MASTER

Geothermal Exploration and Resource Assessment

R&D Program Benefit/Cost Analysis

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ABSTRACT

The Geothermal Exploration and Resource and Reservoir Assessment (GERRA) Research and Development (R&D) Program of the Department of Energy was analyzed to evaluate its cost effectiveness and relevance to the needs of the geothermal exploration industry.

This analysis was conducted in three phases. The first phase involved a review of the state-of-the-art and an identification of major R&D needs, followed by a quantitative assessment of the benefits expected from the achievement of some realistic targets for reducing the proportion of unsuccessful (non-productive) wells drilled in the course of exploration for a reservoir. In the second phase, questionnaires concerning the utility, effectiveness and need for improvement of certain commonly used exploration techniques were mailed to a set of 72 individuals active in geothermal exploration. The third phase consisted of in-person interviews with well recognized experts in geothermal exploration.

The results of the quantitative analysis suggest that a benefit/cost ratio exceeding ten can be realized for the R&D expenditure by achieving a relatively modest target of improving the current weighted average exploratory drilling success ratio by 3 percentage points (i.e., from 0.24 to 0.27). The responses to the mailed questionnaires indicated that the emphasis of R&D should be on improving the data interpretation capability rather than the data collection (measurement) capability. Liquid geochemistry, seismic methods and thermal methods were identified as the techniques deserving most attention. The in-person interviews revealed that the industry is more concerned about finding buyers (utilities) for the discovered resources than about finding new resources in the near term.

On the basis of the results of the three phases of the analysis, it is recommended that in the near term, the GERRA R&D program should concentrate on activities aimed at reducing uncertainty about the characteristics and energy potential of the resources for which the developers are trying to find users (utilities). A program focussed on the development of reliable reservoir assessment models and improvement of well siting techniques should be undertaken. The efforts aimed at the development of new techniques for discovering geothermal resources should be continued, but the level of effort should be based on the consideration that these programs would have long range impacts, which may never be realized if the geothermal development does not gain momentum through rapid growth in the near-term.

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Ms. Barbara Reilly did an excellent job in typing the report and preparing some complicated tables and charts.

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SECTION 1.0

INTRODUCTION, SUMMARY, RESULTS, CONCLUSIONS AND RECOMMENDATIONS

1.0 INTRODUCTION, SUMMARY, RESULTS, CONCLUSIONS AND RECOMMENDATIONS

1.1 Introduction

The Geothermal Exploration and Resource and Reservoir Assessment (GERRA) Research and Development Program of the Division of Geothermal Energy (DGE)/Department of Energy (DOE) is focussed on two main objectives. These are (1) to discover economically exploitable reservoirs to enlarge the proven resource base; and (2) to reduce the cost of discovering, and developing new geothermal (hydrothermal) reservoirs. To accomplish these objectives, DGE has undertaken a program involving basic R&D, development of new instruments, compilation of a comprehensive data base concerning exploration and resource assessment activities, refinement of the existing data interpretation techniques, and the development of new methods for inferring reservoir location, size and future behavior from geological, geophysical and geochemical observations. A summary of this program is presented in Table 1.

To determine the cost effectiveness of this program and its relevance to the needs of the industry, DGE asked The MITRE Corporation to examine the effectiveness, estimate benefits and make recommendations relative to allocation of program resources. This report presents an overview of the state of the art in geothermal exploration technology, along with a summary of the current DGE program for R&D pertaining to exploration and assessment of hydrothermal resources, and its benefits and costs. The methodology utilized for benefit/cost analysis is explained along with a discussion of the results of the analysis. A set of recommendations is presented on the basis of the indications

TABLE 1

SUMMARY OF FEDERAL GEOTHERMAL EXPLORATION, RESERVOIR ASSESSMENT AND CONFIRMATION PROGRAM

R&D PROGRAM	R&D ACTIVITIES	R&D PROGRAM	R&D ACTIVITIES
(1) Pre-Commercial Program (1,250 K)*	<ul style="list-style-type: none"> • Predrilling Survey in Snake River Plain, and Mt. Hood. • Deep Drilling in Snake Plain, and Mt. Hood. 	(6) (Continued)	<ul style="list-style-type: none"> • Establish calibration and test wells. • Petrophysics Research including <ul style="list-style-type: none"> - Studies of electrical properties, permeability, porosity and other properties which characterize crack and pore structure, seismic properties and physical chemistry of aqueous solutions and rock-water interactions as a function of temperature, pressure, rock type and fluid chemistry.
(2) Industry Coupled Program (2,425 K)	<ul style="list-style-type: none"> • Case studies (Roosevelt, Cove Fort, Northern Nevada, others). 	(7) Subsidence (750 K)	<ul style="list-style-type: none"> • Case Histories and Geothermal Subsidence Potential Maps. • Subsidence Field Measurement program. • Development of Subsidence Monitoring Instrumentation. • Study of Environmental and Economic Effects. • Development of Indirect Technique to Estimate Subsidence at Depth. • Physical Processes. • Laboratory Testing. • Subsidence Models • Reservoir Operational Control Policy
(3) State Coupled Program (2,600 K)	<ul style="list-style-type: none"> • Eastern State Non-Electric Reservoir Confirmation. • Western State Non-Electric Reservoir Confirmation. • Technical Support. 	(8) Induced Seismicity (322 K)	<ul style="list-style-type: none"> • Study of properties of earthquakes occurring naturally in geothermal areas. • Study of hydrodynamic behavior of reservoirs under sustained production and injection. • Investigate physics of earthquake triggering mechanisms. • Establish discriminants for distinguishing induced events from these due to natural processes. • Study of methods of aseismic stress release.
(4) Reservoir** Engineering (1,087 K)	<ul style="list-style-type: none"> • Reservoir Engineering Techniques • Reservoir Engineering Support • Reservoir Case Studies (e.g., Cerro Prieto, Coso, East Mesa, Hawaii, Raft River, others). • Non-Electric Experiments Support 		
(5) Surface** Exploration Technology Development (1,400 K)	<ul style="list-style-type: none"> • Location of Exploratory Wells • Reservoir Performance Predictions • Predictions During Drilling • Location of Step-Out Wells • Exploration Cost-Effectiveness • Hidden Resource Exploration • Reservoir Performance Monitoring • Retrospective Case Histories 		
(6) Geothermal Log** Interpretation (400 K)	<ul style="list-style-type: none"> • Evaluate State-of-the-art of well logging. • Stimulate development of new well logging techniques. • Coordinate well log and core depositories. 		

* Figures shown in parenthesis indicate the FY 1978 budget for each R&D program.

** Quantified benefits shown in this report are associated with these R&D programs only.

yielded by the benefit/cost analysis, industry survey analysis, (statistical and structured value analysis) and expert opinion offered during in-person interviews.

1.2 Results

The main results yielded by the benefit cost analysis, the structured value analysis of the inputs received through the industry survey, and the in-person interviews, are presented in sections 3, 4 and 5. The following is a summary of the most important results generated by this study.

- The major impact of the successful completion of the GERRA R&D program will be observed in the improvement of the exploratory drilling success ratio (number of successful wells/total number of wells drilled).
- Although the GERRA R&D program is also aimed at (i) reducing uncertainty about the resource, (ii) reducing investment risk, (iii) reducing the information needs of exploration managers and (iv) decreasing the cost of exploration hardware, the cumulative benefits associated with these impacts will be small compared with the benefits resulting from a modest improvement in the drilling success ratio.
- At this time, the data needed for estimating the quantitative benefits of impacts other than improved drilling success ratio are not available (Section 3.2).
- A 29 percent improvement in the exploratory drilling success ratio (from the estimated current value of 0.24 to 0.31) by 1982 can result in savings ranging from \$287 millions to \$526 millions (present worth in 1978 dollars)* during the time period 1978-2000 (Table 13).
- The achievement of a more ambitious target for increasing the drilling success ratio (90% increase

* All estimated benefit figures are in terms of the present worth (in 1978) of the cumulative benefits in 1978 dollars.

by 1982) can result in cumulative savings exceeding \$1,158 millions during the time period 1978-2000 (Table 13).

- The savings due to a successful R&D program for controlling subsidence and induced seismicity are expected to exceed \$20 millions during the pre-2000 time period.
- The estimated benefits are very sensitive to the rate of increase in the drilling costs. If the current rate of increase (8 to 9 percent in constant dollars) is maintained the cumulative benefits would be substantially larger than the figures given above (Table 13 and Figure 6).
- If the current GERRA R&D program succeeds in improving the drilling success ratio by 30% during the next seven years, the benefit cost ratio for this program is likely to be greater than 20.
- Assuming that a commonly observed relationship between the expenditure on industrial R&D and the associated benefits is applicable to the GERRA R&D program, an annual budget of \$6 millions (the current annual budget is \$2.887 millions) appears to be justifiable for this program (Section 3.7).
- In the opinion of the majority of the respondents to the industry survey, liquid geochemistry, seismic methods and thermal methods should be the focuss of attention of the GERRA program efforts for improving the exploration technology (Section 4.4).
- The inputs received from many of the interviewed industry representatives suggest that the concentration of the near term efforts should be on reducing the uncertainty about the resource (reservoir size, lifetime, fluid characteristics, reliability, etc.). Development of good reservoir assessment and engineering models will be most effective in addressing this need (Section 5.3).
- Although basic R&D may not produce near-term benefits, the historic pattern of technological break throughs resulting from basic R&D indicates that an ongoing program of basic R&D must be supported by the GERRA program (Section 2.1).

1.3 Conclusions

The major conclusions emerging from this analysis are listed below:

- The cost penalties associated with unsuccessful exploratory wells represent a large avoidable component of the exploration expenses, and the avoidance of these penalties is a justifiable target for the GERRA R&D program.
- A relatively modest target for improving the exploratory drilling success ratio (0.24 to 0.31), if achieved, can result in industry wide discounted (at 10%) savings in the range \$287 million to \$526 million during the time period 1978-2000. (Table 13).
- Even if very conservative estimates are made for the potential improvement in the drilling success ratio due to a successful GERRA R&D program, the benefit/cost ratio for this program is likely to be greater than 20.
- Under a set of realistic assumptions* concerning the relationship between R&D costs and the associated benefits, a five year budget (1978-1982) in the range \$2.887 million to \$6 million per year appears to be justified for the GERRA R&D program (Figure 9).
- Improved detection and control of subsidence and induced seismicity can generate savings amounting to \$20 million during the period 1978-2000.
- The geothermal industry interviewees, though generally well disposed towards government supported exploratory drilling, expressed concern about the disruptive effect of these activities with regard to the areas under development at this time.
- Many geothermal industry officials who were interviewed commented that the current GERRA program overemphasizes the development of hardware (instrumentation), whereas the real deficiency is in data interpretation techniques.

* These assumptions include the applicability of the commonly observed relationship between expenditure on industrial R&D, and the associated benefit. This conclusion is also based on conservative estimates of the rate of increase in the cost of geothermal well drilling.

- Many industry decision makers expressed opinions that in the near term they need R&D outputs which will help the developers convince the utilities that the reservoirs already discovered can support power plants with sufficient reliability for a reasonable period of time. The best tool for this purpose is a set of relatively accurate and calibrated reservoir assessment and engineering models.
- The achievement of the long term goals (1986-2000) for hydrothermal development is heavily dependent on the attainment of the development targets for the pre-1985 time period.
- To enhance the chances for reaching the development goals for the year 2000, an active program of basic and applied R&D should be maintained at national laboratories, universities, and other qualified institutions.
- The Government should undertake the preparation of more regional thermal gradient, heat flow, geological, magnetic and gravimetric maps.
- Liquid geochemistry, seismic methods, and thermal methods should be the object of major R&D efforts because these techniques are effective and possess potential for improvement.
- The GERRA R&D program should be supported by an effective mechanism for technology transfer, and the commercialization of the output of research. DGE should encourage commercial firms to undertake the production of hardware developed through GERRA supported R&D. Regular workshops should be held for disseminating the results of R&D.
- Interviewees were almost unanimous in emphasizing that institutional impediments (leasing, permitting, etc.) to exploration are as important as the technological deficiencies. Therefore, an effort should be made to deal with the institutional issues along with the technological problems. DGE may have to work with other governmental agencies (Federal, State and local) to remove these impediments.

1.4 Recommendations

On the basis of the results of the analysis of the GERRA R&D program, and the inputs provided by the participants in the industry

survey, the following recommendations are made:

- A measure for the effectiveness of the GERRA R&D program should be adopted for setting goals for the program and for monitoring its progress towards this goal. In view of the lack of empirical data for assessing impact of R&D on reduced uncertainty about the resource, enhanced investor confidence in geothermal resources and reduced data requirements for exploration and plant design decision, the exploratory drilling success ratio is a suitable measure of effectiveness. This choice is also supported by the fact that the savings due to improved success ratio are likely to be substantially larger than the savings due to the impact of R&D on other aspects of exploration.
- In the near term, the program emphasis should be shifted from hardware development to the development of valid and calibrated reservoir assessment and engineering models.
- The needs of the sites projected for development prior to 1985 should be given greater consideration in formulating the R&D program.
- To enhance the chances of attaining the long-term (year 2000) goals for the development of hydrothermal power, basic and applied research activities should be continued at National Laboratories, Universities and other qualified organizations (it is appropriate to point out that these activities are unlikely to have any impact during the pre-1985 time period).
- Closer cooperation between the industry and GERRA program managers should be maintained during the selection of frontier areas for undertaking Government supported exploratory drilling.
- The program for preparing case histories should be continued. The mechanism for the dissemination of the case studies should be streamlined to improve the timeliness and comprehensiveness of the information.
- A comprehensive program for preparing regional thermal gradient, geological, magnetic and gravimetric maps should be considered.
- Each R&D project with the prospect of generating an output which can be commercialized should have a commercialization/technology transfer plan prepared

for it prior to the completion of the R&D phase. This plan should be pursued to ensure that the products of R&D are commercialized to the extent possible.

- Along with R&D in exploration and resource assessment technology, adequate attention should be devoted to the institutional impediments (leasing, permitting, etc.) which retard geothermal development. Without dealing with these obstacles, it would be impossible to realize the full benefit of successful R&D. The GERRA program managers should monitor the progress in tackling the non-technical issues, so that the technology R&D program is coordinated with the efforts for dealing with the institutional issues.

1.5 Summary

In this subsection, a summary of the background for the study, the objectives of the study, and the approach followed in accomplishing these objectives is provided.

1.5.1 Background

Although geothermal development has been underway in the United States for a number of years, the major impetus to this development was provided only in 1970, when the Geothermal Steam Act was passed by the U.S. Congress. With the imposition of the oil embargo in 1973-1974, the government and private organizations in the energy-related areas began to emphasize the need for exploiting all forms of domestic energy resources. It was around this time that geothermal energy began to be recognized as an important source of energy in the U.S.

Until 1975, the National Science Foundation was the leading entity in sponsoring and funding RD&D activities related to geothermal exploration and exploitation. The Division of Geothermal Energy

(DGE) was created within the Energy Research and Development Administration (ERDA) in 1975 to pursue the task of accelerating the development of the geothermal resources. In 1977, DGE became a part of the newly created Department of Energy (DOE). The Resource and Reservoir Assessment Branch of DGE was charged with the program for Geothermal Exploration and Resource and Reservoir Assessment (GERRA). Among the activities being undertaken as a part of the GERRA program are the development of service exploration instrumentation; data interpretation techniques; logging and log interpretation; exploration strategy; reservoir assessment, confirmation and engineering; and regional and industry coupled cost-shared drilling programs and case studies.

As a part of the efforts to evaluate the cost effectiveness and technical relevance of the DGE RD&D programs, many segments of these programs were analyzed to estimate the benefits, costs and benefit/cost ratios for various projects being funded by DGE. Although some of the ongoing projects will affect the development of the hot dry rock resources and the geopressured reservoirs, the current emphasis is on the development of the hydrothermal resources for electric as well as non-electric utilization. Therefore, the computation of the benefits for various parts of the GERRA R&D program was based on the Interagency Geothermal Coordinating Council's (IGCC) scenario for the development of the installed capacity of hydrothermal electricity for the period 1978-2000. There will be some utilization of the hydrothermal resources for non-electric purposes (space heating, process

heat, etc.) during this time period. Due to the non-existence of credible scenarios for the growth of the direct application of hydrothermal resources and the relatively small magnitude of the total estimated utilization; it was decided to base the analysis entirely on the projected electric utilization of the hydrothermal resources.

The next subsection provides more details of the approach adopted for the benefit/cost analysis of the GERRA R&D program.

1.5.2 Approach

Initially, it was expected that a benefit/cost analysis of individual projects would be feasible. However, a closer look at the titles and statements of the objectives of various projects revealed that it would be virtually impossible to quantify the benefits expected to result from the successful completion of different projects. Many of the projects underway are aimed at the generation of information needed for making decisions pertaining to geothermal exploration and resource assessment. Some of this information is collected through better instruments. At a higher level of aggregation, case studies are another example of the collection of information. Although decision theory techniques appear to be suitable for utilization in this situation, the actual application of decision theory in the benefit/cost analysis of the GERRA R&D program cannot occur until valid data pertaining to the frequency of various decisions and the consequences of these decisions are collected. Additionally, many decisions may be impacted by the

output of more than one project, and it would be extremely difficult to attribute parts of the benefits of improved decisions to various projects.

Recognizing the difficulties in computing benefit/cost ratios for individual projects, it was decided to analyze the current GERRA R&D program in two phases. In the first phase, the program was reviewed to delineate the major R&D activity areas. The technical/decision process impacts and the economic/development benefits were subsequently identified for each R&D activity area. Figure 1 shows the relationships between R&D activities and the economic/development benefits. This phase of the analysis helped identify the important technical/decision process parameters and led to the determination of a practical procedure for estimating the expected benefits of the GERRA R&D program.

In the second phase of the analysis, the benefits associated with the achievement of specific targets for improvement (e.g., improvement in the exploration drilling success ratio) were estimated. Under the assumption that the current GERRA program will bring about the targeted improvement, the benefits, costs and benefit/cost ratios for the total program were estimated for a number of combinations of values for variables such as the level of exploration drilling activity, drilling cost escalation rate, current drilling success ratios and discounting rates. An effort was also made to suggest reasonable limits for the size of the GERRA R&D budget.

