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Environmental Development Plan (EDP)

GEOHERMAL ENERGY SYSTEMS 1977

March 1978

U.S. Department of Energy

Assistant Secretary for Energy Technology

Assistant Secretary for Environment

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FOREWORD

Environmental Development Plans (EDP's) were conceived and prepared as basic documents for planning and managing environmental requirements of energy technology development. Approximately 30 EDP's covering major developing energy technologies were prepared prior to the establishment of the Department of Energy (DOE). Elements of various organizations were involved in the preparation and review of these plans but reorganization of program responsibilities has made it impossible to complete the formal review and concurrence process as originally planned.

These EDP's are now being distributed so that all having interests and responsibilities may assist in a revision and update which we plan to initiate in DOE along with preparation of EDP's covering environmental aspects of additional DOE programs.

James L. Liverman
Acting Assistant Secretary
for Environment

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Acting Assistant Secretary
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ENVIRONMENTAL DEVELOPMENT PLAN

FOR

GEOTHERMAL ENERGY SYSTEMS

SEPTEMBER 1977

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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"This Environmental Development Plan is an internal working document used for planning the environmental health and safety research activities of ERDA energy systems. The Plan is subject to changes characteristic of day-to-day program management."

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1.0 INTRODUCTION

1.1 Purpose

The Geothermal Energy Systems Environmental Development Plan (EDP) identifies the environmental, health, safety, social, and economic (EH&S) issues which are associated with the development, demonstration, and commercialization of geothermal resources and conversion technology. The EDP also describes the ERDA actions and implementation strategy required to resolve the issues identified. These actions may include the initiation of R&D activities, operations monitoring, baseline characterization studies, or activities leading to the development of EH&S standards and criteria in concert with other responsible agencies.

1.2 Background

1.2.1 Resources

Geothermal resources of near-term interest are of three types: hydrothermal, geopressured, and hot dry rocks.

1.2.1.1 Hydrothermal

Hydrothermal resources are convective systems of water and steam which are trapped in fractured rocks or sediments by impermeable surface layers. Geothermal fluids are released when such systems are tapped by drilling. A specific resource is classified as being either "vapor" or "liquid" dominated, according to the state of the fluid produced.

Hydrothermal resources have high potential for accelerated commercial development. For example, vapor dominated resources are presently being utilized for the generation of electricity in the U. S., Japan, and Italy; as are liquid dominated resources in Iceland, Mexico, El Salvador, Russia, and New Zealand.

1.2.1.2 Geopressured

Geopressured zones consist of highly porous sands saturated with brines at high temperature and very high pressure which are thought to occur as a result of normal heat flow being trapped by uncompact clays which serve as an insulating layer. Waters derived from the compaction and dehydration of the clays accumulate in the sands and greatly increase the fluid reserve. The marine sediments are under-compacted below depths of 6,500 to 10,000 feet and the interstitial fluid carries part of the overburden load (i.e., the fluids are at pressures between the hydrostatic and the lithostatic head). Temperatures up to 290° C and pressures up to 1000 atm have been measured in these systems. In the United States, the principal geopressured zone is located under the Gulf coast of Texas and Louisiana.

Difficult technical and economic problems must be solved before geopressured resources can be utilized commercially. The magnitude of the resource is substantial and its economic value is enhanced by the presence of natural gas dissolved in the geopressured fluid.

1.2.1.3 Hot Dry Rocks

Hot dry rock resources are those geothermal reservoirs where the heat is contained in rock without natural circulating fluids that overlays a local heat source, such as a magma chamber. Hot dry rock systems are potentially the most extensive and widely distributed geothermal resource in the nation. A large volume of hot dry rock (normal gradient resource) is located in the earth's crust at depths in excess of 15km (50,000 feet), which are beyond present drilling capability. However, the volume of hot dry rock at shallower, accessible depths is considerable. It is estimated that 95,000 square miles of the Western Heat Flow Province (the 13 Rocky Mountain and Pacific Coast states) is underlain by hot dry rock at temperatures greater than 293°C at depths of less than 5km (16,000 feet). Two specific promising areas are the Valles Caldera, near Los Alamos, New Mexico, and the Coso Hot Springs, near China Lake, California.

Development of these resources requires drilling into the rock, inducing artificial fracturing, injecting fluid, and removal of the resultant fluid through separate wells. Technical problems associated with fracturing and maintaining these fractures must be solved before these resources can be developed commercially.

1.2.2 Federal Program

The federal geothermal program is directed toward providing those initiatives which are needed to effect accelerated commercial development while maintaining environmental acceptability and operational safety. It involves the activities of several agencies including ERDA, DOI, FEA, DOA, EPA, and others. ERDA has the responsibility for coordinating the program and for establishing national goals for geothermal development. Coordination is accomplished through the Interagency Geothermal Coordinating Council (Figure 1.1). The achievement of environmental acceptability and operational safety are the responsibility of several agencies: ERDA, DOI, EPA, CEQ, and OSHA (Figure 1.2).

1.3 Scope

The ERDA geothermal environmental program is comprised of several elements:

- o Projects directly supportive of resource or energy conversion technology development.
- o Projects addressing generic EH&S issues, generally of long term and fundamental in nature, with applicability to other technologies in some instances.
- o Projects designed to support and enhance resource development efforts of other agencies.
- o Projects designed to support promising regional or area geothermal resource development activities outside the federal program.

These elements support ERDA projects for development, demonstration, and commercialization of geothermal resources. Schedules and milestones of the

FIGURE 1.1

ORGANIZATIONAL RESPONSIBILITIES WITHIN THE FEDERAL GEOTHERMAL PROGRAM

FIGURE 1.2

FEDERAL ENVIRONMENTAL LAWS FOR GEOTHERMAL ENERGY SYSTEMS

2.0 GEOTHERMAL ENERGY DEVELOPMENT PROGRAM

2.1 ERDA Program

2.1.1 Resource and Conversion Technology Development

The geothermal resource development, conversion technology development, and demonstration projects which are currently in progress or which are planned by ERDA are shown in figures extracted from the Geothermal Energy Development Program Approval Document for FY 1977. Figure 2.1 shows the schedules and milestones for geothermal technology applications. Figure 2.2 presents the schedule for utilization experimentation; Figure 2.3 the schedule for exploration and assessment of geothermal resources; and Figure 2.4 the schedule for engineering research and development.

2.1.2 Environmental, Health, and Safety Program

The ERDA program to address the environmental, health, and safety impacts of geothermal energy development is covered in detail in Section 4. Briefly, this technical program is of two types. There are generic studies, particularly in the areas of ecology, biology, and human health effects, which examine impacts that may be common to more than one technology. Secondly, there are studies which address impacts unique to geothermal development or to a specific geographic area. These studies generally are a part of an Environmental Project (see Section 4.5). In parallel with these efforts, there are programs to assess control technology needs and to identify EH&S standards needed for technology development.

2.1.3 Institutional Studies

In addition to those projects which are purely technical in nature, there are a number which involve the study of institutional constraints. Those projects which address the problems of cooperation between federal, state, and regional agencies; resource and technology development scenarios; and assessment of political and legal constraints are shown in Figure 2.5. These studies and analyses are particularly important in the determination of which initiatives should be undertaken by ERDA in support of the federal program.

2.1.4 Regional Scenario Development

Technology planning studies have identified and prioritized candidate areas for geothermal commercial development. As a result of these studies to date, initiatives in the form of environmental baseline measurements projects and effects studies have been undertaken or are planned. The first of these Environmental Projects was the Imperial Valley Environmental Project (IVEP). Planning is underway for Environmental Projects in the Raft River region of Idaho and the Texas-Louisiana coast. Other areas in which Environmental Projects are in planning or under consideration include The Geysers, California; Roosevelt Hot Springs, Utah; Long Valley, California; Coso Hot Springs, California; Valles Caldera, New Mexico; Hawaii; and sections of northern Nevada. These and other areas which show promise and which may be likely candidates for development before 1985 are described in Appendix A.

2.2 Environmental, Health, and Safety Impacts

The nature and extent of the potential EH&S impact of the geothermal program can be seen in Table 2.1, which lists those impacts which may result from development activities.

