contact heat exchangers for geothermal brines	W. Suratt	DSS Engineers	ERDA-DGE
7.	Scale formation and control for total flow turbine development	G. E. Tardiff	LLL	ERDA-DGE
	A study of direct contact heat exchange for extraction of energy from geothermal brines	E. Wahl	Occidental Research Co.	ERDA-DGE
8.	A study of scale formation and suppression in heat exchange systems for geothermal brines	J. S. Wilson	Dow Chemical USA	ERDA-DGE

C. GASES, VOLATILE BRINE CONSTITUENTS, CONDENSATE CHEMISTRY

No.		Person in Charge, or Principal Investigator	Performing Organization	Sponsor
1.	Control of hydrogen sulfide emission from geothermal power plants	W. H. Harvey	EIC Corp.	ERDA-DGE
2.	Investigation of hydrogen sulfide removal from simulated geothermal brines by reactions with oxygen	J. S. Wilson	Dow Chemical USA	ERDA-DGE
3.	Removal of hydrogen sulfide from geothermal steam	P. C. Walkup	BPNL	ERDA-DGE

D. ENVIRONMENTAL PROBLEMS

1.	Imperial Valley Environmental Project	P. L. Phelps	LLL	ERDA-DBER

V. PROGRAM IMPLEMENTATION

The purpose of this report is the definition, rather than the implementation, of a program addressed to engineering development and research problems relating to the use of geothermal fluids. However, a brief comment is needed to clarify the way in which this report can be used to implement a program.

The steps leading to the implementation of the program, starting from this report, would be:

A. Development of a Program Plan

1. Review of the contents of the report by a team of experts;
2. Assignment of priorities to various projects;
3. Estimates of appropriate manpower, timing, and costs;
4. Development of various program plan options.

B. Program Implementation

1. Solicitations of qualification statements from interested parties for the various project categories;
2. Release of R.F.P.s;
3. Review of solicited project proposals and incorporation of approved projects in a program plan;
4. Implementation of the program.

Other strategies might be adopted to implement the program. However, this outline is the one envisioned during the preparation of this report.

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