NOTES:

- (A) Exploration strategy development includes the formulation of optimal exploration architecture for specific geological provinces.
- (B) This activity area includes surface technique development, log interpretation program, logging instrumentation development, reservoir modeling, and the preparation and utilization of case studies.
- (C) The regional cooperative programs and the industry coupled (cost shared drilling) programs fall into this category.
- (D) Improved drilling success ratio results when fewer unsuccessful wildcat, stepout and test wells have to be drilled for confirming a reservoir with a given energy potential.
- (E) This impact category includes enhanced certainty about the size and producibility of the reservoir, along with a better determination of physical and chemical characteristics of the fluid.
- (F) Investment risk is reduced directly due to cost sharing by the government and indirectly through improvements in success ratio and enhanced certainty about resource characteristics.
- (G) Reduced exploration investment results from a smaller cost of exploration activities, a shorter time period between resource discovery and development, and fewer instances of incorrect decisions.
- (H) Accelerated development occurs due to the reduction in time wasted in drilling unsuccessful wells, and a shorter time period for determining the resource characteristics.
- (J) Wrong decisions include false rejection of economic reservoirs, continued exploration/exploitation of uneconomic reservoirs, and plant over design or under design due to uncertainty concerning resource characteristics.

- - - -> indicates indirect impact.

FIGURE 1
RELATIONSHIPS BETWEEN R&D ACTIVITIES AND ECONOMIC/
DEVELOPMENT BENEFITS

This phase of the analysis also involved a structured value analysis of the major segments of the R&D program on the basis of 30 responses to questionnaires sent to 72 recognized experts in geothermal exploration industry. Geothermal exploration tools/ techniques were ranked through a structured value analysis in terms of their relative effectiveness and the need for improvement through R&D. Since this ranking was a reflection of the industry's perception of the needs and priorities for the GERRA R&D activities, it would be appropriate to consider this ranking at the time of readjusting the program objectives and emphasis.

To augment the feedback received through this questionnaire, personal interviews were held with 10 individuals representing different segments of the geothermal exploration industry (service companies, explorers, developers, researchers, etc.). These interviews were relatively unstructured and yielded a good indication of the attractive features and the shortcomings of the GERRA program as perceived by the interviewees. The interviews provided some very useful ideas for formulating a strategy for an effective R&D program.

Figure 2 shows an overview of the various steps in the two phases of the analysis.

1.6 Organization of the Report

This report is organized into six sections. This section (Section 1) presents an overview of the background and the objectives of the study along with a summary of the approach, results,

FIGURE 2
OVERVIEW OF THE APPROACH FOR ANALYSIS

conclusions and recommendations associated with this analysis.

In Section 2, a review of the state-of-the-art in geothermal exploration and resource assessment technology is presented. The current GERRA R&D program is summarized in Table 1 which provides the basis for the benefit/cost analysis, a sensitivity analysis and the R&D budget justification conducted in Section 3. The benefit/cost model used for this analysis is detailed in Appendix A.

The geothermal industry perception of the impact, applicability in various geologic provinces, and the effectiveness of the different subprograms which make up the GERRA R&D program is examined in Section 4 (using the Industry Survey Questionnaire presented in Appendix B). The computer program used for the statistical and structured value analyses of responses to the questionnaire is explained and listed in Appendix C. The survey mailing list is given in Appendix E and the names of respondents are listed in Appendix D.

To augment the information and feedback received through the responses to the Industry Survey Questionnaire, personal interviews were conducted with ten recognized experts in the field of geothermal exploration. The significant issues and comments which surfaced during these interviews are discussed in Section 5. The names of the interviewees are listed in Appendix D. Relevant conclusions and recommendations are given in Section 6.

SECTION 2.0

BACKGROUND, STATE OF THE ART, AND R&D NEEDS

2.0 BACKGROUND, STATE OF THE ART, AND R&D NEEDS

2.1 Background and Rationale for GERRA R&D Program

The state of the art in geothermal exploration technology, reservoir assessment, and prediction of reservoir life is still going through a development phase. Due to difficulties in interpreting the observations made during the pre-drilling exploration activity, a substantial penalty is being incurred on account of unsuccessful exploratory and production drilling. The inadequacy of the techniques for siting wildcat wells is confirmed by Table 2, in which the wildcat success rates (percent successful) for 1975, 1976 and 1977 are presented. Of the 150 holes drilled during the 1975-77 period, 42 were drilled in new areas. Of these, only three resulted in new field discoveries (representing about a 7% wildcat success). Holes that were drilled as additional stepout or production wells were far more successful, with a success percentage around 93%.

The low wildcat drilling success ratio of one in fourteen is likely to decline even further with time, as the more obvious targets are explored and developed, unless a countervailing effect of more advanced technology (including improved data interpretation) assists the explorers in locating new sources with greater certainty. The GERRA R&D program can be expected to be the nucleus of the efforts aimed at maintaining or improving the exploratory drilling success ratio through an advancement of the state-of-the-art in this area.

Reportedly, in other fields of natural resource exploration,

TABLE 2

GEOTHERMAL DRILLING SUCCESS RATIOS IN THE U.S.^{1,2,3}

YEAR	TOTAL (1) HOLES DRILLED	TOTAL HOLES PRODUCING	OVERALL PERCENTAGE SUCCESS	WILDCAT ⁽²⁾ HOLES DRILLED	WILDCAT ⁽³⁾ DISCOVERIES	PERCENT WILDCAT SUCCESS
1975	46	37	80	6	1	16.6
1976	52	39	75	21	2-3	9.5-14.3
1977	52	25	48	15	0	0
TOTAL*	150	101	67.3	42	3-4	7.3-10.3

(1) "Total holes" includes wildcat, stepout, and production holes.

(2) "Wildcat Holes" are holes drilled in new unproven fields.

(3) "Wildcat discoveries" includes only wells which were proven to be commercial discoveries at the time of completion of drilling. Holes that were drilled as wildcat holes and either abandoned, suspended, or left open for further observations are all defined as unsuccessful in this analysis. It is conceivable that a percentage of the holes that are currently defined as successful may in the future be completed as successful wells. If this happens, the wildcat discovery percentages are on the conservative side.

* In addition to 101 production holes and 42 wildcat holes the total includes 7 stepout wells for which the success rate is about 93 percent successful.

^{1,2,3} Based upon Smith, et al data (1976, 1977, and 1978).

with a much longer history than that of geothermal exploration, a sawtooth pattern change in success ratio with time (and technology) is clearly evident as shown in Figure 3. This figure shows that initial discoveries based upon intense surface or subsurface manifestations are accompanied by relatively high success ratio. Usually, this phase is followed by a precipitous decline in success ratio until a technological breakthrough ("A" in Figure 3) dramatically increases the success ratio*. After a period of time, most discoveries based upon Technology A will have been made, and an asymptotic decline in success ratio sets in. This process is cyclic. Industries that have lacked the economic incentive to finance new R&D have usually stagnated to some low success rate.

In the petroleum industry, which has had both the economic incentive and the span of time necessary for cyclicity to be clearly identified, it is possible to identify petroleum discovery waves which are associated with the following technological developments: (a) the discovery of the structural trap principle; (b) the stratigraphic trap concept; (c) introduction of gravimetry to map hidden anticlines and salt domes; (d) the utilization of the reflection seismograph; (e) introduction of analog tape recording in reflection seismology, and the associated techniques of Computerized Data Processing (CDP) and signal stacking; and, (f) the introduction of

* Personal communication with T. Meidav, a consultant to MITRE.

FIGURE 3
SUCCESS RATIO IN DISCOVERING NATURAL RESOURCES AS A
FUNCTION OF TIME AND TECHNOLOGICAL BREAKTHROUGHS A-E

* Source: Personal communication with T. Meidav.

digital recording, and the signal deconvolution methodology and the resultant "bright spot" technology. Each of these techniques has had an impact on new discoveries. This impact generally lasted less than one decade.

Figure 4 shows how incremental improvements in success ratio are believed to level off asymptotically at any given technological level. In this figure, the effect of a new technological breakthrough (NT) is shown as a rapid increase in the success ratio, which raises the entire ratio by a discrete percentage for a period of time until hidden resources, that are responsive to the particular characteristics of the new technology, are discovered.

New technology may result from (1) improvement of old technology (like improving the capability of 3-D modeling); (2) discovery of new useful parameters (such as Self Potential applicability in Hawaii); or (3) a better joint interpretation capability leading to enhanced confidence in the likelihood of success.

Because of the relative youth of the entire geothermal exploration effort in the U.S., the magnitude of quantum jumps in exploration success cannot be assessed in a historical context.

2.2 State of the Art

The state of the art of geothermal exploration may be discussed under two separate classifications: (a) intrinsic capabilities and shortcomings of specific techniques; and (b) applicability of the specific techniques, or appropriate combinations thereof, to specific

Note: There is no specific significance to the particular order of the geophysical methods (resistivity, thermometric and seismology) in this example. The dotted graph shows the anticipated impact of a technological breakthrough in any one technique on the success ratio.

FIGURE 4
SUCCESS RATIO AS RELATED TO CUMULATIVE EXPENDITURE ON
GEO THERMAL EXPLORATION

geological provinces.

Table 3 summarizes most of the commonly employed techniques in geothermal exploration and confirmation at present, along with their chief assets and shortcomings. A number of previous studies have listed the weaknesses of current exploration technology and identified potentially fruitful avenues of R&D that may result in significant improvements.^{4,5}

Prediction of well and reservoir performance are still in their infancy. Predictions of the future behavior of The Geysers, and the geothermal field at Wairakei, New Zealand, made in the early days, have not been substantiated by actual performance. The reservoir engineer is required to predict the future decline rate of wells and of the field as a whole, based upon data gathered from a limited number of wells which are tested for a short period of time only. Numerous reservoir savants have attempted to tackle this difficult prediction problem in different ways.^{6,7} One problem of future behavior of a depleting, isolated (non-rechargeable) reservoir is illustrated by Brigham and Morrow⁸. It shows that for a vapor-dominated reservoir, for example, the relationship between the rate of decline of pressure and the cumulative production is not linear, as would be the case for a simple gas reservoir. Instead, the decline curve may either become more steep or flatten out as a function of time depending upon the actual porosity of the rock. A similar problem may be associated with the effect of a fault on the

TABLE 3

CHIEF ADVANTAGES AND SHORTCOMINGS OF EXISTING EXPLORATION TECHNIQUES

TECHNIQUE	CHIEF ASSETS	CHIEF SHORTCOMINGS
1. Field Geology	<ul style="list-style-type: none"> a. Quick identification of targets. b. Assessment of potential heat source, reservoir rock properties, likely size of magma chambers, shallow reservoirs 	<ul style="list-style-type: none"> a. Inability to probe through cover.
2. Hydrogeology	<ul style="list-style-type: none"> a. Valuable in interpreting thermometric hole data 	<ul style="list-style-type: none"> a. Generally incapable of assessing rate of recharge and the parameters that would affect reservoir life
3. DC Resistivity	<ul style="list-style-type: none"> a. Can determine location and approximate depth of low resistivity bodies, presumably hot water or near molten rock 	<ul style="list-style-type: none"> a. Cannot separate effects of salinity, or porosity on resistivity from those of temperature b. Suffers from lateral effects, resulting in ambiguous interpretation c. Bulky equipment, if deep penetration is required
4. Tellurics	<ul style="list-style-type: none"> a. Can locate boundaries between high and low electrical conductance zones to a great depth b. Relatively inexpensive 	<ul style="list-style-type: none"> a. Poor vertical resistivity resolution b. Provides qualitative information only when used by itself

TABLE 3 (Continued)

CHIEF ADVANTAGES AND SHORTCOMINGS OF EXISTING EXPLORATION TECHNIQUES

TECHNIQUE	CHIEF ASSETS	CHIEF SHORTCOMINGS
4. Tellurics, (Continued)		<ul style="list-style-type: none"> c. Subject to natural field vicissitudes (signal strength sometimes very weak) d. Non-planar field will cause interpretation problems
5. Audiomagneto-tellurics (AMT)	<ul style="list-style-type: none"> a. Inexpensive intermediate-depth resistivity sounding tool b. Light and portable c. Valuable in regional reconnaissance 	<ul style="list-style-type: none"> a. Signal vicissitudes as in all other natural EM field methods b. Non-planar waves reduce accuracy c. Man-made noise may cause serious noise/signal problems d. Shallow depth of penetration (<500m generally)
6. Magnetotellurics	<ul style="list-style-type: none"> a. Very deep resistivity sounding capability b. Tensor resistivity obtainable, yielding directions of maximum and minimum conductance 	<ul style="list-style-type: none"> a. Relatively expensive b. Noise, non-homogeneity of source field can distort resistivity very significantly c. Natural-field signal amplitude highly variable
7. Electromagnetics	<ul style="list-style-type: none"> a. Deep resistivity soundings obtainable b. Good detailing technique c. Not dependent on natural field vicissitudes 	<ul style="list-style-type: none"> a. Inadequately field tested, but highly promising

TABLE 3 (Continued)

CHIEF ADVANTAGES AND SHORTCOMINGS OF EXISTING EXPLORATION TECHNIQUES

TECHNIQUE	CHIEF ASSETS	CHIEF SHORTCOMINGS
8. Self-Potential	<ul style="list-style-type: none"> a. Simple and inexpensive b. Effective when signal intensity is very high 	<ul style="list-style-type: none"> a. Inability to separate signal causes when intensity is low b. Electrode polarization and electrochemical noise problem significant when signal is low.
9. Borehole thermometry	<ul style="list-style-type: none"> a. Most direct measure of heat b. The deeper the hole, the more reliable the extrapolation 	<ul style="list-style-type: none"> a. Thermal gradients cannot be safely extrapolated below hole bottom b. Unable to separate conductive from convective heat flow effects
10. Microearthquake	<ul style="list-style-type: none"> a. Valuable reconnaissance tool when signal intensity is high b. Can locate active, permeable faults when signal is high c. May provide some measure of effective production zone in a producing field 	<ul style="list-style-type: none"> a. High microseismicity by itself is not indicative of geothermal reservoirs b. Signal occurrence can be highly unpredictable in all but outstanding geothermal areas c. Relatively costly at present
11. Ground Noise Mapping	<ul style="list-style-type: none"> a. Potentially valuable when signal intensity is high b. Continuous signal 	<ul style="list-style-type: none"> a. Many causes other than steam can cause high ground noise signals b. When ground noise source characteristics are carefully analyzed-method becomes expensive

TABLE 3 (Continued)

CHIEF ADVANTAGES AND SHORTCOMINGS OF EXISTING EXPLORATION TECHNIQUES

TECHNIQUE	CHIEF ASSETS	CHIEF SHORTCOMINGS
12. Seismic Reflection	<ul style="list-style-type: none"> a. Best structural information tool in sedimentary environment, and in determining depth to igneous basement in sediment-filled basins b. Valuable at least in mapping faults in some volcanic terrain 	<ul style="list-style-type: none"> a. Expensive b.. Interpretation difficult in 3-D volcanic terrain c.. Severely attenuated when shallow basaltic flows occur d.. No direct info re temperatures as yet
13. Teleseismic P-Delay	<ul style="list-style-type: none"> a. Useful for mapping molten rock boundaries at depth 	<ul style="list-style-type: none"> a. Relatively slow and expensive
14. Liquid Chemical Thermometry	<ul style="list-style-type: none"> a. Relatively inexpensive b. Provides information on probable reservoir temperatures 	<ul style="list-style-type: none"> a. Useful where hot springs occur b. Subsurface mixing of hot and cold water, chemical effects and water-rock interactions can reduce temperature data reliability
15. Stable Isotope Thermometry Hydrogeology	<ul style="list-style-type: none"> a. May provide info re source of water and original temperature 	<ul style="list-style-type: none"> a. Inadequate industrial experience b.. Very few commercial laboratories to provide service
16. Noble Gas Thermometry	<ul style="list-style-type: none"> a. Relatively inexpensive b. Inert to wallrock interaction 	<ul style="list-style-type: none"> a. Inadequately tested. Not used by exploration companies as yet. No industrial experience

TABLE 3 (Concluded)

CHIEF ADVANTAGES AND SHORTCOMINGS OF EXISTING EXPLORATION TECHNIQUES

TECHNIQUE	CHIEF ASSETS	CHIEF SHORTCOMINGS
17. Infra-red (IR) Imagery	a. Quick and inexpensive wherever applicable	a. Civilian IR has extremely poor sensitivity. Requires heat flow contrast to 1:100 to detect at present technology level b. Presently useless for anything but the most outstanding target
18. Gravimetry	a. Provides valuable structural information b. Can sometimes detect molten magma chambers c. On rare occasions provides semi-direct evidence on geothermal resource occurrence	a. Anomalies generally associated with structural rather than thermal effects
19. Aeromagnetics	a. Valuable structural information at low unit cost b. Can sometimes provide information as to depth to Curie-point temperature (ca. 650°C)	a. Curie point temperature is somewhat controversial

change in rate of pressure decline. Without a very long testing period, the rate of pressure decline is unpredictable at present.

Different modeling schemes are being presently developed and tested. However, it is reasonable to assume that it will take a considerable effort of careful field observation and appropriate adjustments of the models, before confidence in reservoir life prediction could be established.

2.3 R&D Needs

The objectives of geothermal resources exploration/assessment are to locate areas underlain by hot rock, to estimate their volume, temperature, and permeability, and to determine the chemical composition of producible fluids. Geothermal exploration/assessment thus involves measuring geological, geochemical and geophysical parameters at the surface, and interpreting the results in terms of a geothermal model to reflect the deep subsurface conditions of such a reservoir.

The state-of-the-art analysis provides a suitable basis for identifying the shortcomings and gaps in the current exploration/assessment techniques and for indicating the R&D needs for these techniques. As shown in Table 3, some field techniques are well developed and need little or no improvement (e.g., rock age dating, surface gravimetry, aeromagnetism, DC resistivity, and seismic refraction and reflection). However, there is a need for further refinement of interpretation techniques. Some techniques are either unproven for geothermal exploration (e.g., hydrothermal deposit

dating), have poor sensitivity (e.g., thermal infra-red imagery), are of a qualitative nature at present (e.g., gas geothermometry), are inadequate in certain environments (i.e., liquid geothermometry), suffer from misinterpretation (e.g., resistivity), or are currently too expensive (e.g., magneto-telluric) to be routinely employed on a large scale.

The fundamental studies, instrument development, improved data processing and interpretation and other research needs are summarized in Table 4 and discussed below.

(1) Exploration/Assessment Techniques. In particular, current oil exploration techniques should be optimized for discovery of geothermal resources with further emphasis on increasing the reliability of specific geothermal exploration techniques (e.g., geothermometry) and the development of novel techniques for surface measurement of permeability. Apart from addressing regional exploration requirements, these improvements in exploration/assessment techniques (a) satisfy user's need for an improvement in drilling success ratio, improved cost-effectiveness of exploration/assessment techniques, and reducing the uncertainty associated with geothermal exploration, (b) overcome current technological deficiencies and gaps, and (c) help improve the rate of discovery of hot springs in the short-term and hidden geothermal resources in the long-term, and hence improve the likelihood of timely realization of DOE/DGE postulated geothermal power-on-line scenarios.