FIGURE 2.1

☆ Administrator Controlled Milestone
 △ Critical Milestone
 △ Begin Activity
 ▽ Complete Activity
 ◇ Schedule Deviation
 ○ Decision Point

FIGURE 2.1 (Continued)

FIGURE 2.1 (Concluded)

FIGURE 2.2

UTILIZATION EXPERIMENTS

★ Administrator Controlled Milestone

△ Critical Milestone

△ Begin Activity

▽ Complete Activity

◇ Schedule Deviation

○ Decision Point

FIGURE 2.3 (Concluded)

☆ Administrator Controlled Milestone
 △ Critical Milestone
 △ Begin Activity
 ▽ Complete Activity
 ◇ Schedule Deviation
 ○ Decision Point

FIGURE 2.4 (Concluded)

FIGURE 2.5

INSTITUTIONAL STUDIES

POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH GEOTHERMAL DEVELOPMENT

TECHNOLOGY ACTIVITIES	POTENTIAL ENVIRONMENTAL IMPACTS
<u>RESOURCE DEVELOPMENT</u>	
<ul style="list-style-type: none"> o Reservoir exploration <ul style="list-style-type: none"> Field exploration, seismic studies and shallow hole drilling. o Test drilling and production testing <ul style="list-style-type: none"> - Site preparation, drilling operations, well testing, and well abandonment. 	<p>Operations have potential for noise, fumes, contamination of surface or ground water from mud pits, use of local water resources for drilling, increase in water turbidity, siltation of streams, erosion, changes in topography, and accidental contamination of ground water from drilling.</p> <p><u>Air Quality</u> - Water vapor and non-condensed gases are released into atmosphere with possible CO₂, CH₄, H₂S, NH₃, As, Rn, Hg, H₃BO₃ contaminants. Noise may reach high levels if unabated. Vehicle and machinery exhausts may cause degradation of air quality.</p> <p><u>Water Quality</u> - Chemical and thermal contamination of surface or groundwater may occur due to blowouts, leakage from holding ponds, well casing failure, improper interception of fresh water aquifers, improper injection of spent fluids. Increased siltation and turbidity in local water bodies may occur as a result of grading operations.</p> <p>Increased water consumption during drilling operations may severely impact water supply, particularly in arid areas.</p> <p>Operations in coastal areas are subject to storms and hurricanes which can destroy or inundate holding ponds and mud pits resulting in contamination of local areas, both water and land.</p>

Source: ERDA, Environmental Impact Assessment - Hydrothermal Program (EIA/GE/77-2), March 1977; Draft Impact Assessments - Geopressure and Hot Dry Rock Subprograms, October 1976 and March 1977.

Table 2.1 (Continued)

POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH GEOTHERMAL DEVELOPMENT

TECHNOLOGY ACTIVITIES	POTENTIAL ENVIRONMENTAL IMPACTS
<ul style="list-style-type: none"> o Field development 	<p><u>Land Impact</u> - Soil contamination may occur from disposal of drilling muds, improper containment or disposal of fluids, and leaching of salts from evaporation ponds. Topographic alterations and aesthetic impacts may be important.</p> <p>Drilling in wetlands will entail dredging or filling of marshes.</p> <p>Impacts are identical to those of test drilling but impacts are cumulative in nature and therefore more extensive.</p>
<p><u>RESOURCE UTILIZATION</u></p> <ul style="list-style-type: none"> o Electric production <ul style="list-style-type: none"> - Plant construction - Pipeline construction and operation 	<p>Effects would be similar to those of any construction project; e.g., noise, soil erosion, air quality degradation, water pollution if liquid construction wastes are not properly disposed, and diversion of land use.</p> <p>If activity is being carried out in a coastal area, there may be dredging and/or filling of marshy areas.</p> <p>Erosion and siltation from vegetation removal and excavation, wildlife, scenic, and recreational impacts may result.</p> <p>Construction of pipelines in marshy areas will require extensive dredging or filling operations, resulting in damage to plant and wildlife.</p> <p>Failure of pipeline with release of liquids and gases could result in damage to vegetation and aquatic systems. Hurricanes are potential causes of such failures.</p>

Table 2.1 (Continued)

POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH GEOTHERMAL DEVELOPMENT

TECHNOLOGY ACTIVITIES	POTENTIAL ENVIRONMENTAL IMPACTS
<ul style="list-style-type: none"> - Transmission line construction 	<p>Construction and maintenance may take land out of production. Lines may create hazards to birds, particularly in salt marshes used by migratory and wintering species.</p>
<ul style="list-style-type: none"> - Power plant operations 	<p>Environmental effects may be caused by continuous intrusion into wildlife habitats, release of noncondensed gases, and other effluents, subsidence from fluid withdrawal, induced seismicity and freshwater aquifer contamination from spent fluid injection, and diversion of available water resources.</p>
<ul style="list-style-type: none"> - Heat dissipation systems 	<p>Disposal of spent fluids directly into coastal waters may cause excessive local heating.</p>
	<p>Potential impacts associated with use of mechanical-draft, wet cooling towers are drift, fogging, icing, blowdown of concentrated salts to local waters, release of noncondensed gases, water consumption, and noise.</p>
	<p>Spray ponds can have considerable saline drift and chemical treatment is usually required. Greater land requirements, seepage, some fogging and icing may present problems.</p>

Table 2.1 (Continued)

POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH GEOTHERMAL DEVELOPMENT

TECHNOLOGY ACTIVITIES	POTENTIAL ENVIRONMENTAL IMPACTS
<u>NON ELECTRIC APPLICATIONS</u>	
o Construction effects	Effects are similar to those for electric production but impacts are less extensive. There are no transmission lines but pipeline networks to deliver fluids may be more extensive.
o Operation effects	Effects are similar to those for electric production. Need for cooling towers should not be as great.

3.0 ENVIRONMENT, HEALTH, AND SAFETY ISSUES

Environmental changes have been observed to accompany development of hydrothermal resources in various parts of the world. The magnitudes of the associated EH&S impacts have varied widely and depend upon the site, the character of the resource, the nature of the utilization system or process, and the success of control or mitigation efforts. This experience with hydrothermal systems provides a rational means of defining potential problems that must be resolved before significant additional development of hydrothermal systems occurs. For geopressured and hot-dry-rock systems there is no experience with fully developed systems and the initial feasibility experiments are not yet completed. Therefore it is only possible at this time to predict the EH&S issues in a general way.

An important output of the ERDA Environmental Program is to recommend the degree of control that should be maintained over effluents and other factors associated with the development of geothermal resources. These recommendations will be in the form of ERDA environmental policy and design criteria, and may subsequently provide the basis for regulatory actions by other agencies.

The environmental issues are described below, along with a brief discussion of the circumstances that underlie the issues. A more detailed discussion of the issues appears in Appendix B. The program requirements for their resolution are discussed in Section 4.

3.1 Air Quality Issues

The air quality issues concern the constraints that should be imposed on the release of effluents into the atmosphere and on the generation of atmospheric physical disturbances to assure that any degradation of air quality from geothermal energy operations be held to acceptable levels. Geothermal energy operations which could impact air quality are discussed in the following sections.

Energy Extraction System

Hydrothermal fluids generally contain a number of compounds which do not condense during the energy extraction process and which may be released to the atmosphere. These compounds include CO_2 , NH_3 , H_2S , CH_4 , Rn, Hg, and H_3BO_3 . Of these, H_2S is of greatest concern because of its disagreeable odor at very low concentrations and its toxic effects at higher concentrations. Fluids from geopressured zones contain large amounts of CH_4 which will be recovered. Other noncondensed gases may also be present, but data are not presently available. Exogenous fluids will be used to extract energy from hot-dry-rock systems. It is not known at this time whether volatile compounds will be dissolved in these fluids and released at the surface.

Cooling System

Many uses of geothermal energy will require heat rejection systems which typically are wet cooling towers or spray ponds. If steam condensate is used to supply all or part of the water requirements for such systems, dissolved volatile compounds and solids can be carried over into the system and released in the form

of vapor or drift. Cooling water additives may also be released, and the potential for ecological harm of all these compounds must be determined. In addition, the large quantities of water vapor released by wet cooling systems may adversely affect microclimatic conditions by altering patterns of fogging and humidity.

Noise

Uncontrolled noise associated with exploration and drilling, well venting and testing, and operational processes can reach levels as high as 120 dBA and may have deleterious effects on both human populations and local fauna. This issue is particularly important for vapor-dominated hydrothermal resources and may be important for geopressured resources.

3.2 Water Quality Issues

The water quality issues concern the constraints that should be imposed on the release and disposition of effluents from geothermal energy operations that may degrade the quality of ground and surface waters. The two operations of geothermal energy exploitation which could impact water quality are discussed below.

Spent Geothermal Fluids

The management of spent geothermal fluids is a significant problem for hydrothermal and geopressured systems. These fluids may contain dissolved volatile compounds and large quantities of dissolved solids. Present plans are to inject spent hydrothermal fluids back into the reservoir. It may not be economically feasible, however, to inject geopressured fluids back into the reservoir, but they may be injected into shallower layers which contain saline water or perhaps released to surface waters that empty into the ocean. In all cases, the contamination of sources of water of beneficial use must be avoided.

Cooling System Blowdown

Liquid blowdown from wet cooling towers or spray ponds may contain the same contaminating substances described above in Section 3.1. In addition, there may be additional dissolved toxic substances, such as heavy metals and radio-nuclides, contained in this liquid fraction.

3.3 Land Disturbance Issues

The land disturbance issues concern the constraints that should be placed on the development and exploitation of geothermal energy to assure that structural changes to the land do not result in unacceptable consequences. The two land disturbance issues associated with geothermal energy are discussed below.

Subsidence

The removal of large quantities of fluids from liquid-dominated or geopressured reservoirs may result in subsidence. For example, a maximum rate of subsidence of 1.3 feet/year has been measured at the Wairakei, New Zealand, power plant which utilizes a liquid-dominated hydrothermal reservoir with spent fluid discharge to surface waters.

It is anticipated that the injection of spent hydrothermal fluids back into the reservoir will not only solve the liquid waste disposal problem, but also eliminate or mitigate subsidence. For geopressured resources, injection of spent fluids back into the reservoir may not be feasible for economic reasons.

The importance of subsidence will be site-specific. It may be of significant importance at locations such as the Imperial Valley where hydrothermal reservoirs are overlain by agricultural lands irrigated and drained by gravity-flow systems, or on the Gulf Coast where lands overlying geopressured reservoirs are only a few feet above sea level.

Seismicity

Another question is whether the withdrawal and injection of geothermal fluids may enhance the occurrence of microseismic events, or even trigger a major earth movement. The most likely cause of induced seismicity is believed to be the injection process. Studies in Colorado have demonstrated that the occurrence of microseismic events is enhanced as the result of the high-pressure injection of fluids.

It is not known what pressures will be required to maintain the injection of spent hydrothermal fluids over long periods of time at liquid-dominated sites, but field trials indicate that the pressures may be well below those demonstrated to cause induced microseismicity. The possible lubrication of a major fault and the resultant triggering of a major earthquake is an unresolved issue at hydrothermal sites; careful site selection to avoid major faults should alleviate this concern.

The production of seismic events as a result of utilizing geopressured or hot-dry-rock reservoirs is considered unlikely, but field test data are not available.

3.4 Social and Economic Issues

The social and economic issues concern the controls that should be imposed on geothermal energy development to minimize any deleterious effects on society and maximize beneficial effects of such developments. In this context, society includes the population in general as well as the residents of the particular region under development. The areas of social and economic impact are described below.

Water Use

Many proposed methods of utilizing geothermal energy will require the availability of exogenous water for heat rejection systems. As many geothermal resources are located in areas of limited water supply, conflicts may arise as to the most beneficial use of this finite resource. Direct competition with agricultural use is most likely, but conflicts with community and recreational uses may also arise. If they are recognized early, such conflicts can perhaps be resolved by more expensive alternates such as dry-wet hybrid cooling towers or by designing cooling systems that can utilize brackish water. Positive benefits may even be achieved if high-quality steam condensate can be produced and made available for other beneficial uses.

Social Services and Community Structure

All geothermal developments will have an impact through the demand for workers and the influx of money. This impact may be considered as positive or negative depending upon the existing community structure and lifestyle, and may range from negligible to severe depending upon the size of the development and the size and diversity of the local economy. There almost certainly will be increased demands for housing and additional burdens upon public schools and other community services such as recreation, water supply, and sewage treatment. A generic issue is the possible mismatch between the local entities that enjoy increased tax revenues and the ones that experience the actual demand for services.

Fortunately, geothermal developments will probably occur in rather small increments rather than the construction of a single, massive facility. It should therefore be possible to plan for the orderly provision of increased social services. In order to accomplish this, however, it will be necessary to develop realistic development scenarios including projected employment and related demands upon the affected communities.

Land Use

One of the constraints to geothermal developments may be conflicts over land use. Some developments may be opposed because they threaten pristine wilderness areas, impact upon habitat of endangered, threatened or recreationally important species, or conflict with other beneficial uses such as agriculture or recreation. Many such conflicts can be avoided by the early recognition and avoidance of highly sensitive areas, beneficial practices such as habitat enhancement, and careful planning to minimize total land usage.

3.5 System Safety and Occupational Health Issues

The health and safety issues that affect the operation of geothermal energy facilities are the measures that must be taken to ensure that the operation of such facilities adequately provides for the medical and health surveillance and safety of the workers at the facility.

The safety of geothermal energy extraction and utilization systems could become a major issue if early significant failures should occur. Well blowouts have already occurred at several geothermal power plants including The Geysers, California, and Cerro Prieto, Mexico. These events apparently have not caused major damage due to the isolated locations of the power plants, but such events could be much more serious in other locations.

Many proposed geothermal plant designs include secondary or tertiary loops with working fluids such as isobutane and propane. Containment of such fluids is important as they represent potentially explosive mixtures. In addition, many geothermal fluids are corrosive and erosive to standard materials. Because of such potential problems, there is a need for a detailed examination of the overall safety of geothermal energy systems.

4.0

ENVIRONMENTAL, HEALTH, AND SAFETY PROGRAM

4.1

Environmental, Health, and Safety Requirements

The resolution of the issues discussed in Section 3 generates the need for a set of required data and information. These requirements are listed in Table 4.1. These data- and information-gathering requirements generally fall into three categories—baseline characterization, operational site measurements and monitoring, and effects studies. In addition, there are analytical and engineering categories of requirements that make use of the data and information gathered in the earlier efforts.

4.2.

Strategy

The EH&S program consists of numerous tasks that are designed to develop information and data needed to resolve the issues. For effective program management, related tasks are combined into categories, mentioned above, which conform in general to the scientific and technical disciplinary groups or field organizations that perform the work:

- Baseline characterizations to identify potential impacts and to establish the environmental conditions before significant geothermal development takes place. (See Section 4.5)
- Operational site measurements and monitoring to assess environmental conditions during resource development and energy production operations. (See Section 4.6)
- Effects studies to evaluate the ecological, health, safety, social, and economic impacts of geothermal developments, and to develop the capability to predict long-term consequences. (See Section 4.7)
- Integrated assessment and evaluation of our knowledge concerning the issues.
- Environmental control and abatement research to limit emissions and reduce impacts to prescribed or acceptable levels. (See Section 4.8)
- Development of environment, health, and safety guidelines and performance criteria. (See Section 4.9 and 4.10)

One aspect of the EH&S program undertakes specific sets of tasks that make up Geothermal Environmental Projects, each of which is associated with a particular region or site at which geothermal development is planned or in progress. Each Environmental Project is planned and managed so that environmental criteria for design and policy decisions that are important to its region can be provided when they are needed. Geothermal Environmental Projects are discussed in greater detail in Section 4.5.

Table 4.1

Environmental, Health, and Safety Issues and Requirements for Geothermal Energy

Issues	Principal Applicable Requirements	Requirements
AQ <u>Air Quality Issues:</u> What constraints should be imposed on the release of effluents into the atmosphere and on the generation of atmospheric physical disturbances to assure that any degradation of air quality from geothermal energy operations be held to acceptable levels?	A.1,A.2 B.1,B.2 C.1,C.2,C.3 D.1,D.2 E.1,E.2	A. <u>Baseline Characterization</u> A.1 Conduct preplanning assessments and develop operational baseline characterization plans in accordance with regional priorities established by DGE plans. A.2 Conduct baseline characterization as recommended by the GEO Committee and with the concurrence of the cognizant program Divisions and Offices.
WQ <u>Water Quality Issues:</u> What constraints should be imposed on the release and disposition of effluents from geothermal energy operations that may degrade the quality of ground and surface waters?	A.1,A.2 B.1,B.2 C.1,C.2,C.3 D.1,D.2 E.1,E.2	B. <u>Operational Site Measurements and Monitoring</u> B.1 Conduct analyses of process streams and other operational site sources to assess potential effluents and EH&S impacts. B.2 Monitor the operational performance of environmental control apparatus and procedures. B.3 Assess safety and reliability of potentially hazardous ERDA operations. B.4 Assess the adequacy of occupational medical and health surveillance procedures.
LD <u>Land Disturbance Issues:</u> What constraints should be placed on the development and exploitation of geothermal energy to assure that structural changes to the land do not result in unacceptable consequences?	A.1,A.2 C.4,C.5 D.1,D.2 E.1,E.2	C. <u>Effects Studies</u> C.1 Determine the effects of effluents and other operational aspects of geothermal operations on ecological systems. C.2 Determine the effects of effluents and other operational aspects of geothermal operations on plants and animals. C.3 Determine the effects of effluents and other operational aspects of geothermal operations on the health of the general population. C.4 Analyze plans for the development of geothermal energy resources and determine the probable effects on water use allocations. C.5 Analyze plans for the development of geothermal energy resources and determine the probable effects on land use allocations. C.6 Analyze plans for the development of geothermal energy resources and determine the probable consequences for social services and community structure.
SE <u>Social and Economic Issues:</u> What controls should be imposed on geothermal energy development to minimize any deleterious effects on communities involved and to maximize beneficial effects?	A.1,A.2 B.1,B.2,B.3,B.4 C.3,C.4,C.5,C.6 D.1,D.2 E.1	D. <u>Integrated Assessment</u> D.1 Develop environmental decision criteria and develop consensus standards where official standards do not exist. D.2 Develop continuing appraisals of our knowledge concerning the environmental issues and their resolution.
SS <u>System Safety and Occupational Health Issues:</u> What measures should be taken to ensure that the operation of geothermal energy facilities adequately provides for the medical and health surveillance and safety of workers?	A.1,A.2 B.1,B.2,B.3,B.4 C.3,C.6 D.1,C.2 E.1,E.2	E. <u>Measurement and Control Technology</u> E.1 Develop control technologies as needed to meet regulatory standards and environmental design criteria. E.2 Develop improved procedures and systems needed for environmental measurements and monitoring.