TABLE 4

SUMMARY OF IDENTIFIED R&D NEEDS

BASIC CONSIDERATIONS	R&D NEEDS ⁺
<p>I. Power-on-Line POL Scenario Considerations (Necessary for meeting development schedule)</p>	<ul style="list-style-type: none"> ● Subsidence Prediction Models ● Near Term Deficit Make-Up Discoveries ● Long Term Hidden Resource Discovery ● Ascertain interrelationship between liquid and vapor dominated reservoirs in The Geysers ● Easily interpreted core testing and sampling techniques ● More reliable stress/strain model for core data processing ● Modeling new types of resources (Geopressures and hot dry rock)
<p>II. Regional Considerations (Necessary for dealing with different geologic environments)</p>	<ul style="list-style-type: none"> ● Optimize oil exploration technology for discovery of geothermal resources ● Increase reliability of specific geothermal exploration techniques (e.g., geochemical, radio-isotope)

⁺In some cases, it would be desirable to specify the magnitude of the improvement in various instrument, techniques, and models. At this time, it is not possible to indicate the desired improvement quantitatively due to insufficient experience in the application of different exploration instruments and techniques in geothermal activities. It is suggested that a data base of the performance capabilities of various exploration tools be developed and maintained.

TABLE 4 (Continued)
SUMMARY OF IDENTIFIED R&D NEEDS

BASIC CONSIDERATIONS	R&D NEEDS
<p>II. Regional Considerations (Continued)</p>	<ul style="list-style-type: none"> • Statistical analysis of field performance of various geothermal exploration techniques • Pacific Region <ul style="list-style-type: none"> - Establish base temperature in East Mesa by 1979 - Develop exploration techniques for submerged land environment by 1982 - Establish base temperature in Cascade Range by 1980 - Examine reliability of self potential technique by 1980 • Rocky Mountain Region <ul style="list-style-type: none"> - Snake River Plain <ul style="list-style-type: none"> -- Establish high temperature potential by 1982 -- Encourage exploration by cost-shared drilling - Basin and Range <ul style="list-style-type: none"> -- Establish Nature of Resource by 1982 -- An industry coupled program is needed to stimulate drilling - Rio Grande Rift <ul style="list-style-type: none"> -- Confirm existence of high temperature resources by 1980 -- Develop new cost-effective techniques for measuring heat flow in practically dry soil by 1982 - Other Subregions <ul style="list-style-type: none"> -- Better* techniques for heat leakage detection

* See N.E. Goldstein, R.A. Norris, M.J. Wilt and Peter Klock, Assessment of Surface Geological Methods in Geothermal Exploration and Recommendation for Future Research (Lawrence Berkeley Laboratory, University of California, Berkeley, 1978). (Cited Reference #4).

TABLE 4 (Continued)
SUMMARY OF IDENTIFIED R&D NEEDS

BASIC CONSIDERATIONS	R&D NEEDS
<p>II. Regional Considerations (Continued)</p>	<ul style="list-style-type: none"> ● Eastern Region <ul style="list-style-type: none"> - The Appalachians <ul style="list-style-type: none"> -- More reliable methods for detection and depth estimation of warm plutons by 1982 - Hot Plutons <ul style="list-style-type: none"> -- Determination of size and age of radioactive magmatic intrusions by 1982 - Geopressured Subregion <ul style="list-style-type: none"> -- Prediction of true volume of geopressured reservoirs by 1982 -- Remote identification of geopressured reservoirs by proper adaptation of seismic reflection and magnetotelluric techniques by 1980 ● Delineate distinct successful regional exploration sequences by evaluating reservoir exploration/assessment techniques at a number of thoroughly documented sites by 1980 ● Deep penetration subsurface modeling in Pacific Region by 1982 ● New modeling techniques for Rocky Mountain Region by 1982 ● Methods to invert surface data into inferred reservoir parameters under the complexity of the in-situ condition of the Eastern Region Reservoirs by 1982

TABLE 4 (Continued)
SUMMARY OF IDENTIFIED R&D NEEDS

BASIC CONSIDERATIONS	R&D NEEDS
<p>III. R&D To Overcome Exploration/Assessment Shortcomings and Gaps</p>	<ul style="list-style-type: none"> ● Novel thermal exploration techniques (e.g., Nobel gas and radiogenic thermometers) by 1982 ● Novel techniques for permeability measurement by 1982 ● Effective* background noise filters ● Better* interpretation techniques ● Improved* data acquisition and processing procedures ● Correlation of surface geophysical signals with surface and subsurface rock/fluid samples analyses ● Better* assessment of reservoir longevity ● Better* (i.e., More Realistic) three-dimensional forward and inverse reservoir models ● Joint interpretation of multiple data set using statistical linear correlation model. Pattern recognition techniques and Bayesian statistics

* See: N.E. Goldstein, et al, 1978. (Cited Reference #4).

TABLE 4 (Concluded)

SUMMARY OF IDENTIFIED R&D NEEDS

BASIC CONSIDERATIONS	R&D NEEDS
IV. User's Needs (Necessary to enhance industry exploratory activities)	<ul style="list-style-type: none">● Improved success ratio (from 0.24 - 0.29) by 1982● Reduction of uncertainty and risks● Increased cost effectiveness of exploration/assessment techniques● Industry-shared deep drilling program● Industry coupled exploration program● Case studies

(2) Core Testing and Sampling Techniques. Improvements in this area have an important bearing on many facets of geothermal exploration and reservoir evaluation. Precise interpretation of geophysical data requires the study of cuttings and cores to determine physical properties, mineralogy, rock type and stratigraphy which define the background noise that interferes heavily with the true interpretation of geophysical signals in a geothermal environment. Moreover, the economics of any geothermal development are critically dependent on (a) the definition of potential scaling or corrosion problems, (b) the prediction of continued aquifer productivity, (c) the assurance that injection wells will continue to accept effluent, and (d) the timely prediction of subsidence and induced seismicity. All these aspects are controlled by rock-fluid interactions, and their reliable evaluation requires precise correlation of surface geophysical signals with surface and subsurface rock/fluid sample analyses.

(3) Reservoir Modeling. Realistic reservoir models have significant regional impact. In particular, modeling of geothermal systems from surface data is of major concern in Rocky Mountain and Eastern Regions (the existing models are too crude to be reliable).

(4) Data Acquisition, Data Processing and Data Interpretation. Pre-drilling exploration cost-effectiveness and the minimization of exploration decision errors are directly related to improvements in data acquisition, data processing and data interpretation and represent a major concern of geothermal resource developers.

(5) Case Studies. Case studies represent an effective means for the statistical analysis and evaluation of field performance of the existing or novel geothermal exploration techniques in different regions, a matter of significant concern to the geothermal developer. Case studies are also invaluable in disclosing regional experiences with different exploration architecture.

(6) Industry-Coupled Cost-Shared Drilling Program. Federal involvement by cost-sharing of deep drilling is needed to reduce the risk and encourage exploration in the Snake River Plain where the base temperature of the reservoir is still controversial and the rough mountainous nature of the terrain makes drilling extremely costly. This Federal program is also necessary to stimulate drilling in the Basin and Range Province to establish the true nature of the resource (i.e., high or low temperature) in this area.

(7) State-Coupled Program. This program is intended to expedite direct heat application of geothermal energy and to provide technical support for better targeting of geothermal resources.

2.4 Matching Current GERRA R&D Program with Identified R&D Needs

The R&D needs addressed by the current DOE/DGE GERRA program are shown in Table 5. As shown in this table, the DOE/DGE GERRA program closely matches the seven major research needs indicated in the previous section, and is fairly responsive to (1) the geothermal power-on-line scenario consideration, (2) the regional requirement, (3) necessary technological improvements, and (4) the needs of the

TABLE 5

MATCHING DOE/DGE GERRA R&D PROGRAM WITH IDENTIFIED R&D NEEDS OR CONSIDERATIONS

MAJOR DOE/DGE GERRA * R&D PROGRAM ELEMENTS	IDENTIFIED MAJOR EXPLORA- TION/ASSESSMENT R&D NEEDS	GERRA R&D PROGRAM CONSIDERATIONS			
		POL SCENARIO ⁺ CONSIDERATION	REGIONAL R&D REQUIRE- MENT	NECESSARY TECHNO- LOGICAL IMPROVE- MENTS	USER NEED
• Surface Technique Development	• Improved Exploration/ Assessment Techniques	X	X	X	X
• Geothermal Log Interpretation Projects and Petrophysics Research	• Improved Core Testing/ Sampling Techniques	X		X	X
	• Improved Data Acquisition, Data Processing & Data Interpretation	X	X	X	X
• Reservoir Engineering and Modeling	• Improved Reservoir Modeling	X	X		X
• Case Studies	• Case Studies	X	X		X
• State Coupled Program	• Technical Support and Direct Heat Applications		X	X	
• Industry-Coupled Program	• Cost Shared Drilling	X	X		X

* The program elements listed in this column are consistent with the program structure at the time of this analysis. Subsequent reorganization of the program could change the structure of the GERRA R&D program.

+ POL considerations reflect the requirements associated with an exploration program aimed at reaching the development program targets for geothermal power on line.

ultimate users of the output of this program. Benefit/cost analysis, the relative cost-effectiveness of funding levels, and the order of priority of the GERRA program elements will be discussed in the next section.

SECTION 3.0
BENEFIT/COST ANALYSIS

3.0 BENEFIT/COST ANALYSIS

3.1 Introduction

The GERRA R&D program is planned with the objectives of: (1) reducing exploration costs; (2) improving inferred predictions of the reservoir size and fluid quality; and (3) expediting discovery of economically exploitable reservoirs. A summary of this program is given in Table 6. As indicated in this table, the GERRA R&D program involves:

- precommercial and industry coupled programs which are intended to expedite the discovery of economically exploitable reservoirs and help the timely realization of DGE mid-term (1985-1990) geothermal power-on-line goals;
- a state coupled program which is designed to enhance geothermal direct heat application;
- development of a comprehensive data base concerning exploration and resource assessment activities through case studies and other reservoir engineering support activities;
- refinement of existing data interpretation (e.g., log interpretation), and the development of new methods and instruments for inferring reservoir location, size and future behavior from geological, geophysical and geochemical observations; and
- subsidence and induced seismicity research activities which are geared towards (a) the reduction of the uncertainty and risk associated with these environmental hazards and (b) the improvement of reservoir operational policy.

In this section, a measure for estimating the benefits of the GERRA R&D program is selected, and the benefits expected to result from the achievement of a reasonable target for this program are

TABLE 6

SUMMARY OF FEDERAL GEOTHERMAL EXPLORATION, RESERVOIR ASSESSMENT AND CONFIRMATION PROGRAM

R&D PROGRAM	R&D ACTIVITIES	ENVISIONED IMPACT
(1) Pre-Commercial Program	<ul style="list-style-type: none"> • Predrilling Survey in Snake River Plain, and Mt. Hood. • Deep Drilling in Snake Plain, and Mt. Hood. 	<p>Support mid-term Power-On-Line Scenario.</p> <p>Support mid-term Power-On-Line Scenario.</p>
(2) Industry Coupled Program	<ul style="list-style-type: none"> • Case studies (Roosevelt, Cove Fort, Northern Nevada, others). 	Support Near-term Power-On-Line Scenario.
(3) State Coupled Program	<ul style="list-style-type: none"> • Eastern State Non-Electric Reservoir Confirmation. • Western State Non-Electric Reservoir Confirmation. • Technical Support. 	<p>Expedite Eastern States Geothermal Direct Heat Application.</p> <p>Expedite Western States Geothermal Direct Heat Application.</p> <p>Better Targeting of Geothermal Resources.</p>
(4) Reservoir Engineering	<ul style="list-style-type: none"> • Reservoir Engineering Techniques • Reservoir Engineering Support • Reservoir Case Studies (e.g., Cerro Prieto, Coso, East Mesa, Hawaii, Raft River, others). • Non-Electric Experiments Support • Demonstration Reservoir Engineering Support 	<p>Reduce Reservoir Engineering Cost by 40 to 60 percent by 1980.</p> <p>Provide support data for Power-On-Line Scenario of the Region.</p> <p>Anticipate behavior of New Reservoirs.</p> <p>Stimulate development of low temperature geothermal systems.</p> <p>Support Power-On-Line Scenario.</p>
(5) Surface Exploration Technology Development	<ul style="list-style-type: none"> • Location of Exploratory Wells • Reservoir Performance Predictions • Predictions During Drilling • Location of Step-Out Wells • Exploration Cost-Effectiveness • Hidden Resource Exploration • Reservoir Performance Monitoring • Retrospective Case Histories 	<p>Improve near-term success ratio for exploratory wells by 10%.</p> <p>Reduce the uncertainty and investment risk for potential reservoir developers.</p> <p>Enable "stop or go-on" decisions during drilling and locate most promising zones for completion without drilling to excessive depths.</p> <p>Improvement in near-term success ratio of 10%.</p> <p>Improvement in near-term exploration effectiveness and reduction of frontend exploration costs.</p> <p>Essential for locating adequate resources to meet mid-term energy goals.</p> <p>Improved reservoir management.</p> <p>Refinement of exploration and assessment cost effectiveness.</p>

TABLE 6 (Concluded)

R&D PROGRAM	R&D ACTIVITIES	ENVISIONED IMPACT
(6) Geothermal Log Interpretation	<ul style="list-style-type: none"> • Evaluate State-of-the-art of well logging. • Stimulate development of new well logging techniques. • Coordinate well log and core depositories. • Establish calibration and test wells. • Petrophysics Research including <ul style="list-style-type: none"> - studies of electrical properties, permeability, porosity and other properties which characterize crack and pore structure, seismic properties and physical chemistry of aqueous solutions and rock-water interactions as a function of temperature, pressure, rock type and fluid chemistry. 	<p>Reduce uncertainty as to reservoir characteristics.</p> <p>Reduce uncertainty as to future well productivity.</p>
(7) Subsidence	<ul style="list-style-type: none"> • Case Histories and Geothermal Subsidence Potential Maps. • Subsidence Field Measurement program. • Development of Subsidence Monitoring Instrumentation. • Study of Environmental and Economic Effects. • Development of Indirect Technique to Estimate Subsidence at Depth. • Physical Processes • Laboratory Testing • Subsidence Models • Reservoir Operational Control Policy 	<p>Reduce uncertainty and risk associated with potential subsidence areas.</p> <p>Improved models, better estimates of subsidence, better reservoir operational policy.</p>
(8) Induced Seismicity	<ul style="list-style-type: none"> • Study of properties of earthquakes occurring naturally in geothermal areas. • Study of hydrodynamic behavior of reservoirs under sustained production and injection. • Investigate physics of earthquake triggering mechanisms. • Establish discriminants for distinguishing induced events from these due to natural processes. • Study of methods of aseismic stress release. 	<p>Reduce uncertainty and risk associated with induced seismicity.</p>

estimated. The results of this analysis are presented along with an indication of the sensitivity of these results to variations in the assumptions on which the analysis was based.

Due to the difficulties associated with the estimation of the quantitative benefits of specific R&D projects (discussed below), the evaluation of the GERRA R&D program was conducted in two relatively discrete stages. The first stage involved the computation of the aggregate benefits for the entire program by estimating the financial benefits which can be expected to result from a specific improvement in the exploratory drilling success ratio*. As indicated earlier (Section 2), technological improvement in exploration and reservoir assessment due to the GERRA R&D program will conceivably result in a corresponding improvement in the drilling success ratio, and hence will reduce the number of wells required to locate, define and confirm a reservoir. In the second stage, presented in Section 4.0, a structured value analysis, based on an industry survey, was conducted to rank order the exploration and resource assessment instruments/techniques in terms of their importance and the need for improvement as perceived by the participants in the survey.

3.2) Methodology: The Benefit/Cost Analysis Model

Benefit/cost analysis provides the structure to evaluate social benefits and costs of government funded programs. A major problem in

* The exploratory drilling success ratio was chosen as the measure of effectiveness for the GERRA R&D Program.

this analysis is the proper identification of the cost incurred by the government, and the benefits received by the industry. In the case of the GERRA R&D program, the budget allocation gives a fairly good indication of the cost of that program. In order to infer the benefits to geothermal developers, quantitative impacts of the GERRA R&D program such as (1) improvements in the drilling success ratio, (2) reduced uncertainty about resource characteristics, and (3) reduced perceived exploration investment risk,* must be identified and estimated.

Figure 1 relates these impact categories to the three major R&D activity areas within the GERRA program and the expected economic/development benefits. As shown in this diagram, some of the R&D activities have a direct impact, while in other cases, the impact occurs indirectly. The notes in this diagram explain the make up of activity areas, technical/decision process impacts, and the economic/development impacts.

Figure 1 also indicates that, the total quantitative benefits of the GERRA R&D program are the aggregate of the three economic/development benefits. Given sufficient data, it would be possible

* Although the success or failure of the GERRA program could impact the share of the energy market captured by hydrothermal geothermal energy, it was assumed that the projected scenario for hydrothermal (electric) development will be achieved, and the benefits of a successful program would be equivalent to the savings in the development costs associated with the realization of the development scenario.

to quantify various benefits under certain assumptions. Unfortunately the data need for quantifying benefits are not available either due to lack of experience or due to the unwillingness of the experienced organizations to divulge information. Therefore, it is necessary to develop a strategy which allows for the quantification of the expected economic benefits without basing the computation on unrealistic assumptions.

At this time, the most easily observable economic impact of the GERRA R&D activities is the saving expected due to improvements in the exploration drilling success ratio. Any improvement in this ratio not only reduces the direct drilling costs, but also shortens the time period between the start of the exploration, and the utilization of the resource. The cost of deep drilling for exploration is very high, and is escalating rapidly. Consequently, even a modest improvement in the drilling success ratio can be expected to yield substantial savings in the exploration investment. These savings can be expected to be many times the savings which might result from less expensive instruments and/or less extensive pre-drilling exploration activities. Nevertheless, it must be recognized that improvements in drilling success ratios are an indication of better well siting, which results from more effective pre-drilling exploration.

A number of other benefits, which would accrue from a successful R&D program, are discussed below. Each is dismissed from further consideration for largely the same reason: the data needed to

estimate these benefits are not currently available.

(1) Reduced Decision Error

Penalties associated with wrong decisions pertaining to exploration and plant design can be quantified only when enough data have been collected to develop reliable estimates of the probabilities of different decision errors and the economic and the energy extraction and conversion system reliability consequences of these errors. In the context of decisions concerning the abandonment or continuation of the exploration activities at a site, the errors are the Type I and Type II errors* encountered in statistical decision process⁹. To quantify the economic impact of changes in the probabilities of Type I and Type II errors, it would be necessary to determine the economic penalties resulting from each of these errors. At this time, neither the probabilities, nor the penalties associated with the two types of decision errors, are known with any degree of certainty.

In addition to the fact that a large fraction of the total economic impact of improved exploration technology is attributable to improved drilling success ratio, and the lack of enough data to estimate other measures of benefit, the following considerations support the adoption of the success ratio as a determinant of the benefits of

* Type I error in exploration leads to abandoning drilling in good target areas. Type II error in exploration leads to drilling where there is no useful fluid.

improved exploration technology*.