In addition to the work undertaken as integral parts of Environmental Projects, all categories encompass other tasks that have general applicability to geothermal environmental concerns and frequently to other technologies as well. Ecological, biological and human health effects studies of substances that are characteristic effluents of geothermal operations are usually of this generic type.

Environmental Projects and the generic tasks require somewhat different management methods. The plans for management and coordination of Environmental Projects and for the generic tasks are discussed in Section 4.3.

4.3 Program Management

4.3.1 Environmental Projects

ERDA plans for regional developmental activities, which are described in Section 2 and Appendix A, determine the establishment of priorities for regional overview pre-planning assessments, which are the bases for operational planning of Environmental Projects (see Section 4.5). ERDA performs pre-planning assessments in close collaboration with public, private, and institutional groups who represent responsible interested parties and decision makers from within the regions.

4.3.2 Generic Tasks Program

Individual investigations and studies are conducted by ERDA when they are needed to facilitate the resolution of environmental issues. An appraisal of the issue-relevance and relative priority of a proposed task is made prior to its initiation.

4.3.3 Program Quality Control

ERDA monitors the quality of tasks within its programs. Peer reviews are the principal means for exercising this quality assurance responsibility.

4.3.4 The Geothermal Environmental Overview Committee

A Geothermal Environmental Overview (GEO) Committee has been established at ERDA Headquarters to serve in an advisory capacity on ERDA's EH&S program. The intended purpose of this committee is to:

- Review and discuss planned and ongoing geothermal environmental activities.
- Seek and provide advice on EH&S problems of mutual interest and concern.
- Recommend courses of action on EH&S problems.
- Provide comments and assistance on the preparation of geothermal EDPs.

4.3.5 Responsibility

Those offices within the Department of Energy that will assume various Program responsibilities cannot be identified at this time. After assignments of Program responsibilities have been made, they will be included in a revised EDP.

4.4 Environmental Overview Pre-Planning Activities

Pre-planning is a key function in the ERDA environmental overview program. This effort uses local resources for the development of a preliminary assessment of available data regarding prospective Known Geothermal Resource Areas (KGRAs) and the identification of information gaps and key issues for further study. The objective is to develop sufficient information about the geothermal region proposed for development to enable ERDA to forecast future EH&S program requirements and to identify resources needed to meet those requirements. Information developed as a result of pre-planning activities may lead to the preparation of a plan for the establishment of Environmental Projects. Environmental overview pre-planning activities which are currently in progress or which are planned by ERDA are shown in Figure 4.1.

4.5 Environmental Projects

An Environmental Project is a comprehensive study of a designated area which is designed to accomplish the following activities:

- Identify the potential environmental impacts from the development of the resource.
- Determine environmental baseline conditions prior to development.
- Perform effects studies designed to support model development and to predict impacts.
- Monitor effects and evaluate the impacts associated with geothermal development.

Environmental Projects currently underway or planned are discussed below.

4.5.1 Imperial Valley Environmental Project

The IVEP is an example of what a typical Environmental Project entails. The extensive land area involved includes four of the six KGRAs distributed throughout Imperial County, California.

The Project involves extensive planning and evaluation activities as shown in Figure 4-2. The Project plan is updated continuously as data are collected and integrated assessment is completed. Figure 4.3 shows the temporal relationship of the IVEP units. Initial assessments are made to help characterize potential problems and to identify issues where further research efforts and data collection are required for improved evaluation and assessment.

△ Begin Activity

▽ Complete Activity

FIGURE 4.1

GEOHERMAL ENVIRONMENTAL OVERVIEW PRE-PLANNING

FIGURE 4.2
IMPERIAL VALLEY ENVIRONMENTAL PROJECT
MAJOR PLANNING AND EVALUATION FUNCTIONS

PROJECT UNIT		FY 76	FY 77	FY 78	FY 79	FY 80
1.0	Air Quality			Measurement and characterization	Transport/diffusion modeling	Monitoring
2.0	Water Quality			Geothermal well source characterization		
3.0	Subsidence/Seismicity				Subsidence modeling	Subsidence/seismicity monitoring
4.0	Ecosystem Quality			Baseline collections		
5.0	Socioeconomics		Systems characterizations	General tax-recreation studies	Dose response curves	Health statistics
6.0	Health Effects		Development scenarios			

Responsibility picked by non-IVEP Funding

△ Begin Activity

▽ Complete Activity

FIGURE 4.3

IMPERIAL VALLEY ENVIRONMENTAL PROJECT UNITS

Integrated Assessment, the final task listed in the Project, evaluates the total impact of geothermal energy development upon man and his environment. It will be available for the use of all appropriate agencies, legislative bodies, and planning groups. It serves as the focal point for coordinating data collection and research efforts among the primary survey tasks: Air Quality, Water Quality, etc.

Although the IVEP is scheduled to terminate as an integrated Project in FY 1978, certain functions such as monitoring activities and health effects studies are scheduled to continue (Figure 4.3). These functions will be continued to monitor resource development effects on environmental baselines, and to validate/refine predictive models and processes.

4.5.2 Raft River Environmental Project

Environmental baseline and effects studies are in progress for a limited region of the Raft River, Idaho. The initial phase of the Project (RREP) is scheduled for completion during the second quarter of FY 1977. The Project schedule is shown in Figure 4.4. Although the area involved in the Project is only a fraction of the size of that involved in the IVEP, the Project's functional content is almost identical. As in the case of the IVEP, portions of the Project will be continued after baseline studies are complete.

4.5.3 Texas-Louisiana Environmental Project

Planning activities for environmental baseline and effects studies are scheduled to begin during the last quarter of FY 1977 for the geopressed region of the Texas-Louisiana Gulf Coast. A preliminary version of the Project (TLEP) schedule is given in Figure 4.5. As with the IVEP, the Project's functional content is virtually identical.

4.6 Operational Monitoring

The IVEP, the RREP, and the TLEP include activities to monitor the long-term operational effects of geothermal energy systems on a regional basis. These site-specific activities will be carried out mainly by the technology system developer and operator. Data will be input to the Environmental Project data base for use in performance assessment and model verification.

4.7 Environmental, Health, and Safety Effects Studies

Generic and project studies are planned in the areas of ecosystem quality (physical, biological, health, etc.) and socioeconomic effects. In addition, there are a number of other generic EH&S studies which address the issues of Section 3, generally from the long-term viewpoint.

Although each EH&S issue is being addressed by some current or planned effects study, there are areas where the need for additional research has been identified. These requirements will be met by revising existing studies or by initiating new studies in 1977 and subsequent fiscal years.

4.7.1 Noncondensed Gases

Additional studies are planned on H₂S and NH₃ because of their potential for severe ecological and health effects. Specific studies are planned to determine

FIGURE 4.4

RAFT RIVER SITE ENVIRONMENTAL PROJECT UNITS

BUDGET - 4

A. BUDGET - 4

-34-

PROJECT FUNCTION	FY 77	FY 78	FY 79	FY 80	FY 81
1.0 Pre-planning	△	▽			
2.0 Development of Integrated Environmental Project Plan	△	▽			
3.0 Review and Upgrading of Environmental Project Plan		△		▽	
4.0 Project Implementation		△		▽	
5.0 Preliminary Integrated Environmental Assessments		△	▽		
6.0 Integrated Environmental Assessments			△		▽

△ Begin activity

▽ Complete activity

FIGURE 4.5

THE TEXAS-LOUISIANA ENVIRONMENTAL PROJECT
MAJOR PLANNING FUNCTION

ENVIRONMENTAL PROJECTS, INC.

1977

1978

1979

1980

1981

1982

ecological and health effects from long-term low-level exposure and from synergistic interactions with other agents. Research definition will be based on available toxicological data and surveys of existing or planned research.

4.7.2 Volatile Compounds

Additional efforts are planned to determine levels and occurrence in geothermal systems, and the transport and fate of pollutants containing B, As, Hg and other chemicals. More detailed information is needed concerning their toxicological properties to both plant and animal life as a result of long-term low-level exposures.

4.7.3 Cooling System Drift

Additional effort is planned to determine long-term ecological effects of drift and the combined effects of geothermal pollutants and cooling water additives which are used to inhibit scaling and corrosion. Plume model development and atmospheric effects are the subjects of research in progress.

4.7.4 Noise

Both short-term exposure to high levels of noise (120dB) and chronic exposure to more moderate industrial noise levels (90-95dB) will be examined for their effects on animal physiology and population dynamics. Effects of intrusions into wildlife habitats are not well known.

4.7.5 Water Quality

Toxicity studies are planned for aquatic biota from different "typical" geothermal sites and areas. The high degree of site dependence on the type and quantity of potential pollutants in geothermal fluids complicates the process of determining ecological impacts.