- (i) The current success ratio is known with reasonable accuracy.
- (ii) The success ratio and exploration costs are closely related.
- (iii) A realistic target for the improvement of the success ratio can be set.
- (iv) It is possible to track the effectiveness of the GERRA R&D program by monitoring the success ratio in the near term.
- (v) Improvements in the success ratio are also an indication of better reservoir assessment and confirmation techniques.

Thus, reliance on the exploratory drilling success ratio as a measure of effectiveness of the GERRA R&D program in the near term appears to be justifiable. Since the economic benefit associated with improved success ratio is smaller than the total expected benefit, it can be viewed as a conservative estimate of the overall benefit. It is appropriate to point out that the ability to select better sites for exploratory drilling will also affect the siting of production reinjection wells, and generate additional benefits due to a higher proportion of successful production and reinjection wells.

(2) Reduced Misdesign Penalties

Other economic impacts due to uncertainty about resource characteristics result from deliberate overdesign to deal with this

* As explained later, the reservoir site, the development schedule and the location of the development sites must be considered when the computation of benefits is based on the improvement in exploratory drilling success ratio.

uncertainty. This will result in higher plant costs and a lower efficiency of utilization of the resource due to off design operation. Uncertainty about the resource may also cause unintentional under-design resulting in plant reliability problems, and high O&M costs along with lower plant efficiency. A determination of the frequency of occurrence, and the magnitude of the penalties associated with plant misdesign and operation requires data pertaining to geothermal power plant design and operation over a long time period. At present the existing data are insufficient for relating improvements in reservoir assessment and engineering to the resultant reduction in misdesign penalties.

(3) Accelerated Resource Development

The economic benefit resulting from accelerated development of the resource will be in the form of more rapid recovery of the investment made in exploration and development of a field. In this case, fewer unsuccessful wells, and better reservoir assessment and engineering models will shorten the time period between the start of the exploration and utilization of the resource. Here also, the available data are insufficient to help estimate the impact of improvements in exploration technology, and reservoir assessment and engineering on the time period between the start of the exploration and the utilization of the resource.

The aggregate savings in exploratory drilling cost (i.e., aggregate benefit to geothermal developers) will necessarily depend on the

total reduction in the number of wildcat, step-out and confirmation wells drilled as well as on the cost of drilling each of these wells present worth of the potential cumulative savings to geothermal developers to the present value of DOE/DGE exploration and reservoir assessment R&D budget*. The stepwise algorithm of benefit/cost analysis is shown in Figure 5, and the computer program based on this algorithm is documented in Appendix A. The following analysis is restricted by the assumption that the Program Managers and the geothermal industry officials accept the geothermal (hydrothermal-electric) development scenario produced by the Interagency Geothermal Coordinating Council (IGCC) as the focal point of all programs. The underlying assumption is that this scenario was projected after a realistic assessment of the competing alternatives, and barring a disaster, this scenario will be achieved. Therefore, the expected benefits of the GERRA R&D program (and most other programs of DGE) are computed with regard to this scenario**.

3.3 Estimation of Aggregate Benefits of GERRA R&D Program

A rational estimate of the benefits of the GERRA program to the geothermal developer is based on:

- (1) The definition of a reasonable scenario for geothermal development,

* It is assumed that the targeted improvement occurs on account of the DGE R&D program alone.

** This is the standard practice for the benefit/cost analyses of the DGE R&D programs.

FIGURE 5
BENEFIT/COST MODEL FLOW CHART

- (2) An estimation of exploration well requirements,
- (3) Estimation of the costs to be incurred in drilling the required exploration wells, and
- (4) Computation of the potential savings in drilling as a result of improvement in drilling success ratios due to DOE/DGE R&D program in exploration, and reservoir assessment.

Scenario of Geothermal Development

The power-on-line scenario adopted by the IGCC¹⁰ (Table 7) represents a reasonable goal for geothermal development in both the short term (i.e., up to 1985) and the long term (1985-2000). As such, this scenario is used here as a basis for estimating the exploration drilling needed to identify a sufficient number of economic reservoirs that can support the required power production goals.

Exploration Wells Requirement

It is assumed that exploratory wells will be required for each and every power plant. These wells are assumed to precede the plant by a certain lead time. Thus, the first power plant in the prospect must have its exploration completed at least five years prior to the scheduled power-on-line date. We further assume that subsequent power plants may have their exploration completed four years prior to power-on-line date.

The type (i.e., wildcat, stepout, or confirmation) and number of wells to be drilled for exploratory purposes for the first plant will be a function of the current knowledge of the prospect. To this end, the extent of previous geothermal exploration activity in various locations was used to differentiate three different classes¹¹ of

TABLE 7

POWER-ON-LINE SCENARIO (MW_e)

PROSPECT	MW _e OF INSTALLED CAPACITY EXPECTED TO BE BROUGHT ON LINE DURING THE YEAR																							TOTAL
	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
GEYSERS (STEAM)	271.	190.	275.	165.	275.	160.	220.	110.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	1666
BRAZORIA	0.	0.	0.	0.	0.	0.	0.	0.	25.	0.	100.	100.	200.	200.	200.	200.	200.	500.	500.	0.	0.	0.	0.	2225
SALTON SEA	0.	0.	0.	0.	0.	50.	0.	100.	75.	75.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	1600
VALLES CALDERA	0.	0.	0.	0.	0.	50.	0.	0.	100.	0.	100.	0.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	1350
BRADY	0.	0.	0.	0.	0.	50.	0.	0.	50.	0.	100.	0.	100.	100.	100.	100.	100.	100.	100.	100.	0.	0.	0.	1000
BRAWLEY	0.	0.	0.	0.	0.	50.	0.	50.	0.	100.	100.	100.	100.	100.	100.	100.	100.	100.	0.	0.	0.	0.	1000	
ROOSEVELT	0.	0.	0.	0.	0.	50.	0.	0.	50.	0.	50.	0.	100.	100.	100.	100.	100.	100.	100.	50.	0.	0.	0.	1000
BEOWAWE	0.	0.	0.	0.	0.	50.	0.	0.	50.	0.	50.	0.	100.	100.	100.	100.	100.	100.	100.	50.	0.	0.	0.	1000
COSO	0.	0.	0.	0.	0.	0.	0.	50.	50.	50.	150.	150.	150.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	600
MONO-LONG VALLEY	0.	0.	0.	0.	0.	0.	0.	50.	0.	100.	0.	0.	100.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	250
COVE FORT/SULPHURDALE	0.	0.	0.	0.	0.	0.	0.	50.	0.	50.	0.	50.	50.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	1200
HEBER	0.	0.	0.	0.	0.	0.	0.	50.	0.	50.	0.	100.	100.	100.	100.	100.	100.	100.	100.	0.	0.	0.	0.	1000
GEYSERS (HYDRO)	0.	0.	0.	0.	0.	0.	0.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	0.	0.	0.	0.	0.	0.	1000
EAST MESA	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	100
STEAMBOAT	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	0.	100.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	200
SURPRISE VALLEY	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	50.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	1300
CHANDLER	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	100.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	200
LEACH	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	1100
CALCASIEU PARRISH	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	50.	100.	100.	0.	0.	0.	0.	0.	0.	0.	350
BRUNEAU-GRANDVIEW	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	1150
LASSEN	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	100
KENEDY COUNTY	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	50.	50.	50.	50.	0.	0.	0.	0.	0.	0.	300
ALVORD	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	50.	50.	50.	50.	0.	0.	0.	0.	0.	0.	300
MATAGORDA	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	50.	50.	50.	50.	100.	100.	0.	0.	0.	0.	500
CAMERON	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	50.	50.	50.	50.	50.	50.	100.	0.	0.	0.	500
ACADIA	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	50.	50.	50.	100.	0.	0.	0.	0.	0.	0.	350
CORPUS CHRISTI	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	50.	50.	50.	50.	100.	100.	100.	100.	100.	100.	200.	1050
SAFFORD	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	0.	0.	0.	100
WEISER/CRAVE CREEK	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	100.	100.	100.	100.	100.	100.	100.	100.	50.	0.	0.	1000
VALE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	50.	600
THERMO	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	0.	100.	100.	100.	100.	100.	50.	0.	0.	0.	500
RAFT RIVER	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	100
GLASS MOUNTAIN	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50
PUNA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	100.	200.	200.	200.	200.	100.	0.	0.	0.	0.	0.	1000
MT. HOOD	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50
BAKER HOT SPRINGS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50
W. YELLOWSTONE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	50
TOTAL	271	190	275	165	275	460	220	660	600	1075	1200	800	2650	2150	2250	2250	2250	2250	1950	1350	950	800	850	25891

prospects, each with different exploratory drilling requirement as follows:

Class 1, indicates a location with considerable previous exploration activities, and hence, two confirmation (i.e., test) wells are the only drilling requirement for locating an exploitable reservoir site.

Class 2, represents a situation where the prospect is reasonably well known but some exploration is still required to define the boundaries of the reservoir. Thus, 5 stepout wells are needed to delimit the reservoir in addition to two test wells for reservoir confirmation (a total of 7 wells).

Class 3, is typical of a location where no exploratory drilling has occurred. An average of 15 sites¹² within the project must be explored to find a suitable power plant site. Thus 15 wildcat exploratory holes must be drilled to select a site. In addition seven wells have to be drilled for defining the reservoir perimeter and confirming the reservoir capacity in the selected site.

Initially, wildcat and stepout drilling is necessary at class 2 and class 3 sites. The exploratory drilling requirement at these locations is reduced as they are upgraded successively to class 1. At class 1 locations, however, the drilling requirement will remain the same until the assumed reservoir site capacity of 200 MW is used up and a new (class 3) site has to be explored. Based on these assumptions, the computer program listed in Appendix A, used the

power-on-line scenario (Table 7) to generate the exploratory well requirements by year and location (Table 8).

Drilling Cost Estimates by Prospect

For most of the geothermal prospects covered by the DOE/DGE power-on-line scenario, there is no published data on the cost of drilling because they have yet to be drilled. Even where these drilling cost data are available, they are of limited use because: (1) the data may have been obtained from a government-sponsored drilling operation which is often experimental and hence non-typical, (2) the reported costs for drilling and completion are not separated from other associated costs such as licensing, environmental control and legal costs, and (3) the validity of any drilling cost data before 1975 is questionable due to the high escalation rates which have prevailed since then.

Therefore, the characteristics of the geological formation, and the probable depth of the wells for each prospect in the DOE/DGE power-on-line scenario were used to estimate the drilling cost. The geological characteristics were used to define the type and hardness of rock found at each prospect. The depth to the top of the reservoir was determined either from U.S. Geological Survey data, or by comparison with other, similar prospect geologies¹³. The drilling cost per foot is given¹⁴ in Table 9 as a function of rock type and depth. It should be noted, however, that the cost of unsuccessful wildcat or stepout wells may be equal to, higher than, or lower than

TABLE 8

ESTIMATED NUMBER OF WELLS REQUIRED TO SUPPORT POWER-ON-LINE SCENARIO

PROSPECT	NUMBER OF WELLS REQUIRED TO SUPPORT POWER-ON-LINE SCENARIO DURING THE YEAR																						TOTAL
	1978	1979	1980	1981	1982	1983	1984	1985	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
GEYSERS (STEAM)	2.	2.	2.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	8
BRAZORIA	0.	0.	0.	0.	2.	0.	9.	7.	22.	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	128
SALTON SEA	2.	0.	2.	2.	2.	2.	0.	2.	4.	2.	2.	2.	2.	2.	2.	2.	0.	2.	0.	0.	0.	0.	32
VALLES CALDERA	0.	2.	0.	0.	2.	0.	0.	2.	2.	2.	2.	2.	2.	2.	0.	2.	2.	2.	0.	0.	0.	0.	26
BRADY	2.	0.	0.	2.	0.	2.	0.	2.	2.	2.	0.	7.	7.	9.	0.	0.	0.	0.	0.	0.	0.	0.	35
BRAWLEY	0.	2.	0.	0.	2.	2.	2.	2.	2.	2.	2.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	20
ROOSEVELT	0.	2.	0.	0.	2.	2.	0.	2.	2.	2.	2.	2.	2.	0.	2.	2.	0.	0.	0.	0.	0.	0.	22
BEOWAWE	2.	0.	0.	2.	0.	2.	0.	2.	2.	2.	0.	2.	7.	9.	7.	0.	0.	0.	0.	0.	0.	0.	37
COSO	0.	0.	5.	24	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	117
MONO-LONG VALLEY	0.	0.	22.	0.	22.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	66
COVE FORT/SULPHURDALE	0.	0.	2.	0.	2.	0.	2.	2.	2.	2.	4.	7.	7.	7.	7.	22.	22.	0.	0.	0.	0.	0.	88
HEBER	0.	0.	2.	0.	2.	0.	2.	2.	2.	2.	0.	2.	2.	2.	2.	0.	0.	0.	0.	0.	0.	0.	20
GEYSERS (HYDRO)	0.	0.	2.	2.	2.	2.	2.	2.	7.	7.	9.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	35
EAST MESA	0.	0.	0.	2.	0.	0.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4
STEAMBOAT	0.	0.	22.	0.	0.	22.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	66
SURPRISE VALLEY	0.	0.	0.	2.	0.	2.	2.	2.	2.	5.	7.	7.	9.	7.	7.	22.	22.	0.	0.	0.	0.	0.	96
CHANDLER	0.	0.	0.	22.	0.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	44
LEACH	0.	0.	0.	0.	2.	0.	2.	2.	2.	2.	9.	7.	7.	7.	7.	22.	22.	0.	0.	0.	0.	0.	91
CALCASIEU PARRISH	0.	0.	0.	0.	22.	0.	0.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	88
BRUNEAU-GRANDVIEW	0.	0.	0.	0.	2.	0.	0.	2.	2.	0.	2.	7.	24.	22.	22.	22.	22.	0.	0.	0.	0.	0.	127
LASSEN	0.	0.	0.	0.	7.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	29
KENEDY COUNTY	0.	0.	0.	0.	0.	0.	0.	7.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	73
ALVORD	0.	0.	0.	0.	2.	0.	0.	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	90
MATAGORDA	0.	0.	0.	0.	7.	2.	0.	0.	22.	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	117
CAMERON	0.	0.	0.	0.	2.	0.	0.	0.	7.	24.	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	121
ACADIA	0.	0.	0.	0.	22.	0.	0.	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	110
CORPUS CHRISTI	0.	0.	0.	0.	0.	0.	0.	2.	2.	0.	2.	2.	24.	22.	22.	22.	22.	0.	0.	0.	0.	0.	120
SAFFORD	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	22
WEISER/CRAVE CREEK	0.	0.	0.	0.	0.	2.	0.	2.	2.	2.	4.	7.	7.	22.	22.	22.	22.	0.	0.	0.	0.	0.	92
VALE	0.	0.	0.	0.	0.	2.	0.	2.	0.	2.	7.	9.	22.	22.	22.	22.	22.	0.	0.	0.	0.	0.	132
THERMO	0.	0.	0.	0.	0.	5.	2.	0.	22.	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	117
RAFT RIVER	0.	0.	0.	0.	0.	2.	0.	7.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9
GLASS MOUNTAIN	0.	0.	0.	0.	0.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	22
PUNA	0.	0.	0.	0.	0.	0.	0.	7.	22.	22.	22.	22.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	95
MT. HOOD	0.	0.	0.	0.	0.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	22
BAKER HOT SPRINGS	0.	0.	0.	0.	0.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	22
W. YELLOWSTONE	0.	0.	0.	0.	0.	0.	0.	22.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	22
TOTAL	8	8	54	62	150	72	47	322	218	229	228	195	212	155	122	160	134	4	0	0	0	0	2380

TABLE 9*

DRILLING COST AS A FUNCTION
OF ROCK TYPE AND DEPTH

ROCK HARDNESS	COST/FOOT (1977 \$)	
	<5,000 Feet	>5,000 Feet ¹
Soft	80	160
Medium	100	120
Medium Hard	125	250
Hard	200	400

¹ The exploratory well depth rarely exceeds 10,000 feet.

*Source: E.J. Friedman and A. El-Sawy, Prospects for Improvement in Geothermal Well Technology and Their Expected Benefits, (MTR-7613), 1977), p. 52.

that of a completed well drilled to its full depth, depending on the drilling environment at a specific site.

As shown by Friedman, et al¹⁵, the foregoing method of estimating drilling cost will lead to a root mean square error of 8 percent. Since there is a lot of uncertainty about the cost of drilling at various sites, an error of this magnitude would be acceptable.

Potential Savings in Drilling

Realization of the DGE postulated power-on-line scenario of Table 7 implies an exploration drilling schedule of a sufficient number of economic reservoirs that can support the required power production goal. The savings in exploratory drilling cost realized as a result of more efficient exploration well siting, and hence fewer dry wells due to improvement in drilling success ratio, represent the expected benefits that could be generated by government sponsored, or private industry supported research.

Since there is some uncertainty about the current success ratios, sets of estimated values of the current success ratio were analyzed for each of the three phases of exploration, namely; wildcat exploratory drilling, stepout well drilling and test well or confirmation drilling. For instance, a current wildcat drilling success ratio of 1 in 10 is regarded as a baseline for a GERRA R&D program aimed at improving this success ratio to 1 in 8. Similar improvement is targeted for both the stepout and test well (i.e., confirmation well) success ratio as shown in Table 10.

TABLE 10

TARGETED CHANGES IN DRILLING SUCCESS RATIO

TYPE OF SUCCESS RATIO	BASE CASE CURRENT ESTIMATE OF SUCCESS RATIO	TARGET LEVELS OF IMPROVEMENT IN SUCCESS RATIO*			
		LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Wildcat	0.1	0.125	0.2	0.3	0.3
Stepout	0.3	0.4	0.5	0.6	0.7
Development (Test Well)	0.8	0.9	0.95	1.0	1.0

* The set of values included in each level of improvement were used in the sensitivity analysis discussed later.

The estimated savings are spread over a number of years (1978-2000). Future benefits are, therefore, discounted to reduce their weight in the computation of total benefits; the more distant benefits have greater uncertainty associated with them. The choice of the proper discount rate is thus a crucial parameter in the estimation of aggregated saving of exploratory drilling.

Currently, the Federal government has two distinct policies in effect regarding the choice of discount rates to be used in cost/benefit analysis. One policy is limited in application to water resource related projects, and requires a 7 percent discount rate. The other policy is applicable to all remaining projects, and enforces a 10 percent discount rate¹⁶. In this analysis, a range of 5 to 10 percent discount rate was used.

The cost of drilling (\$/foot) is another important factor that has a significant impact on the estimated saving in geothermal exploratory drilling*. Indications are that drilling costs for wells have increased during the last two years mainly due to escalation in material, and labor costs. For fixed discount and escalation rates, the benefit/cost computer program listed in Appendix A is used to estimate the expected benefits for three separate cases involving different assumptions regarding the cost of unsuccessful wells. In

* An RD&D program aimed at reducing the cost per foot of well drilled is underway within DGE. This program may neutralize the expected increase in well drilling costs. If a reduction in well drilling costs materializes, the estimated benefits of the GERRA R&D program will be reduced.

the first case (Base Case), the drilling cost for unsuccessful wildcat and stepout wells is taken to be equal to that of a completed successful well. In the other two cases, the drilling cost of an unsuccessful well is assumed to be 0.60 and 1.10 times that of a completed well respectively.

For the base case, corresponding to the current exploration technology, the success ratios for the three types of wells are assumed to be:

- (a) 0.1 for wildcat wells,
- (b) 0.3 for stepout wells, and
- (c) 0.8 for test wells.

When combined with the schedule for the development of 27 prospects in the Pacific Coast and Mountain Regions (Table 7), these success ratio estimates yield a weighted success ratio of 0.24 for all types of exploratory drilling (see Table 11).

3.4 Estimation of Cost (the GERRA R&D Budget)

Table 12, shows a breakdown of FY 1978 budget among the various R&D components of the GERRA program. Only part (\$2887 K) of the total FY 1978 GERRA R&D budget amount of \$10.23 million shown in Table 12, is directly related to the power-on-line scenario and the improvement in drilling success ratio. This portion of the GERRA program budget can be identified with the estimated benefits due to improved drilling success ratio. The remaining part of the GERRA R&D budget is allocated to (1) the non-electric R&D program which is

TABLE 11

WEIGHTED AVERAGE SUCCESS RATIO COMPUTATION

WELL TYPE	ASSUMED* SUCCESS RATIO (1)	PERCENT COMPOSITION OF EXPLORATORY WELL MIX (2)	PRODUCT (1)x(2)
Wildcat	0.1	60	0.060
Step-Out	0.3	28	0.084
Test	0.8	12	0.096
Weighted Average Success Ratio = 0.240			

* These assumed values approximate the current success ratio values for the three types of exploratory drilling.

TABLE 12

GERRA R&D BUDGET FOR FY 1978

GERRA PROGRAM COMPONENTS	BUDGET \$	PRESENT WORTH OVER 5 YEARS AT 10% DISCOUNT RATE
Industry Coupled Program	2,425 K	
State Coupled Program	2,600 K	
Precommercial Reservoir Confirmation	1,250 K	
Reservoir Engineering*	1,087 K	4,120.8 K
Exploration Technology*	1,400 K	5,307.4 K
Geothermal Log Interpretation*	400 K	1,516.4 K
Subsidence	750 K	
Induced Seismicity	322 K	
TOTAL	10,230 K	10,944.6 K

Source: Draft Summary of FY 1978 Funding, DOE/DGE.

* (See text).

not relevant to the power-on-line scenario, (2) the industry coupled, and precommercial programs which are aimed at the reduction of drilling investment risk in some selected areas, and (3) reservoir engineering activities which are designed to accelerate the development of hydrothermal resources by reducing the uncertainty about the reservoir performance and longevity through the application of more reliable reservoir engineering models.

3.5 Results

3.5.1 Estimated Benefits

Applying the logic shown in Figure 5, the benefits resulting from a uniform improvement in drilling success ratio (over a 5-year period of R&D) were computed for three cases involving different assumptions regarding the cost of unsuccessful wells. The benefits with four levels of improvement in the success ratio (Table 8) above the current estimated value of 0.24 were estimated for each of the three cases. To account for the increase in the cost of wells with time, a 5% per year escalation rate was applied to the well cost in 1978 dollars. In calculating the present worth of all future benefits, a discount rate of 10% per year is utilized for reducing the weight of the benefits expected to occur in the future.

Table 13, shows the estimated discounted benefits expected to result from different levels of the improvement in the drilling success ratio. The costs of the R&D program, aimed at achieving these improvements in the next five years, were estimated, and the present

TABLE 13

EXPLORATION TECHNOLOGY R&D PROGRAM BENEFIT/COST RATIOS BASED ON DRILLING SUCCESS RATIO IMPROVEMENTS

PERCENT IMPROVEMENT IN SUCCESS RATIO*	CASE I ⁺⁺ (Base Case)		CASE II ⁺		CASE III ⁺⁺⁺	
	BENEFIT \$ (MILLIONS)	BENEFIT COST RATIO	BENEFIT ^Δ \$ (MILLIONS)	BENEFIT [#] COST RATIO	BENEFIT \$ (MILLIONS)	BENEFIT COST RATIO
29	478.47	43	287.08	26	526.31	48
54	903.39	82	542.13	49	993.72	90
75	1,054.09	96	632.43	57	1,159.52	105
90	1,157.89	105	694.73	63	1,273.62	116

* The percent improvement in the drilling success ratio is equal to

$$\frac{\text{Improved weighted average success ratio} - \text{current weighted average success ratio}}{\text{Current weighted average success ratio}} \times 100$$

The current weighted average success ratio is 0.24

⁺⁺ In Case I, unsuccessful wells are assumed to cost as much as the successful wells.

⁺ Case II is based on the assumption that the cost of an unsuccessful well is equal to 60% of the cost of a successful well.

⁺⁺⁺ In Case III, unsuccessful wells are assumed to cost 1.1 times the cost of a successful well.

^Δ The benefit computation is based on a cost escalation rate of 5% per year and a discount rate of 10% per year for estimating the present worth. Since the basic benefit computations are in terms of 78 dollars, the use of discounting for estimating the present worth is aimed at reducing the weight of the benefit which will occur far in the future.

[#] The estimated costs are equivalent to the present worth of the R&D budget (i.e., 2887K) for five years (FY78 to FY82) discounted at 10% per year).

worth of these costs were computed and used to determine the corresponding benefit to cost ratios.

Table 13, shows that a 29% improvement in the current success ratio (from 0.24 to 0.31) will yield cumulative benefits ranging from \$287 millions to \$526 millions depending on the case under consideration.* If the success ratio is doubled (to 0.48), the cumulative benefits will be in the range \$700 millions to \$1.3 billions. The lowest benefit/cost ratio associated with the 12 improvement level-case combinations in Table 13 is 26, and the highest benefit/cost ratio value is 116**.

It is appropriate to point out that the assumptions associated with this analysis can have a significant impact on the benefit/cost ratios for the R&D program. The major assumption related to the results in Table 13 is that the entire projected improvement in the success ratio is attributed to a successful GERRA R&D program. This assumption tends to enlarge the expected benefit because a part of the improvement in the success ratio will result from industry efforts. On the other hand, the estimated benefits do not include any credit for the savings expected to result from a higher success ratio in production drilling which result from a successful GERRA R&D program. The estimated benefits are also exclusive of the savings which may

* These benefits are equivalent to a reduction in the cost of geothermal electric power which ranges from 0.21 mills/kwhr to 0.38 mills/kwhr.

** It should be noted that the lowest benefits would occur when the discount rate is 10 percent and the escalation rate is zero. In this case, the estimate benefit is as low as \$170 millions and the benefit/cost ratio is 16.

occur in the geopressured zone and also at reservoirs suitable for direct utilization. The rate for the escalation in the cost of geothermal drilling (5% per year) is also conservative. The drilling costs have risen 8% to 9% faster than inflation in recent years¹⁷.

Some of the activities which are considered to be a part of the program aimed at improving the drilling success ratio will have an impact on resource assessment and reservoir confirmation. Because of the difficulties in estimating the benefits of these efforts, as explained earlier, the expected benefits are not added to the figures in Table 13.

3.5.2 Additional Benefits of the GERRA R&D Program

So far, only the benefits associated with the exploration and reservoir assessment portion of the GERRA program (i.e., those indicated with an asterisk in Table 12) have been estimated. Additional benefits generated by some of the remaining portion of the GERRA program (i.e., subsidence and exploration equipment development) should also be considered as indicated below.

(1) Benefits Due to Improved Detection and Control of Subsidence:

At present only 1 out of 3 producing sites¹⁸ is identified as environmentally acceptable, and is issued an operating permit. It is reasonable to assume that, with improved detection and control of subsidence and induced seismicity, the probability of securing an operating permit will increase to $\frac{1}{2}$. As a result, 17 percent (i.e., 0.5-0.33) fewer production prospects will be rejected as environmentally unacceptable.

Typically, improved subsidence and induced seismicity detection and control are the decisive

environmental acceptance factors in 20 percent¹⁹ of the cases leading to an additional saving of 3.4 percent of the exploratory drilling cost. On the average the additional exploratory drilling cost savings due to subsidence and induced seismicity R&D activities will thus amount to an estimated 20 million dollars during the time period 1978-2000.

(2) Benefits Due to Improvements in Geoscientific Techniques

By using combined cost effective field methods and multiple-data-set interpretation, the geoscience costs could be cut in half. Based on Greider's²⁰ geoscience cost estimate this reduction amounts to 3.17 million dollars per 200 MW filed. For the total power-on-line scenario, the geoscience cost reduction will thus amount to \$300.17 million of additional benefits.

3.6 Sensitivity Analysis

As already indicated, the estimated benefit is a function of various parameters, including the discount rate, the drilling cost escalation rate, and the initial weighted average success ratio. However, the sensitivity of the estimates of benefits to changes in these parameters is different. Figure 6, displays the relationship between the percent improvement in the success ratio and the cumulative benefits for a given value of (0.24) of the initial weighted average success ratio, as a function of the drilling cost escalation rate and the discount rate. The corresponding relationship between improvement in success ratio and the expected reduction in cost per kwhr of geothermal electricity is shown in Figure 7. It can be observed that a smaller discount rate increases the value of the

FIGURE 6
SENSITIVITY OF BENEFITS TO PERCENT IMPROVEMENT IN SUCCESS
RATIO AT VARIOUS LEVELS OF DISCOUNT RATE AND DRILLING
COST ESCALATION RATE

FIGURE 7
SENSITIVITY OF REDUCTION IN COST OF POWER GENERATION
TO PERCENT IMPROVEMENT IN SUCCESS RATIO AT
VARIOUS LEVELS OF DISCOUNT RATE AND DRILLING
COST ESCALATION RATE

estimated benefits and results in greater reductions in cost per kwhr of geothermal electricity. The cumulative benefits also increase when the drilling cost escalation rate is raised.

The effect of changing the level of the initial weighted average success ratio is depicted in Figure 8. This figure indicates the incremental improvement in success ratio that would be needed to generate a given amount of benefit for different levels of initial weighted average success ratio. The smaller the initial weighted average success ratio, the smaller is the increment required to improve it by a given percentage. It can also be observed that the smaller the initial weighted average success ratio, the larger the benefits associated with a given absolute improvement.

Curves similar to those in Figures 6 and 8 can be developed and utilized for reading the estimated benefits for different sets of values of the initial weighted average success ratio, discount rate and the drilling cost escalation rate.

3.7 Sensitivity of Expected Benefits to R&D Budget Level

In the preceding analysis, it was assumed that the budget for the GERRA R&D program is fixed, and an attempt was made to estimate the benefits which will be realized if different levels of improvement in drilling success ratio were achieved. However, it has been shown²¹ that the impact of a well planned R&D program is basically a function of the level of funding. It is reasonable to assume that an increased funding of the GERRA R&D program would increase the level of improve-

FIGURE 8
INCREMENTAL IMPROVEMENT IN SUCCESS RATIO REQUIRED TO
REALIZE A GIVEN BENEFIT* (EFFECT OF CHANGE IN INITIAL
LEVEL OF SUCCESS RATIO ON BENEFIT)

* The relationship shown in the figure cannot be extrapolated linearly beyond 0.09.

** Initial weighted success ratio.

ment in drilling success ratio at a progressively diminishing rate that can be expressed mathematically by the six-tenth rule²²:

$$HSR = BSR \left(\frac{HBL}{BBL} \right)^{0.6} \quad (1)$$

where:

HSR = Improved Success Ratio,

BSR = Base Case or Initial Weighted Average Success Ratio,

HBL = High Budget Level,

BBL = Base Line Budget,

The incremental improvements in success ratio derived from equation (1), for multiple increases in budget levels, are entered in Figure 6 to determine the corresponding increase in estimated benefits displayed in Figure 9. For a budget level of \$2.887 million per year (for 5 years) and an expected improvement in the current weighted average success ratio from 0.24 to 0.29, equation (1) indicates that the minimum possible budget level (i.e., base budget level) is \$2.14 million per year*. This base level will keep the GERRA R&D program just visible, but is not expected to result in any improvement in the current level of success ratio over that induced by private geothermal industry on its own.

The curves in Figure 9 can also be used to determine the marginal benefit/cost ratios for the exploration R&D program under different assumptions. It appears that the marginal benefit/cost ratio for this

* This is based on the assumption that 20% of the improvement in the success ratio is generated by the efforts of the industry.

FIGURE 9
SENSITIVITY OF BENEFITS TO CHANGES IN EXPLORATION
R&D BUDGET

program approaches 1 as the budget is increased to about double the current budget (i.e., at about \$6 millions per year).

3.8 Justification of R&D Budget

The total savings in exploration drilling can be used to target a reasonable research expenditure needed to achieve the projected savings. The idea is, to select an appropriate benefit to cost ratio, and apply it to the projected savings (i.e., benefits) to calculate the corresponding cost (i.e., budget). For conventional projects, any benefit to cost ratio greater than 1 would be adequate, and would indicate that the project is economically desirable. For research projects of highly uncertain outcome, and impact, a higher benefit to cost ratio is more appropriate. For this analysis, a benefit to cost ratio of 10* is selected to target a reasonable government research budget. Under the conservative assumption of a 10 percent discount rate, no escalation in the cost of drilling, and a reasonably low expectation of improvement in success ratio of 20 percent, the minimum benefits of the GERRA R&D program is calculated from Figure 6 to be \$220 million. On the basis of 10:1 benefit to cost ratio, this amount of generated benefits justifies a research budget of 22.0 million dollars which is twice the current DOE/DGE budget allocated for the GERRA R&D program.

* This is the same ratio used in targeting a research budget for drilling technology. (See Friedman, et al., op cit, 1977) p. 63.

3.9 Conclusion

Assuming that the Federal GERRA R&D program is achieving its goal of improvement in drilling success ratio, the estimated benefits range from \$220 million to \$2.0 billion depending on the current initial weighted average success ratio, the discount rate, and the rate of escalation in drilling cost. Under the most conservative assumption of a 10% discount rate, no escalation in the cost of drilling, and a reasonably low expectation of improvement in success ratio, the resultant benefits are expected to exceed \$220 million (Figure 6). On the basis of 10:1 benefit to cost ratio, this amount of generated benefits justifies a research budget twice that currently allocated.

Although there is some uncertainty about the magnitude of the savings, the estimates presented here are relatively conservative. No credit is being taken for the savings which the GERRA R&D Program will produce in exploring and assessing the resources for nonelectric utilization. The benefits associated with the exploration and utilization of the geopressured zones are also excluded.

The results presented here are focussed on the technological improvements in the geothermal exploration technology. Despite the relatively large projected savings in this area, it is possible that the institutional/legal obstacles faced by the industry are equally important. However, the importance of exploration/assessment R&D in this area is clear, no matter what is done with regard to the institutional/legal issues.

The benefit/cost ratio estimates presented in this section are based on the assumption that the improvement in the drilling success ratio is attributable entirely to the government R&D Program. Although the private companies improve the techniques and equipment, the impact of these improvements may be limited, by competitive considerations, to individual companies.

This analysis suggests realistic targets for the GERRA R&D program. However, it does not suggest how this target can be reached. The structured value analysis and the feedback of in-person interviews that follows has yielded some indications regarding the composition of an effective program.

SECTION 4.0

INDUSTRY PERCEPTION OF THE DOE/DGE GERRA R&D PROGRAM

4.0 INDUSTRY PERCEPTION OF THE DOE/DGE GERRA R&D PROGRAM

4.1 Introduction

The usefulness of any government funded R&D program is determined basically by its budget justification and responsiveness to the needs of users of the output of R&D. The budget justification of the GERRA R&D has already been discussed in Section 2. Determination of the needs of the users of geothermal exploration and reservoir confirmation and assessment techniques was the primary objective of various workshops*, consortia** and other efforts sponsored by DOE/DGE over the past two years.

Unlike these R&D planning exercises, the users survey, discussed in this section, is intended to examine the users' perception of expected impact of the GERRA R&D program in terms of: (1) improvement in exploration decision making due to the GERRA R&D program, (2) increased cost-effectiveness of improved/developed exploration/assessment techniques, and (3) reduced exploration/assessment risk and uncertainty. The Users Survey Questionnaire designed for that purpose is presented in Appendix B.

A total of 72 copies of that questionnaire were mailed to a selected sample of individuals/organizations, that are known for their expertise, are active in the geothermal area, and make up a truly representative cross section of expected users of the products of the

* Workshop hosted by ERDA (DOE), U.S. Geological Survey and NSF since 1975.

** For example, the University of Utah Consortium, 1978.

GERRA R&D program. As shown in Appendix E, the users survey sample included geothermal exploration companies, geothermal field developers, field service companies, oil companies, utilities, consultants, universities and others (e.g., U.S.G.S., national laboratories and state surveyors). Of those selected, only 30 responded in time to be included in the survey analysis presented here. However, this number of respondents is enough to allow a meaningful statistical analysis*.

4.2 The Questionnaire

To the extent possible, the questionnaire used in the foregoing survey was designed to provide well defined answers that could be easily coded for further computer processing. As shown in Appendix B, the questionnaire is made up of 4 tables (B1-B4), each covering a different aspect of the survey.

4.3 Survey Analysis

Two types of analysis were used to evaluate the survey responses received; statistical analysis, and structured value analysis. Various types of statistical computations were used to (1) develop a profile of the respondents based on frequency counts, (2) calculate weighted averages of various scores, and (3) test for built-in bias and randomness of responses using the chi-square test²³. The algorithm and computer listing of the survey statistical analysis is given in Appendix C.

* For detail see (Statistical Significance) Appendix C.

Structured value analysis is used for ranking individual R&D projects within the GERRA R&D program according to their effectiveness, need for improvement, and regional applicability as reflected by the responses to questions in Table B-3 and Table B-4 of the questionnaire (Appendix B). Subroutine SORT listed in Appendix C, was developed to undertake this rank-ordering analysis.

4.4 Survey Results

The results of the geothermal industry survey analysis are summarized in the following subsections.

4.4.1 Users' Perceived Impact of GERRA R&D Program

Table 14, summarizes the perceived impact of GERRA R&D program on the main components of the geothermal exploration/assessment decision-making process (i.e., improved drilling success ratio, and reduced decision errors and investment risk), based on the analysis of responses in Table B-2.