4.8 Environmental Control and Impact Abatement

The environmental control problems of greatest immediate concern to hydrothermal programs are H₂S emissions, subsidence from geothermal fluid withdrawal, and management/disposal of spent geothermal fluids. Programs aimed at the assessment and resolution of each of the three have been initiated. The principal elements of these programs are:

- Identification and assessment of the state-of-the-art of control technologies and identification of requirements for RD&D.
- Review of environmental analyses and project proposals for identification and assessment of control measures and needs for those controls.
- Design, development, testing, and implementation of advanced control technology.
- Evaluation of the operational performance of environmental control technologies.

Specific program elements currently underway are described below.

4.8.1 H₂S Control and Abatement

Hydrogen sulfide (H₂S) exhausted from direct-contact condensers and cooling towers of electric generating plants at The Geysers, California, result in atmospheric releases exceeding the allowable ambient levels of the State of California. As a result, no additional generating capacity has been installed since 1974. Attempts have been made to alleviate the problem by treating condenser effluents with Fe₂(SO₄)₃ to convert the dissolved H₂S to elemental sulfur. Later system designs include surface condensers which will eliminate the scrubbing actions of direct-contact condensers and concentrate the H₂S in the condenser ejector stream where single point treatment can be applied.

ERDA is expending considerable effort on the H₂S problem. A general survey of H₂S control and abatement technology state-of-the-art, and two specific control system development projects are underway as shown in Figure 4.6. Both ERDA-supported control systems treat the geothermal fluid ahead of the turbine, either as steam or as liquid.

4.8.2 Spent Fluid Disposal

An assessment program is underway which will survey the spent fluid (brine) disposal state-of-the-art and provide an R&D program plan for disposal systems development. The schedule for these activities is also shown in Figure 4.6.

4.8.3 Subsidence

A major research program designed to develop both understanding and control of geothermal related subsidence, and a study involving identification and assessment of computer codes which might be adapted for use in reservoir modeling have been initiated. Major milestones are included in Figure 4.6, and a detailed schedule of the subsidence research program is shown in Figure 4.7. It is anticipated that mutual support will be derived from these projects and the measurement activities in the IVEP and RREP.

4.8.4 Planned Projects

Plans are being developed for study and research projects in the areas of induced seismicity, noise and control of well venting and blowout. Implementation is scheduled for FY 1978 (Figure 4.6).

4.9 Environmental, Health, and Safety Standards and Criteria

The development of consensus standards and environmental performance criteria is necessary in those instances where official standards do not exist. Ideally, such standards should be arrived at through joint evaluations of impacts associated with a process by both the technology developer and the monitor/regulator. Although such standards can serve only as guidelines for development, they can become the basis for formal standards.

Under ERDA sponsorship, the National Bureau of Standards is developing an overview plan to assure that appropriate EH&S standards and criteria covering developing technologies (including geothermal) are developed in a timely manner. The results of this effort are expected to lead to a systematic approach to standards development involving ERDA and other governmental agencies and private institutions as appropriate. The plan is scheduled for completion on October 1, 1977.

FIGURE 4.6

ENVIRONMENTAL STUDIES AND CONTROL TECHNOLOGY DEVELOPMENT

FY '77

FY '78

FY '79

FY '80

△ Interim Report/Results; ▲ Final Reports/Results.

FIGURE 4.7

SUBSIDENCE RESEARCH PROJECT

The Pacific Northwest Laboratory is conducting an ERDA study which will generate a comprehensive analysis of existing EH&S problems associated with all phases of geothermal development and make recommendations for new standards, guidelines and regulations, as applicable. This study will facilitate the identification of standards needed for development as well as assess the adequacy of existing standards as applicable to the geothermal energy program. The milestone schedule is shown in Figure 4.8.

A set of guidelines for preparation of geothermal EIA/EIS reports has been prepared and issued. The schedule for updating is shown in Figure 4.6.

An EPA survey of existing standards and regulations has been completed, and pollution control guidelines for the geothermal industry are being developed.

4.10 Safety, Quality, and Reliability Assurance

Proposed geothermal power plant designs will involve the use of components and systems which are critical to safe operations. To provide for the performance of those functions necessary for reasonable assurance of safe operation of these plants, ERDA is developing a program to identify potentially hazardous operations. This program will also involve the application of quality, reliability, and human engineering techniques to the operations of critical components, subsystems, and systems. The Sandia Corporation has prepared a quality, reliability, and human factors program plan following a survey of selected non-nuclear programs. The plan is scheduled for issuance in October, 1977. Other key elements of the Safety, Quality, and Reliability Assurance Program are described below.

4.10.1 Performance Measuring System

A performance measuring system (PMS) is being developed to provide means for evaluating the EH&S performance of ERDA programs and operations. When implemented, this system will: (a) provide information on the status of EH&S program performance; (b) predict EH&S performance trends; (c) identify EH&S problem areas and needed program improvements; (d) track corrective actions; and (e) assist in prioritizing the distribution of ERDA's EH&S measures. Conceptualization of the PMS system is currently underway with implementation projected for FY 1979.

4.10.2 Independent Safety Review System

An ERDA-wide safety assessment system is being developed which will require an independent, uniform safety analysis to be performed on all technology development activities. System development activities planned for FY 1978 include: (1) developing procedures which will cover the technical aspects of the program, and (2) conducting a general safety review of all potentially hazardous ERDA activities. Implementation of the review system is projected for FY 1979.

4.11 EIA/EIS

A summary of the EIA/EIS activities scheduled for the geothermal program (Figures 2.1-2.4) is shown in Table 4.2. All EISs scheduled will be supported by the baseline measurements projects and effects studies which are in progress. Specifically, the preoperational baseline report (Figure 4.4) will precede the Raft

TASK	FY 1977								FY 1978								FY 1979								
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
1. Planning																									
2. Characterization and Appraisal of Specific Problem Areas																									
3. Literature Review																									
4. Analysis of Literature and Comparison to Problems																									
5. Site Surveys and Investigations																									
6. Standards Definitions																									

FIGURE 4.8

PACIFIC NORTHWEST LABORATORY PROJECT
TASK SCHEDULE

River Demonstration Plant EIS start and the first IVEP integrated Assessment Report (Phase A3) is scheduled prior to the start of the EIS for a proposed Demonstration Plant Number 1. Preliminary monitoring and assessment data will be available to support preparation of the Moderate Temperature Test Facility at East Mesa.

**TABLE 4.2
EIA/EIS REQUIREMENTS SUMMARY**

Figure	Project	Activity	Date
2.1	Add turbine to Thermal Test Loop-Niland	EIA Comp.	Sept. 1977
2.1	Test Facility-Niland	EIA Comp.	Nov. 1977
2.1	Moderate Temperature Test Facility-East Mesa	EIS Start	Mar. 1977
2.1	Thermal Loop-Raft River	EIA Start Comp.	July 1977 Nov. 1977
2.1	Pilot Plant-Raft River	EIS Start Comp.	June 1979 June 1980
2.1	Test Facility and Thermal Loop-Volcanic Resource	EIA Start	Oct. 1978
2.1	Low to Moderate Temperature Non-Electric Field Experiments	EIA Comp.	Apr. 1978
2.2	Demonstration Plant No. 1	EIS Start Comp.	Aug. 1977 Aug. 1978
2.2	Demonstration Plant No. 2	EIS Start Comp.	Mar. 1978 Apr. 1979
2.3	Reservoir Assessment - Industry Coupled Case Studies Non-Electric Eastern Radiogenic Non-Electric Reservoir Confirmation	EA Comp.* EIA Start EIA Comp.	Feb. 1977 June 1978 June 1978
2.3	Pre-commercial Reservoir Case Studies Hawaii Program Long Valley	EIA Comp. EIA Comp.	Aug. 1977 Aug. 1977
2.4	Utilization Technology - Impulse Turbine - Helical Screw Expander	EIA Comp. EIA Comp.	Mar. 1978 Mar. 1978
2.4	Wellhead Generator Systems - Flashed Steam - Binary	EIA Comp. EIA Comp.	Sept. 1977 Oct. 1977
-	Quick Response Geopressured Well Test	EIA Comp.	Oct. 1977
-	Geopressured Well Test - Brazoria County	EIA Comp.	Nov. 1977
-	Geopressure Subprogram	EIA Comp.	July 1977
-	Hydrothermal Subprogram	EIA Comp.	Mar. 1977
-	Hot Dry Rock Subprogram	EIA Comp.	Oct. 1977

*EA = Environmental Analysis

River Demonstration Plant EIS start, and the first IVEP Integrated Assessment Report (Figure 4.2) is scheduled prior to the start of the EIS for a proposed Demonstration Plant Number 1. Preliminary monitoring and assessment data will be available to support preparation of the EIS for the Moderate Temperature Test Facility at East Mesa.

1970-1971	1970-1971	1970-1971
1971-1972	1971-1972	1971-1972
1972-1973	1972-1973	1972-1973
1973-1974	1973-1974	1973-1974
1974-1975	1974-1975	1974-1975
1975-1976	1975-1976	1975-1976
1976-1977	1976-1977	1976-1977
1977-1978	1977-1978	1977-1978
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2015-2016	2015-2016	2015-2016
2016-2017	2016-2017	2016-2017
2017-2018	2017-2018	2017-2018
2018-2019	2018-2019	2018-2019
2019-2020	2019-2020	2019-2020
2020-2021	2020-2021	2020-2021
2021-2022	2021-2022	2021-2022
2022-2023	2022-2023	2022-2023
2023-2024	2023-2024	2023-2024
2024-2025	2024-2025	2024-2025
2025-2026	2025-2026	2025-2026
2026-2027	2026-2027	2026-2027
2027-2028	2027-2028	2027-2028
2028-2029	2028-2029	2028-2029
2029-2030	2029-2030	2029-2030
2030-2031	2030-2031	2030-2031
2031-2032	2031-2032	2031-2032
2032-2033	2032-2033	2032-2033
2033-2034	2033-2034	2033-2034
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2036-2037	2036-2037	2036-2037
2037-2038	2037-2038	2037-2038
2038-2039	2038-2039	2038-2039
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2040-2041	2040-2041	2040-2041
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2042-2043	2042-2043	2042-2043
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2065-2066	2065-2066	2065-2066
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2093-2094	2093-2094	2093-2094
2094-2095	2094-2095	2094-2095
2095-2096	2095-2096	2095-2096
2096-2097	2096-2097	2096-2097
2097-2098	2097-2098	2097-2098
2098-2099	2098-2099	2098-2099
2099-2100	2099-2100	2099-2100

APPENDIX A

FORECAST GUIDE FOR ACTIVE GEOTHERMAL DEVELOPMENT AREAS

FORECAST GUIDE FOR THE MOST ACTIVE GEOTHERMAL DEVELOPMENT AREAS

Area	Development State	1975-1976	1977-1979	1980-1985
<u>Dry Steam (Vapor Dominated)</u>				
The Geysers, CA	500 MW of plant installed by PG&E in 11 units; over 150 holes drilled across 18 mi ² , of which 2 in 3 encounter steam; most of remainder are hot but nonproductive; wells drilled by Union Oil, Thermal Power, Pacific Energy Company, Burmah Oil, Shell Oil, Sun Oil and others.	To average about 200 holes drilled per year (Union Oil, Shell Oil, Pacific Energy, Burmah Oil, others); step-out drilling to SE and N; occasional redrilling of existing wells.	Units #12-15 to be installed (400 MW; step-out drilling to N, NW, possibly NE and SE, covering additional 10' to 15 mi ² ; continued re-drilling within productive area.	Development to exceed 1500 MW, probably the field limits and dimensions will be known; may exceed 25-30 mi ² (2500 MW capacity) in area.
<u>High Enthalpy (>200-250 BTU/lb) Hot Water (324-550°F)</u>				
Valles Caldera, NM	Approximately 9 producible wells, of about 15 holes drilled in 10 mi ² area (Union Oil); negotiations with utility over contract to sell steam.	Continued drilling of development wells and testing of field; possible agreement to construct 50 MW flashed-steam power plant.	Drilling of wildcat holes by other operators; construction of first plant; continued development drilling.	Further construction of plant facilities; definition of field dimensions; continued drilling and testing.
Imperial Valley, CA	4 areas being tested for development; Heber: 9 holes across 3 mi ² ; lower enthalpy hot water; Chevron, Magma Power. Brawley: 3 holes in limited area; lower enthalpy water; Union, Niland: 15 holes in 10 mi ² ; high enthalpy, heavy brine; Phillips, Magma Power, Southern Pacific Co. East Mesa: 4 holes in limited area; lower enthalpy hot water; USBR.	Continued testing of heat-exchangers for Niland brine; further drilling in other areas; testing of heat-exchanger components for binary cycle power generation; testing of desalination apparatus at East Mesa.	Construction of first binary-cycle plant at Heber (20 MW); continued drilling at Heber and Brawley; possible decision to construct pilot desalination facility at East Mesa; possible decision to construct power plant at Brawley and/or Niland; wildcat drilling elsewhere.	Development of Heber continuing; possible continued activity elsewhere.

Areas	Development State	Forecast		
		1975-1976	1977-1979	1980-1985
Roosevelt, UT	Approximately 4 holes drilled in limited area (Phillips Petroleum); testing and further drilling underway.	Continued testing and drilling; possible wildcat drilling in adjoining areas (Cove Fort to northeast).	Possible decision to construct power plant; if so, further drilling.	Possible construction of plant, with continuing drilling and testing of wells.
Carson Desert, NV	4 areas have been drilled to varying degree. Brady's: about 12 holes, across 2 mi ² area; Union, Magma Power. Soda Lake: 2 holes, widely spaced; Chevron, Phillips. Fernley: 2 holes; Magma Power. Stillwater: 1 hole; O'Neill-Olliphant.	Continuing drilling and testing (Brady's and Soda Lake); possible wildcat drilling in adjoining areas.	Possible decision to construct power plant at undecided site; if so, further drilling in 1 or more areas.	Possible construction of plant, with continuing drilling and testing of wells.
A-2 Surprise Valley, CA	Approximately 7 holes drilled across several square miles; Magma Power, Gulf Oil; sites for 3 additional holes approved.	Continued drilling and testing; possible wildcat drilling in adjoining areas.	Possible decision to construct power plant; if so, further drilling.	
Long Valley, CA	Approximately 10 holes drilled in limited area; Magma Power; surface exploration continuing; drilling delayed because of environmental and leasing questions.	Leasing and drilling of additional holes; testing of wells.	Probable continued drilling and testing of wells.	Possible decision to construct power plant; if so, further drilling and testing of wells.
Beowawe, NV	Approximately 12 holes drilled in limited area; Magma Power, Chevron; additional holes planned.	Continued drilling and testing of wells; possible wildcat drilling in adjoining areas (Crescent Valley to south).	Possible decision to construct power plant; if so, further drilling and testing.	Possible construction of plant, with continued drilling and testing of wells.

Low Enthalpy (<200 BTU/lb) Hot Water (T=225 - 330°F)

Klamath Falls, OR	Some 400 holes drilled into hot water aquifer; most utilized for space heating via heat exchange with pure water; supplies heat to homes, schools, businesses for about 10,000 persons.	Continued occasional drilling and construction of facilities for space heating; possible deep drill hole to test higher enthalpy regime.	Probably continued drilling, with possibility of large-scale heat-exchange project.	Probable continued drilling and testing; possible development of higher enthalpy regime.
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A-3

Area	Development State	Forecast		
		1975-1976	1977-1979	1980-1985
Raft River, ID	2 holes drilled in limited area; publicly sponsored research; testing and evaluating aquifer for possible application of binary-cycle heat exchange.	Continued testing; possible drilling of additional holes.	Possible pilot development of heat-exchange facilities; possible additional drilling.	
Calistoga, CA	Over 60 wells produce hot water for space heating in area of 3 mi ² , 1 deep hole; numerous resorts.	Continued occasional drilling of holes for space heating.	Possible deep drill hole to test higher enthalpy regime; continued occasional drilling of holes for space heating.	
Amedee, CA	2 deep drill holes (Gulf Oil); use of hot water for greenhouse operations.	Possible continued drilling of holes for hot water.	Possible deep drill hole to test higher enthalpy regime.	
Susanville, CA	Publicly sponsored research into large-scale development of hot water heating system.	Possible drilling of 1 or more holes to test extent of thermal aquifer.	Possible drilling of additional holes.	Possible construction of pilot facilities to test suitability of development.
Steamboat Springs, NV	Dozens of shallow wells drilled along 20-mile long zone north to Reno; some used for space heating.	Possible continued drilling of holes for hot water; leasing of federal lands.	Possible deep drill hole to test higher enthalpy regime; continued drilling of holes for hot water.	
Boise, ID	2 wells in Boise supply hot water for space heating; publicly sponsored research underway into this thermal system.	Possible continued drilling of hot water wells.	Possible deep hole to test higher enthalpy regime; possible continuing drilling of hot water wells.	

Area	Development State	1975-1976	Forecast 1977-1979	1980-1985
		<u>Geopressed Aquifers</u>		
Gulf Coast, TX & LA	Evaluation of data from very deep oil and gas wells into hot water aquifers.	Probable continued evaluation of existing data.	Possible drilling of deep exploratory hole.	Possible continued drilling and testing of deep hot water aquifers.
		<u>Hot Dry Rock</u>		
Valles Caldera, NM	2 holes drilled west of Caldera as research project by Los Alamos Laboratory; testing and evaluation.	Continued testing and evaluation; probable attempt to operate fractures between holes by pumping water under great pressure.	Continued fracturing and evaluation of results; possible drilling of additional holes.	Possibility of decision to develop pilot facilities for heat exchanging in fractured holes.
In addition to these areas, exploratory test drilling may take place at some or all of the following geothermal targets:				
Black Rock Desert, NV		Cove Fort, UT		Ruby Valley, NV
Dixie Valley, NV		Buena Vista, CO		Crump-Adel, OR
Coso, CA		Animas, NM		Vale, OR
San Emidio, NV		Borax Lake, CA		Weiser, ID
Lakeview, OR		Bieber, CA		Mountain Home, ID
Alvord Desert, OR		Wilbur Springs, CA		San Luis Valley, CO
Grand View, ID		Crescent Valley, NV		Preston, ID
				Beryl, UT

Source: Geothermal Handbook, 1976. Office of Biological Services, U.S. Fish and Wildlife Service, Department of the Interior, Washington, D.C. pgs. 70-71.