Inspection of this table indicates that, except for the case of the Geysers steam fields, the GERRA R&D program is expected to have its highest impact on improving the exploratory drilling success ratio in all types of geothermal fields, and least impact on reducing the decision errors (i.e., Type I and II errors). Table 6 shows that, of all research subprograms covered by GERRA R&D program, only reservoir engineering is partially intended to reduce the decision errors.

Table 15 shows that irrespective of the geothermal field type, the respondents are highly in favor of the state coupled, industry

TABLE 14

RELATIVE IMPACT OF OVERALL PROGRAM

TYPE OF RESOURCE	AREA OF INTEREST		
	IMPROVE SUCCESS RATIO	REDUCE EXPLORATION DECISION ERRORS	REDUCE INVESTMENT RISK
Steam	49	27	25
Hydrothermal	49	22	29
Geopressure	48	16	36
Hot Dry Rock	36	22	42
Overall	41	27	32

TABLE 15

RANK ORDER OF THE IMPACT OF VARIOUS GERRA R&D
SUBPROGRAMS ON DIFFERENT GEOTHERMAL RESOURCE TYPE

RESEARCH SUBPROGRAM	TYPE OF GEOTHERMAL RESOURCES				
	STEAM	HYDROTHERMAL	GEOPRESSURE	HOT DRY ROCK	OVERALL
Pre-Commercial Program	5	4	4	3	4
Industry Coupled Program	2	3	2	2	2
State Coupled Program	1	1	1	1	1
Reservoir Engineering	3	2	3	4	3
Surface Exploration (Hardware Development)	7	7	7	7	7
Geothermal Log Interpretation	6	6	6	6	6
Subsidence and Induced Seismicity	4	5	5	5	5

Legend: 1 = Highest, 7 = Lowest

coupled, and reservoir engineering subprograms, respectively.

According to Table 6, these components of the GERRA R&D programs are intended to help reduce explorational assessment investment risk and uncertainty either by direct cost sharing, or by providing for better anticipation of reservoir behavior. Reducing the uncertainty and investment risk is thus of great concern to potential geothermal reservoir developers. Any R&D effort that could achieve this goal is most desirable.

Table 15 also indicates that further improvement in surface exploration hardware will have limited impact on geothermal exploration decision-making process in any type of geothermal field. This reflects the industry feeling that the existing geothermal exploration/assessment technology is adequate if better data interpretation techniques were available.

4.4.2 Users Perceived Regional Applicability of Exploration/Assessment Techniques

In Table 16 the fourteen most widely used exploration/assessment techniques are rank ordered according to their applicability in the different geothermal provinces (i.e., Salton Trough, Basin and Range, Basaltic Island and other regions). In any geothermal province the most applicable exploration/assessment technique is ranked as number 1, and the least applicable as number 14 based on the responses in Table B-3 (Appendix B).

The results in Table 16 show that thermal methods are thought to be the most applicable in all geologic environments with two

TABLE 16
EVALUATION OF REGIONAL APPLICABILITY OF EXPLORATION/ASSESSMENT TECHNIQUE

TECHNIQUE	OVERALL REGIONAL RANKING APPLICABILITY	RANKING OF TECHNIQUES ACCORDING TO APPLICABILITY IN											
		SALTON TROUGH	BASIN AND RANGE	CAS- CADES	BASALTIC ISLAND REGIME	SNAKE RIVER PLAIN	WASATCH FRONT	RIO GRANDE RIFT	GEYSERS	ALEUTIAN ARC ISLAND	APPA- LA- CHIAN	EASTERN AND SE PLUTONS	GEOPRES- SURED REGION
Thermal Methods	1	1	1	1	2	1	1	1	1	1	1	1	2
Surface Geological Mapping	2	9	2	2	1	2	2	2	2	2	3	5	9
Gravimetry	3	2	7	5	4	3	7	7	3	4	2	2	5
Electrical Methods	4	3	4	3	3	8	4	3	8	5	8	6	7
Borehole Logging	5	5	8	10	10	4	8	9	7	3	15	4	1
Seismic Methods	6	4	5	8	6	6	5	5	6	6	9	7	3
Liquid Geochemistry	7	6	3	4	5	9	3	4	5	7	6	8	4
Air Photogeology	8	7	6	7	8	5	9	8	4	9	7	9	12
Age Dating	9	10	9	6	7	7	6	6	9	8	10	10	14
Magnetics	10	8	10	9	9	10	10	10	10	11	4	3	6
Gas Geochemistry	11	11	13	13	11	13	13	13	11	12	11	12	8
Remote Sensing	12	12	12	12	13	11	11	11	12	13	12	11	10
Thermal Infra Red	13	13	11	11	12	12	12	12	13	10	13	13	11
Other	14	14	14	14	14	14	14	14	14	14	14	14	13

LEGEND

1 = Most Applicable to 14 = Least Applicable

exceptions; the Geopressured and the Basaltic Island regimes. Unlike conventional hydrothermal systems, temperature, hence, thermal methods of exploration play a minor role in delineating the geopressured reservoir behavior. The best evidence for geopressured regimes comes from actual drill logs for holes that have already penetrated into the reservoir itself. Borehole logging is thus more effective.

Basaltic Island Regimes represent another unique geological situation where volcanology and electric resistivity appear to be more diagnostic of these geologic environment than thermal methods.

Other methods which have the widest applicability across the different geological environments are surface geologic mapping, gravimetry, electric methods and liquid geochemistry. The applicability of borehole logging and seismic methods is limited to the Salton Trough and Geopressured regimes, while, magnetic methods are useful in the Appalachians and Eastern and South Eastern Plutons. Air photogeology is of some interest only in the Geysers. Thermal infrared technique has the lowest applicability rating in all regions.

Further inspection of Table 16 delineates seven reasonably distinct exploration ensembles. These exploration ensembles (of the five most effective exploration techniques in each geological environment) are listed in Table 17 which provides a useful checklist of possible exploration strategies and R&D funding priorities.

TABLE 17

EFFECTIVE ENSEMBLES OF EXPLORATION TECHNIQUES
IN VARIOUS GEOLOGIC ENVIRONMENTS

GEOLOGICAL ENVIRONMENT	USERS PERCEIVED MOST APPLICABLE TECHNOLOGY
Geysers	Thermal Methods Surface Mapping Gravimetry Air Photography Geochemistry
Salton Trough	Thermal Methods Gravimetry Electrical Methods Seismic Methods Borehole Logging
Basaltic Island Arc	Surface Mapping Thermal Methods Electrical Methods Gravimetry Geochemistry
Geopressured Zone	Borehole Logging Thermal Methods Seismic Methods Geochemistry Gravimetry
Basin and Range Snake River Plain Wasatch Front Rio Grande Rift	Thermal Methods Surface Mapping Geochemistry Electrical Methods
Appalachian Province Eastern and S.E. Plutons	Thermal Methods Gravimetry Magnetic Methods
Cascade and Aleutian Arc Islands	Thermal Methods Surface Mapping Gravimetry Electrical Methods

4.4.3 Users Perceived Effectiveness and Need for Improvement of Exploration Techniques

In Table B-4 (Appendix B), the effectiveness of an exploration technique was measured by its weighted average respondent ratings on diagnostic capability, applicability, dependability and immunity to background noise. These ratings were used to rank order various techniques as shown in Table 18, with 1 corresponding to the highest and 14 to the lowest rank. Inspection of Table 18 shows that thermal methods, surface geological mapping liquid geochemistry are the exploration techniques with highest effectiveness.

For further analysis, the ratings in Table B-4 were used to rank order the exploration techniques by perceived effectiveness and need for improvements as shown in Table 19. Techniques falling within the heavily marked area in Table 19 are the most attractive candidates for further research and development. Thus liquid geochemistry, seismic methods and thermal methods are high priority research areas. These techniques are most effective and their need for improvement is reasonable. Electrical methods, while ranking as highly effective, will probably require a high research budget for their improvement. The remaining exploration techniques are either of low to medium effectiveness, or need no further improvement to warrant further R&D funding.

TABLE 18

RANKING OF TECHNIQUES EFFECTIVENESS

TECHNIQUE	OVERALL RANKING	RANKING BASED ON			
		DIAGNOSTIC CAPABILITY	APPLICA- BILITY	DEPENDA- BILITY	IMMUNITY TO BACKGROUND NOISE
Thermal Methods	1	1	1	1	5
Liquid Geochemistry	2	3	4	2	6
Surface Geological Mapping	3	2	5	4	10
Electrical Methods	4	4	3	3	5
Seismic Methods	5	5	2	5	1
Gravimetry	6	7	6	7	3
Borehole Logging	7	6	8	8	4
Air Photogeology	8	8	7	6	9
Magnetics	9	9	9	9	8
Age Dating	10	10	10	10	7
Remote Sensing	11	11	13	13	12
Gas Geochemistry	12	12	12	12	11
Thermal Infra-Red	13	13	11	11	13
Other	14	14	14	14	14

TABLE 19

CLASSIFICATION OF TECHNIQUES BY EFFECTIVENESS AND NEED FOR IMPROVEMENT

NEED FOR IMPROVEMENT EFFECTIVENESS	NO	MEDIUM	HIGH
HIGH	Surface Geological Mapping	Liquid Geochemistry Seismic Methods Thermal Methods	Electrical Methods
MEDIUM	Air Photogeology Gravimetry Magnetism Age Dating		Borehole Logging
LOW		Remote Sensing Thermal Infra-Red Gas Geochemistry	

SECTION 5.0

IN-PERSON INTERVIEW FINDINGS

5.0 IN-PERSON INTERVIEW FINDINGS

To augment the information and feedback received through the responses to the industry survey questionnaire, in-person interviews were conducted with ten recognized experts in the field of geothermal exploration. In selecting the individuals for interviewing, an effort was made to give an adequate coverage to different aspects of geothermal exploration and resource and reservoir assessment/confirmation. The individuals interviewed by the MITRE research team represented the entire spectrum of participants in geothermal exploration and development. Geothermal service companies, exploration companies, developers, research laboratories and U.S.G.S. were represented by the officials or researchers with whom interviews were conducted.

Most of the individuals interviewed by the MITRE research team had a fairly clear perception of the objectives of this study. Many of them had received the questionnaire long before the interviews were conducted. The interviews were relatively unstructured, although an effort was made to probe deeply into the areas of expertise and concern represented by the individual being interviewed. After being assured that the confidentiality of the sources of individual statements or inputs would be maintained, most of the people interviewed were forthcoming with a very frank expression of their views regarding the industry needs, and their own perceptions of the effectiveness of the GERRA R&D program.

The names of the persons interviewed by MITRE are included in Appendix D. The significant issues and comments which surfaced during these interviews are discussed below.

5.1 General Impressions Regarding the GERRA R&D Program

The geothermal exploration activities are being undertaken by a relatively small number of organizations. These explorers range in scale of operation from small explorers, who discover a potential reservoir and pass it on to a resource developer, to large oil companies which engage in all phases of exploration and field development. Although there is intense competition among these organizations, all of them feel fairly comfortable in an environment where the rules governing the competition are implicitly set by the participants themselves. This implicit understanding influences the level and location of the exploration and development activities.

The creation of the GERRA Program has introduced a new element into the scenario. Through the industry coupled cost shared drilling program, the Federal government is trying to accelerate development in existing KGRA's and is also promoting the identification of new KGRA's in the frontier areas. Although the motives of the government are not questioned by the selected group of industry interviewees, their reaction to the artificial stimulation of the geothermal exploration through government cost sharing is not completely favorable. The initiation of government supported exploration in new areas forces the organizations currently active in exploration to move into these areas

in order to maintain their competitive position. This generally results in a slowing down of their current exploration efforts due to the diversion of some of their exploration/development resources to new areas.

Government financed exploration activities in new areas also increase the cost of leasing these areas. A higher cost of leasing leads to the requirement of a larger investment for development and this discourages organizations with limited resources from participating in the development of the new sites.

The individuals interviewed were generally well disposed towards the basic R&D part of the GERRA Program. They favored the continuation of these efforts and indicated that basic R&D should be focused on attaining the long term (post-1990) goals for geothermal development. In the near term, the GERRA R&D Program should address the problems being faced by the developers in convincing the users (utilities) about the reliability and magnitude of the reservoirs which are ready for development.

The specific comments made by the interviewees are discussed in more detail in the following subsections.

5.2 GERRA Program and its Relevance to Industry Needs

One of the most important components of the GERRA Program is the industry coupled cost shared exploratory drilling effort. As indicated earlier, the selected group of industry representatives view this segment of the GERRA Program with admiration as well as concern. On the positive side, this program is bound to encourage the development of new

areas and promote more speedy and less expensive development of existing KGRA's through information dissemination in the form of case studies. This program provides an opportunity for developers to lower their exploration costs and risks through cost sharing by the government. On the negative side, it was felt by some interviewees that the government involvement in geothermal exploration does not represent a good utilization of the resources and creates instability in the industry by providing artificial stimulation for the development of new areas. This instability could result in the diversion of resources from areas with current activity and slow down the development of existing KGRA's.

It was not suggested that the cost shared program be terminated. The general feeling among interviewees is that the government can be fair to all the participants in geothermal exploration by making it possible for a larger number of industry organizations to benefit from the cost shared program. Obviously, a larger budget would be needed for broadening the scope of this program. Closer cooperation between the industry representatives and the government officials responsible for selecting frontier areas for cost shared drilling would apparently make this program more effective and attractive for the industry.

The interviewees were generally in favor of an active government funded program aimed at preparing thermal heat flow, geological, areomagnetic and gravimetric maps of the U.S. It was felt that such a task was beyond the technical and financial capabilities of

individual organizations. The existence of such maps will result in a substantial saving in the cost and time associated with the preliminary selection of areas for geothermal exploration.

It was also suggested that continued support of basic research by the Federal government would be beneficial. Such research has produced many significant breakthroughs in the past and could lead to the development of techniques which might be needed when resources without surface manifestations have to be discovered. The national laboratories and universities were considered by interviewees to be appropriate vehicles for carrying out this kind of research*.

With regard to applied R&D (e.g., development of instrumentation and logging techniques) it was indicated that the government program is not totally relevant to the industry needs. Although it would be desirable to develop instruments capable of providing a higher accuracy of measurement in the harsh environment of geothermal wells and reservoirs, the emphasis should be placed on developing better techniques for interpreting these observations. Enhanced precision unaccompanied by improved interpretation techniques was not believed likely to have a significant effect on the cost and effectiveness of the exploration activities in the near term.

Some interviewees suggested that in a few cases applied R&D was bound to produce instruments or techniques which are already being

* This is consistent with an often explicitly stated objective of preventing any one company from getting a competitive advantage over others with public funds.

used by certain companies. The companies do not react favorably to the prospect that their competitors will close the technological gap as a result of government funded R&D. Although this is an indication of a negative attitude on the part of some companies, the government may find it more expedient and cost effective to induce these companies to share their expertise and methods with other participants in geothermal development if suitable mechanisms for providing compensation or incentive could be devised.

Another observation made by the interviewees pertains to the need for pursuing the commercialization of technology. It was felt that the GERRA Program is very diligent in pursuing the R&D of new techniques and instruments, but the effort generally ends short of commercialization. It was pointed out that the geothermal exploration industry is small and fragmented, and there are no entities big enough to take the risk of commercial development of new technology. Therefore, the government role in applied R&D should extend to the commercialization stage.

Although these interviews were focused on technological issues, the interviewees repeatedly mentioned the institutional problems faced by geothermal explorers. They felt that the elimination of the delays in permitting and leasing can accelerate the rate of development significantly. Developers and explorers have to incur substantial financial penalties because of these delays. Tax incentives for speedy development will also motivate developers to shorten the lead time between the discovery of a resource and its utilization.

5.3 Strategy for an Effective GERRA Program

On the basis of the input provided by the interviewees, it appears that a two phase strategy is needed for promoting a balanced growth of the geothermal (hydrothermal) exploration and development. These two phases should address the near term and the long term goals for the development of hydrothermal resources.

Phase A - Near Term

In the near term, the industry representatives interviewed are less worried about discovering and confirming new resources than about finding users for resources which are ready for utilization. It is apparent that the developer's task is not even half finished by the time the resource is ready for utilization. The more difficult job is to convince an electric utility that it is not taking undue risks by committing itself to the use of the resource. In general, the developers are faced with the task of assuring the end user (utility) that the reservoir has the necessary potential for supporting a power plant (e.g., 200 MW for 30 years). Since this assurance cannot be based on real experience, the developers have to rely on acceptable reservoir assessment and engineering models for making their point.

The unique characteristics of geothermal reservoirs (geology, lithology, etc.) make it difficult to apply oil and gas reservoir models with any degree of certainty. Therefore, there is an urgent need for reliable non-linear and three dimensional reservoir models. It is also necessary to collect data for validating and calibrating these models in a short period of time.

As mentioned earlier, the development of good data interpretation techniques is more vital than the development of more precise instruments in the near term. These models can be regarded as a tool for development decision making in the near term, and will help maintain the pace of development necessary for achieving the development goals for the time period 1985 - 1990. The achievement of the post 1990 goals is also dependent on the rate of development during the 1980's. As more operational experience is gained, the reliability of these models can be improved through validation and calibration. The benefits of more precise instrumentation can be realized only when the techniques for interpreting the readings of these instruments are sufficiently sophisticated and reliable.

Therefore, the near term strategy for the GERRA R&D Program should place more emphasis on data interpretation techniques rather than measurement devices. Nevertheless, it would be unwise to give up efforts aimed at the improvement of instrumentation.

Phase B - Long Term

Although there are enough confirmed reservoirs for achieving the pre-1985 hydrothermal development goals, the planners of the GERRA Program should recognize that without the development of new exploration technology, the achievement of the long term (post - 1990) development goals may be in jeopardy. As the reservoirs associated with surface manifestations are confirmed and developed, new findings will be confined to "hidden resources." These resources are more

difficult to find and will probably require significant innovation in exploration technology. The history of exploration activities for oil and gas indicates that new techniques for exploration have repeatedly reversed the downtrend in the rate at which new discoveries are made, and it is logical to expect that the exploration of geothermal resources will follow a similar pattern. Therefore, it will be necessary to develop instrumentation and measurement techniques with better precision and resolution. Without the development of new technology, it may be impossible to reverse the expected downtrend in the rate of new discoveries. Such techniques are generally the result of prolonged basic research followed by a phase of applied research. Consequently, the benefits of such efforts cannot be realized for a number of years following the start of the basic research. In the context of geothermal exploration, noble gas thermometry, bright spot (Seismic reflection) and mercury measurements in soil are three examples of innovative techniques being investigated at this time.

It was suggested by many interviewees that a modest but sustained effort in basic research at universities, national laboratories and other non-commercial institutions is bound to have a positive impact on the achievement of the long term goals for geothermal development. At the same time, it may be necessary to scale down the activities aimed at the development of new techniques in the immediate future so that more funds may be diverted to projects dealing with the development of reservoir assessment and engineering models.