APPENDIX B

ENVIRONMENTAL ISSUES

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ENVIRONMENTAL ISSUES

The importance of general and particular environmental issues will be site specific due to large differences among the major types of geothermal reservoirs and in reservoir characteristics such as the concentration of dissolved salts and noncondensable gases. The acceptability of any resulting effect will also be site dependent due to differences in use of the surrounding land. In addition, the airborne and waterborne effluents and the nonpollutant effects are strongly dependent upon the utilization technology; release rates and even pathways can be substantially altered by the choice of condenser and heat rejection systems, for example, as well as by specific effluent control devices.

Airborne Effluents

The fluids in hydrothermal reservoirs contain varying amounts of chemical species which do not condense during the heat extraction process. The fractional content of such noncondensed gases varies widely, from 0.4 percent by weight at The Geysers, California, to 30 percent at Monte Amiata, Italy. The major constituent of this fraction is typically CO_2 , with lesser amounts of NH_3 , H_2S , and CH_4 and with trace amounts of Rn, Hg, H_3BO_3 , and other compounds. Most extraction and utilization techniques will result in the release of these chemicals to the atmosphere unless control devices are used. An exception would be the use of a down-hole pump to maintain pressure on the fluid through a heat exchanger and an injection well. In theory, a closed loop could be maintained. Such down-hole pumps are now used in Iceland, and are undergoing tests in Imperial Valley, California.

The release of CO_2 by hydrothermal power plants is significant only in a global context, and it is extremely unlikely that hydrothermal power plants will make a significant contribution to the total flux of CO_2 to the atmosphere.

The release of H_2S is a substantial problem at The Geysers, and has resulted in adverse reactions from the downwind communities. The odor detection threshold of humans for H_2S is about 0.005 ppm (by volume), and the California standard for ambient air is 0.030 ppm. These levels are sometimes exceeded, and the California Public Utilities Commission has required the operator to develop a pollution abatement program as a condition for the expansion of the power production facilities. Health effects from the exposure of H_2S at these low levels have not been unequivocally demonstrated, but have been claimed by residents in The Geysers area. Effects of H_2S on vegetation have been demonstrated at concentrations in air of several ppm. The presently available evidence indicates that vegetation damage via this mechanism will not occur due to hydrothermal operations; but more research is needed to confirm this with additional vegetation species and to examine the synergistic action of H_2S with other pollutants such as O_3 . H_2S in the atmosphere is slowly oxidized to SO_2 and SO_4^{2-} . The formation of sulfate and other sulfur containing particulates is therefore certain. However, the slow conversion rate of H_2S to other sulfur compounds indicates that this will probably not present an actual problem, because considerable dispersion will have occurred while conversion is taking place. In actuality, it is very unlikely that any new, commercial-scale hydrothermal power plant will be built in the U.S. without either H_2S abatement mechanisms or demonstrable proof that they are unnecessary due to the nature of the reservoir.

The Geysers and several other hydrothermal power plants use direct-contact condensers. Because H_2S is soluble in water, about 70 percent of the H_2S is carried to the cooling tower and exhausted to the atmosphere there. The use of indirect-contact condensers could therefore result in significant abatement of H_2S , but condensate might then be unavailable for cooling water use. Ammonia is also soluble in water, and essentially all of the NH_3 exhausted to the atmosphere at The Geysers is via the cooling towers.

Substantial amounts of NH_3 are released at The Geysers. Measurements at other hydrothermal sites indicate that emission rates of NH_3 are lower. The significance of ammonia release appears to be minor. Ammonia is frequently used as a plant fertilizer and is probably nontoxic to vegetation and mammals at expected concentrations. Dissolved ammonia is toxic to aquatic life, but airborne releases of ammonia should not be significant to aquatic life. There may be complex interactions of ammonia, sulfur compounds, and particulates that produce potentially harmful pollutants. This possibility deserves further analysis, but it is not presently considered to be an important issue.

Although presumed not due to H_2S , vegetation stress has occurred at The Geysers in the immediate area of the power-generating units. Presently available evidence indicates that this stress may be due to H_3BO_3 . This is a minor problem at The Geysers, but could be of more importance at other reservoirs or with other adjacent land uses. More data are needed on the presence of H_3BO_3 in hydrothermal fluids.

Mercury emission rates have recently been reported for The Geysers and Cerro Prieto, Mexico. The airborne release rates are small, $90 \mu\text{g}/\text{kW-hr}$ at Cerro Prieto and 30 to $70 \mu\text{g}/\text{kW-hr}$ at three measured units at The Geysers. These releases appear to be inconsequential. Ambient air at The Geysers has the same concentration of Hg as was measured at background locations, although ambient air at Cerro Prieto was above background levels. Additional measurements at other sites are needed to resolve fully this issue.

The release of ^{222}Rn and other radionuclides has also recently been measured at The Geysers. The average emission rate of ^{222}Rn is $130 \text{ nCi}/\text{kW-hr}$. Concentrations in ambient air of the short-lived radon daughters at The Geysers are within the range of concentrations measured at background locations. Levels of other naturally occurring radionuclides in The Geysers area were also within normal background levels. Measurements of radon in fluids at other sites also indicate that the release of radionuclides at hydrothermal sites will not be an important issue. However, confirmatory measurements of emission rates and ambient concentrations in the vicinity of new uses, particularly non-electric applications, will be necessary.

More detailed source-term measurements at sites of hydrothermal use are needed to determine the levels of some toxic trace constituents which may be released. In particular, information on compounds such as HF, mercaptans, and volatile hydrides are needed. These compounds very likely exist in hydrothermal fluids, but very few measurements are now available.

Fluids that may be recovered from geopressed reservoirs typically contain large amounts of dissolved CH_4 . This will almost certainly be recovered and

beneficially used. Other materials may also be present which may not condense during the heat extraction process, but only limited data are presently available. Trace amounts of H_2S have been measured during one well test.

The process of extracting energy from hot dry rock reservoirs will probably involve establishing a circulation loop with exogenous water as the circulating medium. During this process, noncondensed gases may accumulate which might have to be removed. At this time, however, it is not known if this will occur, or what the composition of such gases might be.

Airborne effluents in the form of cooling system drift are also expected at all geothermal power plants. The magnitude of this potential problem is very dependent upon technological options. In the Imperial Valley, for example, commercial power plants will very likely be forced to maintain fairly high salinity levels in their cooling systems because high quality water is not expected to be available. If steam condensate is used as cooling water makeup, then the concentration of many ionic species in the cooling system will be altered. Expected emissions will be in the form of particles composed of common salts and many trace contaminants including boron and cooling system additives. Cooling system drift may therefore stress surrounding vegetation.

By far the largest of the airborne emissions from geothermal power plants will be water vapor. Because the thermodynamic efficiency of such power plants is low, the release rate per unit energy produced is higher than for other conventional power plants. In some locations, this water vapor release may result in local fogging and icing conditions.

Waterborne Effluents

The management of spent hydrothermal fluids is one of the most important issues confronting development at many locations, although some hydrothermal fluids are so pure they have been used for irrigation and other beneficial uses. The fluids in Imperial Valley, however, are typically very saline, and discharges to surface waters would not be desirable. The anticipated disposal scheme is to inject the spent fluids back into the geothermal reservoir. Injection of excess steam condensate has been carried out successfully for several years at The Geysers. Prior to injection, the excess condensate was released to surface waters. This was found to be detrimental to aquatic life, probably due to the dissolved ammonia.

Long-term injection tests are currently being conducted in Imperial Valley with spent fluids of much greater salinity. These tests appear to be successful although there are still serious concerns of scaling and well-bore plugging due to the precipitation of silica. Tests of chemical treatment of brines to maintain silica in solution have produced very encouraging results. Therefore it does appear realistic to assume that hydrothermal power plants utilizing liquid-dominated reservoirs can be operated over long periods with no intentional release of spent hydrothermal fluids to surface waters or underground aquifers of beneficial use. Research studies and long-term monitoring at selected sites are necessary, however, to ensure that there are no unintentional contaminations. The accidental release of geothermal fluids could, in some areas, have a serious impact on aquatic and/or terrestrial ecosystems.

Fluids from geopressured reservoirs are frequently very saline. Because of the pressures and depths involved, it may not be economically feasible to inject these spent fluids back into the reservoir. Possible alternatives are to inject the fluids into other saline aquifers, or to discharge to surface waters that eventually will flow into the ocean. The latter option would probably result in localized disturbances to freshwater and estuarine ecosystems.

It is not known at this time if the hot dry rock technology will release "geothermal" fluids. On balance, it will be a consumer of water from an outside source; if dissolved salts build up in the circulating system, it may be necessary to discharge "blowdown" water for salinity control.

There are also problems with waterborne effluents during the well-drilling process. These problems are not unique to geothermal energy, but have occurred on several occasions at geothermal sites. These releases are of an accidental nature, and are already covered by regulations. Improved procedures will hopefully eliminate or greatly reduce such releases in the future.

Another potentially major issue involving waterborne effluents concerns heat rejection systems. There are many options for the design of such systems, but the options may be severely limited by available water quantity and quality and by cost. Most practical cooling systems will probably require the discharge of cooling water blowdown. This water will be brackish, and may contain additives or geothermal fluid carryover if steam condensate is used as makeup water. For hydrothermal systems, it may be possible to inject this blowdown with the spent hydrothermal fluids, but there are serious questions whether the two fluids can be mixed without worsening the scaling problem in some liquid-dominated systems. The cooling system design of any proposed geothermal use must be evaluated carefully for possible effects on aquatic ecosystems, both by the dissolved solids and by the thermal discharge.

Noise

Noise has been a significant problem at The Geysers and has been the cause of complaints from nearby residents. Major noise-producing events are the venting during well completion and the dumping of mainline steam to the atmosphere when power producing units are shut down. (This venting has been allowed to continue if the power unit is down for only a short period. The reopening of shut-in wells can dislodge damaging debris.) This problem has been reduced by the use of better mufflers, and the installation of crossties between steamlines so that it is not necessary to release as much steam to the atmosphere when power units are shut down. Studies of the possible impact of noise on wildlife at The Geysers are currently underway. Presently available results are inconclusive.

The noise issue is expected to be much less important at liquid-dominated hydrothermal sites. Steam pressures are lower, and noise levels associated with well tests are much lower than at The Geysers. Measurement programs will be necessary, however, and mitigation measures will be employed if necessary.

Due to the high pressures involved, noise may also be a significant problem at geopressured reservoir sites. No data are presently available. Noise is not anticipated to be a significant problem at the hot dry rock sites.

Subsidence

The removal of large quantities of fluid from a geologic formation may result in subsidence, or sinking of the land. Such subsidence has been common following the withdrawal of water and oil. It has also been observed at the Wairakei, New Zealand; hydrothermal power plant where a maximum rate of subsidence of about 1.3 feet/year has been measured. However, the injection of spent geothermal fluids back into the formation is not done at Wairakei; the spent fluids are discharged into surface waters.

It is hoped that the injection of spent hydrothermal fluids back into the reservoir will not only solve the liquid waste problem, but will also eliminate or mitigate the subsidence problem. However, this is not known with certainty; localized sinking around withdrawal wells and uplifting around injection wells may occur.

Subsidence is generally anticipated to occur at geopressed reservoirs where it probably will not be economically feasible to inject spent fluids back into the reservoir. This is not known with certainty, however, and better models are needed. Subsidence is not generally expected at hot dry rock sites.

A better understanding of geothermal reservoirs and the factors that control subsidence may eventually lead to the development of management strategies that can completely control subsidence. In the meantime, it is necessary to assess the problem by acquiring precise leveling data to measure actual rates of subsidence at geothermal facilities. Baseline data are also important because many geothermal sites can be expected to be undergoing tectonic subsidence. A naturally occurring subsidence of 13 cm was observed in the northern end of Imperial Valley during a recent two-year period.

The importance of subsidence will be site-specific. It may be of significant importance at locations such as the Imperial Valley where the geothermal reservoirs are overlain by agricultural systems using gravity-flow irrigation and drainage systems. Even here, it is expected that subsidence can be mitigated by employing releveled procedures. These are expensive, but feasible. Subsidence in naturally hilly locations may cause only minor or insignificant problems. Significant subsidence at geopressed sites could result in serious impacts because the resource areas are on the coast and are located on land only a few feet above sea level.

Seismicity

Many hydrothermal reservoirs are located in regions with a high frequency of naturally occurring seismic events. A significant issue is whether the withdrawal and injection of geothermal fluids may enhance the rate of microseismic events, or even trigger a major earth movement. Although one study implicates the process of reservoir cooling, the most likely cause of enhanced seismicity is believed to be the injection process. Studies in Colorado have demonstrated that the frequency of microseismic events is enhanced as a result of the high-pressure injection of fluids.

It is not known what pressures will be required to maintain the injection of spent hydrothermal fluids over long periods of time at liquid-dominated sites, but

field trials indicate that the pressures may be well below those demonstrated to cause enhanced microseismicity. The possible lubrication of a major fault and the resultant triggering of a major earthquake is another unresolved issue; careful site selection to avoid major faults should alleviate this concern.

The possibility exists that spent geopressured fluids may be injected under high pressure, and microseismic events produced. As geopressured reservoirs are in regions of low seismic activity, it should be easy to detect such events. Seismic events might also be produced while utilizing the heat stored in hot dry rock reservoirs. The success of this technology does in fact depend upon the development of spontaneous fractures in the rock as it cools.

Because these potential effects are unresolved, detailed microseismic studies must be conducted at geothermal sites. Baseline data on the frequency of seismic events and the depth at which they occur will provide valuable information in distinguishing between naturally occurring and induced events. In the Imperial Valley, for example, the depth of occurrence of nearly all naturally occurring seismic events is far below the depth of the hydrothermal reservoirs. Any sudden shift in the depth of earthquake foci to the depth of the reservoir would be strong evidence that geothermal production had, in fact, enhanced seismicity.

System Safety

There have been three well blowouts at The Geysers, two at Cerro Prieto, and several at other installations. These appear not to have caused significant environmental damage, but such occurrences in more industrialized or sensitive environments could result in major damage. The use of potentially explosive fluids such as isobutane and propane in binary or tertiary loops also carries a potential for major damage if leaks in the system should occur. These factors are of even more concern because many geothermal reservoirs are in regions that are very active seismically.

Because these potential problems could result in serious damage, a comprehensive review of the overall design and operation of geothermal energy utilization facilities is needed.

Habitat Intrusion

Any human activity, including the exploration for and the development of geothermal reservoirs, can put pressure upon native flora and fauna. Because geothermal energy is extracted as heat, it cannot be transported over long distances and must be utilized where found. This may result in issues which are generally referred to as habitat intrusion. Such issues will be extremely site-specific. The most significant issues are expected to arise where geothermal reservoirs are located on or adjacent to areas designated or nominated as critical habitat areas under the Endangered Species Act. Such issues may be expected not only at sites of exploration and energy extraction, but also for powerline corridors as well.

It is therefore essential that information concerning the presence of endangered and threatened species be obtained prior to development. Because geothermal power plants will probably be built in small incremental units and

because limited flexibility in siting is possible, most major problems should be avoided by careful planning. There may, in fact, be excellent opportunities to enhance wildlife habitat in the vicinity of geothermal developments if potential problems and opportunities are recognized early.

Social, Economic, Cultural, and Political Issues

Geothermal resources are located in a variety of areas with greatly differing land uses and socioeconomic resources. Many social, economic, cultural, and political issues may arise as geothermal energy uses are planned; these will be highly site-specific. The Geysers power plant has been opposed by some segments of the population in nearby communities because it threatens to alter a rural, retirement and recreationally oriented lifestyle. Some geothermal resources are located in pristine wilderness areas where development may be opposed by conservationist groups. The Imperial Valley resources are located within a highly developed agricultural system, however a recent public opinion survey indicates that geothermal energy development is highly favored by more than 90 percent of the populace. However, competition for land and water resources may ultimately develop between agriculture and geothermal energy unless the development is carefully planned to avoid such conflicts.

The development of geothermal resources will provide many positive impacts in the social and economic areas. Tax bases will be broadened and the economic base in affected communities will also be diversified. Early planning with affected communities could be effective in developing appropriate manpower resources so that positive steps can be taken to reduce local unemployment.

Geothermal projects will probably occur as phased development with exploration leading to the construction of power generating units, or nonelectric uses, in modest size increments. (Typical power generating units have been added at The Geysers in increments of about 100 MWe.) These phased developments should not therefore result in the overwhelming of existing social services, such as has occurred where very large coal-fired power plants have been built.

More serious issues may be expected concerning the long-term allocation or availability of water for heat rejection systems. Many of the areas where geothermal resources are located are in areas of limited water supply. These issues are largely political, and could be serious constraints.

Because social, economic, cultural, and political issues may be significant in determining the acceptability of geothermal resource development, these potential issues must be identified and addressed. Development scenarios must be developed and potential impacts identified. Effective mitigation of these issues will require working with or providing assistance to local communities so that land-use plans can be developed, the need for increased social services identified and planned, and the appropriate political issues identified in advance of development.