Many interviewees suggested that the GERRA Program managers should try to collect and disseminate well log data available from companies which are active in oil and gas exploration. Abandoned oil and gas wells provide a good opportunity for testing new techniques. A program for inducing active geothermal explorers to divulge selected proprietary data pertaining to their efforts could be very cost effective. Some inducement is already being offered in the form of cost shared precommercial drilling.

Some individuals indicated that the nature of their business prevents them from attending seminars/workshops at which new developments in the area of geothermal exploration are discussed. They suggested that DGE should pursue a vigorous program for technology transfer. On the opposite side, there were complaints that too much gray literature is being passed onto them. This generally causes the recipients to overlook some documents/papers with real merit. Therefore, it would be desirable to set up a mechanism for ensuring that literature of inferior quality does not get circulated.

5.4 Conclusions

The MITRE research team feels that the in-person interviews were extremely useful. The interviewees were frank in their comments and provided a fair critique of the current GERRA R&D Program.

Perhaps the most significant finding generated by this segment of the study is the need for two distinct phases in the overall strategy for the GERRA Program. In the immediate future, the

industry needs tools (reservoir assessment and engineering models) for selling their product (geothermal fluid) to the user (utility). The concern of the developers about a long lead time between the confirmation of a reservoir and the eventual commitment of the utility to utilize the fluid was evident. It is also becoming obvious that the long term goals for geothermal development may not be achieved unless there is unhindered development of the confirmed reservoirs during the next five to seven years.

Although most interviewees were not enthusiastic about the basic research projects, they did not suggest that these projects be terminated. They see long term benefits of such efforts. Nevertheless, it was pointed out that the hardware orientation of the current GERRA R&D Program is not in the best interests of the industry. Most interviewees favor the enlargement of the program for geological, thermal, magnetic and gravimetric mapping of geothermal areas. It was also suggested that the program of case studies and cost shared drilling be enlarged, but future decisions about specific sites for such activities should be made in consultation with industry.

SECTION 6.0

CONCLUSIONS AND RECOMMENDATIONS

6.0 CONCLUSIONS AND RECOMMENDATIONS

In this section, the conclusions and recommendations, based on the findings made in this study are presented. The conclusions are confined to the specific subject areas on which this study was focussed. The recommendations pertain to the actions/strategy which can be expected to enhance the effectiveness of the GERRA R&D program.

6.1 Conclusions

The evaluation of the GERRA R&D program was conducted in three relatively discrete phases, and the conclusions based on each phase of the analysis are presented separately in the following subsections.

6.1.1 Conclusions Based on the Benefit/Cost Analysis

The following major conclusions emerged from the results of the benefit/cost analysis (Section 3.0):

- The success ratio for exploratory drilling are appropriate measure of effectiveness of R&D activities aimed at reducing the cost of geothermal exploration; savings associated with improved success ratio are substantially larger than those likely to result from reduced pre-drilling exploration activities. The exploratory drilling success ratio can be monitored without indulging in a massive data collection activity.
- The achievement of relatively modest targets for improvement of exploratory drilling success ratio (improvement ranging from 0.24 to 0.31) can be expected to result in savings ranging from \$260 million to \$1.0 billion depending on the current initial weighted average success ratio, the discount rate and the rate of escalation in drilling costs. (Figure 6). These benefits are realized over a 23 year period following 5 years of properly funded and successful GERRA R&D program (1978-1982). Although there is some uncertainty about the magnitude of the

savings, the estimates presented here are relatively conservative. No credit is being taken for the savings which the GERRA R&D program will produce in exploring and assessing the resources for non-electric utilization. Benefits which might result from the area of geopressured methane are also not included.

- Under the most conservative assumption of a 10% discount rate, no escalation in the cost of drilling, and a reasonably low expectation of improvement in exploratory drilling success ratio, the estimated savings can be expected to exceed \$260 million (Figure 6). On the basis of 10:1 benefit to cost ratio, this amount of expected benefits would justify a research budget 2.0 times that currently allocated.
- The estimated benefits are most sensitive to the current initial weighted average success ratio. The smaller the initial value of the weighted average success ratio, the larger are the benefits associated with a given incremental improvement that initial level.
- The cumulative estimated benefits increases at an exponentially diminishing rate with increase of R&D funding level (under the assumptions stated in Section 3.0). This diminishing return on increased funding should be expected, since there is no increase in budget level that can help improve the drilling success ratio beyond 100 percent. The maximum achievable benefits from GERRA R&D program, are realized when the current R&D budget of 2.887 million is tripled.
- If the private industry is given credit for some of the anticipated improvement in the exploratory drilling success ratio, the GERRA R&D program starts making an impact on the success ratio at a budget level of \$2.1 million per year (Figure 8 and assumptions). This base level will keep the GERRA R&D program just visible but is not expected to result in any observable improvement in the current level of success ratio over that brought about by private geothermal industry on its own.
- Improved detection and control of subsidence and induced seismicity will reduce the number of prospects rejected for development on account of environmental and safety issues. As a result, additional exploratory drilling cost savings will be realized. These additional

benefits due to subsidence and induced seismicity R&D activities are estimated to amount to \$20 million.

6.1.2 Conclusions Based on Industry Survey Analysis

The following conclusions are based on the responses to a mail questionnaire sent to about 72 recognized specialists in geothermal exploration and development.

- The set of respondents to the mail questionnaire represents a good cross section of the geothermal industry. Oil companies, field service companies and developers constituted 57 percent of the set of respondents (these segments of the industry represented 50% of the survey sample). Therefore, the major beneficiaries of the GERRA R&D program were well represented in the respondent set.
- An analysis of the responses indicates that, except for the Geysers Steam Field, the GERRA R&D program is expected to have its highest impact on improving the exploratory drilling success ratio in all types of geothermal fields and its lowest impact on reducing the decision errors of the geothermal developers.
- The respondents are generally in favor of cost shared drilling and the development of more reliable reservoir engineering models. Since these programs are aimed at reducing the uncertainty and the investment risk, these two factors appear to be of great concern to potential geothermal developers. Any R&D effort addressing these factors is highly desirable.
- Geothermal industry representatives feel that the existing geothermal exploration/assessment technology is adequate (i.e., instrumentation and data collection methods). However, a need for significant improvement in data interpretation techniques was perceived by all respondents.
- Thermal methods are most effective in narrowing target areas in all geological environments except the Geopressured and Basaltic Island regimes.
- Surface geologic mapping, gravimetry, electric methods and liquid geochemistry offer useful

information in all regions, but have limited diagnostic utility.

- The utility of air photogeology is somewhat limited and is confined to the Geysers region.
- Thermal infra-red techniques have the lowest applicability rating in all regions.
- Structured value analysis show that: (1) liquid geochemistry, seismic methods and thermal methods are high priority research areas since they are perceived by users as highly effective and possess considerable potential for improvement through R&D; (2) electrical methods, though effective at this time, will require a substantial R&D investment to enhance their utility.

6.1.3 Conclusion Based on In-Person Interviews

The conclusions presented in this subsection were derived from the interviews conducted with a set of individuals with well established credentials in geothermal exploration and development.

- The general impression given by the interviewees, particularly those belonging to geothermal development companies, was that a primary concern was the ability to convince the utilities that the discovered confirmed reservoirs have the longevity and producibility for justifying the construction of power plants to be fueled by these resources. In the near term, the discovery of new resources is a second order issue for most developers.
- The individuals interviewed were generally well disposed towards the basic R&D segment of the GERRA R&D program. However, their reaction to the artificial stimulation of the geothermal exploration through government cost sharing is not favorable. It is felt that the government cost shared exploration programs force active developers to divert some of their exploration and development resources to new areas. This diversion causes a slow down in the development of existing KGRA's and increases the cost of leasing land in the areas

where the government supported exploration is initiated. Closer cooperation between the industry representatives and the government officials responsible for selecting these frontier areas will make the cost sharing program more effective and more attractive to the geothermal industry.

- Interviewees were generally in favor of an active government funded program aimed at preparing thermal gradient heat flow, geological, aeromagnetic and gravimetric maps of the U.S. It was felt that such a task was beyond the technical and financial capabilities of individual organizations.
- With regard to applied R&D (e.g., development of improved instruments and logging techniques) it was indicated by interviewees that the government program is not totally relevant to the industry needs. Enhanced precision, unaccompanied by improved interpretation techniques, is not likely to have a significant effect in the cost and effectiveness of the exploration activities in the near term.
- The GERRA R&D program is very diligent in pursuing the R&D of new techniques and instruments but stops short of commercialization. Interviewees felt that commercialization of new techniques and instruments should be pursued by the program.
- The transfer of technology should be pursued by DGE with greater vigor and planning.

6.1.4 General Conclusions

The following conclusions pertain to some of the general observations/comments made by the participants in the industry survey:

- The main emphasis of the GERRA R&D program is focused on technological impediments due to the general belief that the industry needs help in this area; the industry experience expressed by interviewees indicates that in many cases the institutional problems (leasing delays, permitting hurdles, environmental constraints) are bigger deterrents to speedy and successful exploration than technological deficiencies.
- The general impression in the industry is that the current GERRA program is hardware oriented. The near

term priorities and problems suggest that this emphasis should be shifted to efforts aimed at developing better data interpretation and diagnostic techniques.

- Some large companies involved in geothermal exploration and development seem to feel that some of the ongoing R&D will lead to the commercialization of technology which they have developed, and therefore a successful R&D program will dilute this advantage which they have gained through their own efforts.
- Although a number of data collection efforts are underway, there seems to be a real need for a consolidated data base covering various aspects of geothermal exploration.
- The achievement of the long-term goals for hydrothermal development is dependent very heavily on the attainment of the near term (pre-1985) goals. The strategy for improving the chances of pre-1985 goals should, therefore, be a vital element of the GERRA R&D program plan.

6.2 Recommendations

The quantitative analysis conducted as a part of this study revealed that the GERRA R&D program can be expected to be cost effective even with moderate improvements in the exploratory drilling success ratio over a five year time period (1978-1982; assuming that these improvements are attributable to a successful R&D program). The planners of the GERRA R&D program can enhance the chances of achieving the hydrothermal power-on-line development goals by pursuing a two phase strategy for supporting the industry efforts in geothermal exploration and development. On the basis of the inputs received from the industry participants in this study, it is recommended that a two phase strategy for R&D be pursued.

- Phase A - Near Term (Pre-1985). The near term strategy (Phase A) should emphasize the efforts aimed at

generating information needed by the developers to convince the ultimate user of the resource (utility) that the reservoir possesses the characteristics necessary for fueling a power generation plant.

Techniques for reliable assessment of the producibility and longevity of the reservoir should be developed in this phase. Therefore, Phase A should be concentrated on the development of reliable, validated, and calibrated models for reservoirs assessment, and engineering. The existence of these models will enhance the probability of achieving the near-term goals by expediting the development and utilization of resources which have already been discovered.

- The near term strategy should also be guided by the specific needs of the sites projected for development by 1985. To address the site specific needs, it is recommended that the industrial organizations engaged in exploring and developing these sites be consulted to reorient the current R&D program, so that the GERRA R&D program may supplement the industry efforts to deal with these problems.
- It is also recommended that the experience gained at any site be disseminated to as large a segment of the industry as possible with minimum delay. The current program of case studies and cost-shared drilling could generate information for dissemination.
- Closer cooperation between the industry and the GERRA R&D program managers is recommended for selecting the frontier areas for government supported exploration activities.
- In the near term, it is necessary to maintain a program of basic R&D at national laboratories, universities, and other non-commercial institutions. The effectiveness of these programs should not be evaluated in terms of regular benefit/cost ratios, because such programs do not normally show any quantitative benefits until there is a technological breakthrough. Such breakthroughs will be needed to discover resources which are not associated with surface manifestations.

● Phase B - Mid and Long Term (1986-2000).

- It is recommended that the long-term strategy for

the GERRA R&D program should emphasize the efforts needed to maintain the resource development momentum created in the near-term. This can be accomplished by developing techniques for discovering new and hidden (i.e., without surface manifestations) resources necessary for reaching the long-term development goals. An intensive program of basic and applied R&D, (without site specific orientation) should be pursued. (Figure 3).

- The development of regional thermal gradient, heat flow, geological magnetic and gravimetric maps should be pursued.
- It is recommended that any alterations and realignments of the long-term R&D strategy be based on consultation with industrial organizations active in geothermal exploration and development.
- The efforts to create a data base for geothermal exploration should be continued, with regular updating and refinement of the data base.
- It is recommended that the drilling success ratio (or related measures such as drilling cost per MW of installed capacity etc.) be adopted as the measure of effectiveness of the GERRA R&D program in reducing the cost of exploration. Such a measure should also be the basis for setting realistic targets for the GERRA R&D program.
- It is recommended that the sites for cost shared drilling and case studies be chosen with the objective of maximizing the impact of the information obtained through these activities. Therefore, these studies should be targeted at geological provinces and development sites for which the available information is inadequate for logical decision-making.

LIST OF REFERENCES

1. Smith, J.L., C.F. Isselhardt, J.S. Matlick, 1976, "Summary of 1975, Geothermal Drilling, Western United States", Geothermal Energy Volume 4, Number 6, pp. 28-31.
2. Smith, J.L. et al, "Summary of 1976, Geothermal Drilling, Western United States", Geothermal Energy Volume 5, Number 5, pp. 8-17.
3. Smith, J.L. et al, "Summary of 1977, Geothermal Drilling, Western United States", Geothermal Energy Volume 6, Number 5, pp. 8-17.
4. Goldstein, N.E., R.A. Norris, J.J. Wilt and Peter Klock, Assessment of Surface Geophysical Methods in Geothermal Exploration and Recommendations for Future Research (Lawrence Berkeley Laboratory, University of California, Berkeley, 1978).
5. Ward, S.H., Program Review: Resource Evaluation, Reservoir Confirmation and Exploration Technology (University of Utah, Salt Lake City, Utah 84112, May, 1978).
6. Brigham, W.E. and W.B. Morrow, "P/Z Behavior for Geothermal Steam Reservoirs", Jour. Soc. Pet. Sug. Volume 17, 1977, pp. 407-412.
7. Whiting, R.L. and H. Ramey, "Application of Material and Energy Balances to Geothermal Steam Production", Journal Pet. Tech., 1969, pp. 898-900.
8. Ibid, 1977.
9. Miller, I., and J. Fruend, Probability and Statistics for Engineers (Prentice Hall, Inc., Englewood Cliffs, N.J., 1965), pp. 153-160.
10. J. Leigh, A. Cohen, W. Jacobsen and R. Trehan, "Site-Specific Analysis of Geothermal Development", MITRE Technical Report 7586, The MITRE Corporation, Metrek Division, August 1978, Volume 1, p. 5.
11. Friedman, E.J., and A. El-Sawy, Prospects for Improvement in Geothermal Well Technology and Their Expected Benefits (MITRE, MTR-7613, 1977).
12. Salisbury, J.W., "ERDA Strategy for Resource Evaluation and Reservoir Confirmation", (Geothermal Resource Assessment and Reservoir Engineering. Proceedings of the ENEL-ERDA Workshop. Larderello, September 1977).

LIST OF REFERENCES (Concluded)

13. U.S. Department of Interior, Geological Survey, "Geothermal Resource File (GEOTHERM) Revision 8", (Reston, VA, January 1977).
14. Friedman, et al, op cit, 1977.
15. Friedman, et al, op cit, 1977.
16. Sassone, Peter G., and William A. Schaffer, Cost-Benefit Analysis: A Handbook (Academic Press, NY, 1978), p. 129.
17. Business Week, September 11, 1978.
18. Junl-Dam, T. & H.F. Dunlap, "Economic Analysis of a Geothermal Exploration Production Venture", (Proceedings, 2nd United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, CA, USA, pp. 20-29, May 1975).
19. Maslan, Frank, Theodore J. Gordon and Liliam Deitch, "Economic and Social Aspects of Geothermal Resource Development", (Proceedings, 2nd U.N. Symposium on the Development and Use of Geothermal Resource, 1975), pp. 2330.
20. Ward, Stanley H., Program Review: Resource Evaluation, Reservoir Confirmation, and Exploration Technology (University of Utah, Salt Lake City, Utah 84112, 1978).
21. Blackman, A. Wade, "Forecasting Through Dynamic Modeling", Technological Forecasting and Social Change (Volume 3, 1972), pp. 291-307.
22. Rudd, F., and C.C. Watson, Strategy of Process Engineering, (Wiley, NY, 1968), pp. 116,124.
23. Miller I., and J. Fruend, op cit, 1965, p. 134.
24. Ibid, pp. 185-203.
25. Ibid, pp. 185-203.

APPENDIX A

USERS GUIDE FOR BENEFIT/
COST COMPUTER PROGRAM

APPENDIX A

USERS GUIDE FOR BENEFIT/COST COMPUTER PROGRAM

1.0 PURPOSE

This appendix is a guide to the benefit/cost computer program GERABAC used to estimate the benefits and cost of the GERRA R&D program discussed in Section 3 of this document. It describes the logic, program access procedure, main options and features, and the results returned by the GERABAC program.

2.0 PROGRAM LOGIC

The basic logic of GERABAC program is depicted in Figure A-1 and the data processing algorithm is indicated below.

- a) calculate rate of improvement in success ratio
- b) read footage cost and power-on-line scenario
- c) locate exploration date at site
- d) check extent of exploration at site and type of well
- e) calculate number of wells required to support scenario
- f) check depth of well needed and calculate the necessary total footage to support scenario
- g) calculate total footage cost as function of depth and hardness
- h) calculate the reduction in well footage due to improved success ratio and the associated monetary savings (i.e., benefits).
- i) calculate present worth of benefit
- j) calculate present worth of total research budget
- k) calculate benefit/cost ratio

The program listing is given in Section 5.0 of this appendix.

3.0 PROGRAM ACCESS PROCEDURE

To provide more flexibility of usage GERABAC is designed as an interactive program which allows the user to define the parameters used in computing the benefit/cost at will. The key parameters the user can change interactively are listed with their default values in Table A-1. To change the default values for these parameters it is necessary to follow the procedure indicated in the typical terminal session flow chart in Figure A-2. An actual terminal session is shown in Exhibit A-1. The name GERABAC is used to call and access the GERABAC program.

4.0 PROGRAM FEATURES AND OPTIONS

4.1 Interactive Feature

As already indicated, the GERABAC program is an interactive program which provides the option of changing the values of key parameters (ESC, SRM, SRO, R, MTYPE, and PWR) by editing the program listing or via a remote terminal in an interactive mode.

4.2 Input-Output Design

For more flexibility, the input and output data is specified in G-format. This format is used to transmit real data normally transmitted in F-format. If the user specified field size is exceeded, the G-format allows an automatic shift to E-format. If the field is not exceeded, G-format displays all results in F-format.

TABLE A-1

DEFINITION OF KEY PARAMETERS AND THEIR DEFAULT VALUES

PARAMETER	DEFINITION	DEFAULT VALUE
ESC	Drilling Cost Escalation Rate	0.00
SRM	Maximum Success Ratio	0.90
SRO	Initial Success Ratio	0.80
R	Discount Rate	0.05
MTYPE	Well Type (1 = test well, 2 = stepout well, 3 = wild cat well)	1
PWR	Size of Field (in MWe)	200

FIGURE A-2
TERMINAL SESSION

EXHIBIT A-1
TERMINAL SESSION

GERABAC
GLOBAL TXTLIB FORTMOD1
FI 6 PRINTER
FI 2 TERMINAL
FILEDEF FT09F001 DISK GERABAC DATA * (RECFM F BLOCK 80 LRECL 80)
LOAD GERABAC (CLEAR)
START
DMSLIO740I EXECUTION BEGINS...
&PARAM
ESC= .0 ,SRM= .899999976 ,SRO= .800000012 ,R=
.500000007E-01,MTYPE= 1,PWR= 200.000000
&END
ARE ALL THESE OK? (YY,NN)
YY
6F

TOTAL BENEFITS .4255E+08
TOTAL RESEARCH BUDGET .1641E+08
BENEFIT/COST RATIO 2.5932

ANYMORE? (Y OR N)

Y

LOAD GERABAC (CLEAR)

START

DMSLIO740I EXECUTION BEGINS...

&PARAM
ESC= .0 ,SRM= .899999976 ,SRO= .800000012 ,R=
.500000007E-01,MTYPE= 1,PWR= 200.000000
&END

ARE ALL THESE OK? (YY,NN)

NN

&PARAM ESC=.05,SRM=1. &END

&PARAM

ESC= .500000007E-01,SRM= 1.00000000 ,SRO= .800000012 ,R=
.500000007E-01,MTYPE= 1,PWR= 200.000000
&END

&END

ARE ALL THESE OK? (YY,NN)

YY

6F

TOTAL BENEFITS .1231E+09
TOTAL RESEARCH BUDGET .1641E+08
BENEFIT/COST RATIO 7.5008

ANYMORE? (Y OR N)

N

R; T=6.82/8.94 07:52:10N

EXHIBIT A-2

PARAMETERS FOR THIS RUN

SRM=0.900 ESC=0.0 R=0.050 SRO=0.800 MTYPE= 1 PWR= 200.00

POWER-ON-LINE SCENARIO

[illegible]

NUMBER OF TEST WELLS REQUIRED
TO SUPPORT SCENARIO

[illegible]

EXHIBIT A-2 (Continued)

WELL FOOTAGE NEEDED
(10**3 FT)

16.	16.	16.	16.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	30.	0.	59.	30.	30.	30.	30.	30.	30.	30.	30.	0.	0.	0.	0.	0.	0.	0.
10.	0.	10.	10.	10.	10.	0.	10.	10.	20.	10.	10.	10.	10.	10.	10.	10.	10.	10.	0.	0.	0.
0.	10.	0.	0.	10.	0.	10.	10.	10.	10.	10.	10.	10.	10.	10.	0.	10.	10.	10.	0.	0.	0.
7.	0.	0.	7.	0.	7.	0.	7.	7.	7.	7.	0.	7.	7.	13.	0.	0.	0.	0.	0.	0.	0.
0.	13.	0.	13.	13.	13.	13.	13.	13.	13.	13.	0.	13.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9.	0.	0.	9.	9.	0.	9.	9.	9.	9.	9.	9.	9.	0.	9.	9.	0.	0.	0.	0.	0.
10.	0.	0.	10.	0.	10.	0.	10.	10.	10.	10.	0.	10.	10.	20.	10.	0.	0.	0.	0.	0.	0.
0.	0.	0.	20.	10.	10.	10.	10.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	10.	0.	10.	0.	0.	10.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	13.	0.	13.	0.	13.	13.	0.	13.	26.	13.	13.	13.	13.	13.	13.	13.	0.	0.	0.	0.
0.	0.	10.	0.	10.	0.	10.	10.	10.	10.	10.	0.	10.	10.	10.	10.	0.	0.	0.	0.	0.	0.
0.	0.	16.	16.	16.	16.	16.	16.	0.	16.	16.	33.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	10.	0.	0.	10.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	5.	0.	0.	5.	0.	5.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	10.	0.	10.	10.	10.	10.	0.	10.	10.	20.	10.	10.	10.	10.	0.	0.	0.	0.	0.
0.	0.	0.	16.	0.	0.	16.	16.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	16.	0.	0.	16.	0.	16.	16.	33.	16.	16.	16.	16.	16.	16.	0.	0.	0.	0.
0.	0.	0.	0.	30.	0.	0.	30.	30.	30.	30.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	30.	0.	0.	30.	30.	30.	30.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	16.	0.	0.	16.	16.	16.	0.	16.	16.	33.	16.	16.	16.	16.	0.	0.	0.	0.
0.	0.	0.	0.	10.	0.	0.	10.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	30.	0.	0.	30.	30.	30.	30.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	13.	0.	0.	13.	13.	13.	13.	13.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	30.	0.	0.	59.	30.	30.	30.	30.	30.	30.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	30.	0.	0.	0.	30.	30.	59.	30.	30.	30.	30.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	30.	0.	0.	30.	30.	30.	30.	30.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	30.	0.	0.	30.	30.	30.	0.	30.	30.	59.	30.	30.	30.	30.	0.	0.	0.	0.
0.	0.	0.	0.	16.	0.	0.	0.	0.	0.	0.	16.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	10.	0.	10.	0.	10.	10.	20.	10.	10.	10.	10.	10.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	10.	0.	10.	10.	0.	10.	10.	20.	10.	10.	10.	10.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	13.	0.	13.	0.	13.	13.	13.	13.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	13.	0.	13.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	16.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	16.	16.	16.	16.	16.	16.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	10.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	16.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	16.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

EXHIBIT A-2 (Continued)

YEARLY NUMBER OF TEST WELLS NEEDED
TO SUPPORT SCENARIO

YEAR	NUMBER OF WELLS
1	8.0000
2	8.0000
3	14.0000
4	22.0000
5	40.0000
6	26.0000
7	22.0000
8	62.0000
9	42.0000
10	48.0000
11	44.0000
12	48.0000
13	40.0000
14	42.0000
15	30.0000
16	22.0000
17	20.0000
18	14.0000
19	4.0000
20	0.0
21	0.0
22	0.0
23	0.0
TOTAL	556.0000

EXHIBIT A-2 (Continued)

NUMBER OF TEST WELLS NEEDED PER SITE
TO SUPPORT SCENARIO

SITE	NUMBER OF WELLS
1	8.0000
2	20.0000
3	34.0000
4	28.0000
5	22.0000
6	22.0000
7	24.0000
8	24.0000
9	12.0000
10	6.0000
11	28.0000
12	22.0000
13	20.0000
14	4.0000
15	6.0000
16	28.0000
17	6.0000
18	24.0000
19	10.0000
20	24.0000
21	4.0000
22	12.0000
23	12.0000
24	16.0000
25	18.0000
26	12.0000
27	24.0000
28	4.0000
29	22.0000
30	24.0000
31	12.0000
32	4.0000
33	2.0000
34	12.0000
35	2.0000
36	2.0000
37	2.0000
TOTAL	556.0000

EXHIBIT A-2 (Continued)

TOTAL YEARLY FOOTAGE
TO SUPPORT SCENARIO

YEAR	FOOTAGE (10**3 FT)
1	42.66
2	47.90
3	80.72
4	128.0
5	349.8
6	151.6
7	164.1
8	460.0
9	385.9
10	408.8
11	382.6
12	408.8
13	303.8
14	330.1
15	196.9
16	143.1
17	133.2
18	105.0
19	19.69
20	.0
21	.0
22	.0
23	.0
TOTAL	4243.

EXHIBIT A-2 (Continued)

TOTAL FOOTAGE PER SITE NEEDED TO SUPPORT SCENARIO D

SITE	FOOTAGE (10**3FT)
1	65.62
2	295.3
3	167.3
4	137.8
5	72.18
6	144.4
7	102.4
8	118.1
9	59.06
10	29.53
11	183.7
12	108.3
13	164.1
14	19.69
15	15.75
16	137.8
17	49.22
18	196.9
19	147.6
20	196.9
21	19.69
22	177.2
23	78.74
24	236.2
25	265.8
26	177.2
27	354.4
28	32.81
29	108.3
30	118.1
31	78.74
32	26.25
33	16.41
34	98.44
35	9.844
36	16.41
37	16.41
TOTAL	4243.

EXHIBIT A-2 (Continued)

TOTAL FOOTAGE COSTS

(\$/FT)

TOTAL SITE FOOTAGE COSTS

(\$*(10**3))

SITE	COSTS	SITE	COSTS
1	120.0	1	7875.
2	160.0	2	.4725E+05
3	80.00	3	.1339E+05
4	200.0	4	.2756E+05
5	200.0	5	.1444E+05
6	160.0	6	.2310E+05
7	125.0	7	.1279E+05
8	200.0	8	.2363E+05
9	125.0	9	7383.
10	125.0	10	3691.
11	250.0	11	.4593E+05
12	80.00	12	8663.
13	120.0	13	.1969E+05
14	80.00	14	1575.
15	125.0	15	1969.
16	125.0	16	.1723E+05
17	120.0	17	5906.
18	250.0	18	.4922E+05
19	160.0	19	.2362E+05
20	250.0	20	.4922E+05
21	125.0	21	2461.
22	160.0	22	.2835E+05
23	400.0	23	.3150E+05
24	160.0	24	.3780E+05
25	160.0	25	.4252E+05
26	160.0	26	.2835E+05
27	160.0	27	.5670E+05
28	250.0	28	8203.
29	125.0	29	.1354E+05
30	80.00	30	9450.
31	120.0	31	9449.
32	160.0	32	4200.
33	250.0	33	4101.
34	400.0	34	.3937E+05
35	100.0	35	984.4
36	250.0	36	4101.
37	160.0	37	2625.
		TOTAL	.7278E+06

EXHIBIT A-2 (Concluded)

WELL FOOTAGE, DIFFERENCE IN WELL FOOTAGE, & BENEFIT
DUE TO IMPROVED SUCCESS RATIO

YEAR	WELL FOOTAGE (10**3FT)	DIFFERENCE IN WELL FOOTAGE (10**3FT)	BENEFIT (\$)
1	41.62	1.040	.1189E+06
2	45.62	2.281	.3311E+06
3	75.09	5.632	.3892E+06
4	116.3	11.63	.1914E+07
5	310.9	38.86	.6090E+07
6	134.7	16.84	.2011E+07
7	145.8	18.23	.1619E+07
8	408.9	51.11	.6919E+07
9	343.0	42.87	.3455E+07
10	363.4	45.43	.3486E+07
11	340.1	42.51	.6214E+07
12	363.4	45.43	.2024E+07
13	270.1	33.76	.2148E+07
14	293.4	36.68	.1482E+07
15	175.0	21.87	.1315E+07
16	127.2	15.90	.9103E+06
17	118.4	14.80	.7750E+06
18	93.33	11.67	.1212E+07
19	17.50	2.188	.1385E+06
20	.0	.0	.0
21	.0	.0	.0
22	.0	.0	.0
23	.0	.0	.0

PARAMETERS FOR THIS RUN

SRM=0.900 ESC=0.0 R=0.050 SRO=0.800 MTYPE= 1 PWR= 200.00

TOTAL BENEFITS	.4255E+08
TOTAL RESEARCH BUDGET	.1641E+08
BENEFIT/COST RATIO	2.5932

4.3 Definition of Variables

All symbols used as address locators of different variables used within the program are defined in Table A-2.

4.4 Dimension Statement

Apart from the dimension statements for RB, COSTF, JVAL 1, JVAL 2, JVAL 3, and FCTR, which need not be changed, all other dimension statements are specified to handle the memory storage requirement for a power-on-line scenario covering 23 years and 37 sites (i.e., 37 x 23 matrix). In order to change the program to handle a different scenario, the dimension statement related to the years / or sites covered by the new scenario have to be changed accordingly.

4.5 Output Design

With proper input the program will print out the following:

- Power-on-Line Scenario
- Number of Wells Required
- Well Footage Required
- Yearly Number of Wells Needed
- Number of Wells per Site Required
- Total Yearly Footage Required
- Total Footage Required per Site
- Cost per Foot at Each Site
- Total Footage Costs per Site
- Well Footage (per year), Difference in Well Footage and Benefit Due to Improved Success Ratio
- Total Benefits

TABLE A-2

DEFINITION OF VARIABLES

VARIABLE NAME	DEFINITION
POL	Power on line scenario (23 years for 37 sites in this case)
TF	Total footage
WN	Number of wells
RB	Research budget
B	Benefits
SRN	Success ratio (improved)
DIFF	Savings
WF	Well footage
DEPTH	Depth of well
HARD	Rock hardness of rock overlying resource
COSTF	Cost/ft
NWO	Number of wells drilled with improved success ratio
COST	Total footage costs
TYPE	Extent of exploration activity at the site
NI	Number of years to be examined (in scenario)
ESC	Drilling cost escalation rate
SRO	Success ratio (original)
SRM	Success ratio (maximum)
R	Discount rate
TOTB	Total benefits
TRB	Total research budget
BTCR	Benefit/cost ratio
MTYPE	Type of well for analysis
MI	Number of research years
JUAL 1,2,3	Switches which follow the value of MTYPE
FCTR	Switches which follow the value of MTYPE

- Total Research Budget
- Benefit/Cost Ratio

A sample output is shown in Exhibit A-2.

5.0 PROGRAM LISTING

5.1 The Exec

```

GLOBAL TXTLIB FORTMOD1
FI 6 PRINTER
FI 2 TERMINAL
FILEDEF FT09F001 DISK GERABAC DATA * (RECFM F BLOCK 80
  LRECL 80)
- RESTRT
LOAD GERABAC (CLEAR)
START
&BEGTYPE
ANYMORE? (Y OR N)
&END
&READ VARS &X
&IF &X EQ N &EXIT
&GOTO - RESTRT

```


5.2 The Main Program

```

      DIMENSION POL(37,23),TF(23),WN(23),RB(5),B(23),SRN(23),DIFF(23)
      DIMENSION WF(37,23),DEPTH(37),HARD(37),COSTF(4,2),NWO(37,23),COST(
*23),TYPE(37),SF(37),TSCOST(37),WELST(37),TWELS(37)
      DIMENSION JVAL1(3),JVAL2(3),JVAL3(3),FCTR(3)
C.... INPUT DATA
      DATA JVAL1/2,0,0/,JVAL2/2,5,0/,JVAL3/2,5,15/,FCTR/25.,10.,3.33/
      DATA AP/5*3.79/
      DATA SF/37*0./
      DATA WELST/37*0./,TWELS/37*0./
      DATA IYY/'YY'/
      DATA TF/23*0./
      DATA WF/851*0./
      DATA TSCOST/37*0./
      DATA NWO/851*0/
      DATA TYPE/1.,3.,1.,1.,2.,1.,1.,2.,3.,3.,3.,1.,2.,1.,17*3.,2.,5*3./
      DATA HARD/2.,1.,1.,4.,4.,1.,3.,4.,3.,3.,3.,1.,2.,1.,3.,3.,2.,3.,1.
*,3.,5.,1.,4.,1.,1.,1.,1.,3.,3.,1.,2.,1.,3.,4.,2.,3.,1./
      DATA DEPTH/8.203,14.765,4.922,4.922,3.281,6.562,4.265,4.922,4.922,
*4.922,6.562,4.922,8.203,4.922,2.625,4.922,8.203,8.203,14.765,8.203
*,4.922,14.765,6.562,14.765,14.765,14.765,14.765,8.203,4.922,4.922,
*6.562,6.562,8.203,8.203,4.922,8.203,8.203/
      NAMELIST/PARAM/ESC,SRM,SRC,R,MTYPE,PWR
C.... INITIALIZE PARAMETERS & COUNTERS
400  NI=23
      COSTF=0.
      STOTF=0.
      YTOTF=0.
      YTWELS=0.
      STWELS=0.
      ESC=.0
      MI=5
      SRO=.0
      SRM=.9
      R=.05
      TOTB=0.
      TRB=0.
      NWO1=0
      MTYPE=1
      PWR=200.
C.... CHECK PARAMETERS BY TERMINAL DISPLAY
6900 WRITE(2,PARAM)
      WRITE(2,7000)
7000 FORMAT('ARE ALL THESE OK? (YY,NN)')
      READ(2,7001) IANS
7001 FORMAT(A2)
      IF(IANS.EQ.IYY) GO TO 7900
      READ(2,PARAM)
      GO TO 6900

```

```

C...  CALCULATE RATE OF IMPROVEMENT IN SUCCESS RATIO
7900  XM=MI
      X=(SRM-SRO)/XM
      WRITE(6,8001)
9001  FORMAT(2X,'PARAMETERS FOR THIS RUN'//)
      WRITE(6,8000) SRM,ESC,R,SRO,MTYPE,PWR
8000  FORMAT(2X,'SRM=',F5.3,2X,'ESC=',F5.3,2X,'R=',F5.3,2X,'SRO=',F5.3,2
      *X,'MTYPE=',I2,2X,'PWR=',F7.2)
      DO 100 I=1,4
C...  READ FOOTAGE COSTS & POWER-ON-LINE SCENAFIO.
      READ(9,70) (COSTF(I,J),J=1,2)
70    FORMAT(2F4.0)
100   CONTINUE
      DO 101 I=1,37
      READ(9,71) (POL(I,J),J=1,23)
71    FORMAT(17F4.0/6F4.0)
101   CONTINUE
C...  LOCATE EXPLORATION DATE AT SITE
      DO 51 I=1,37
      DO 50 J=1,23
      M=1+(23-J)
      IF(POL(I,M)-0.) 4,4,6
4      GO TO 50
C...  CHECK EXTENT OF EXPLORATION AT SITE & TYPE OF WELL
6      IF(TYPE(I)-2) 1,2,3
1      L=M-4
      IF(L.LE.0) GO TO 50
C...  CALCULATE NUMBER OF WELLS REQUIRED TO SUPPORT SCENARIO
      NWO(I,L)=NWO(I,L)+JVAL1(MTYPE)
      NWO1=NWO1+NWO(I,L)*FCTR(MTYPE)
      IF(NWO1-PWR) 3050,3051,3051
3050  GO TO 50
3051  TYPE(I)=3.
      NWO1=0.
      GOTO 50
2      L=M-5
      IF(L.LE.0) GO TO 50
      NWO(I,L)=NWO(I,L)+JVAL2(MTYPE)
      NWO1=NWO1+NWO(I,L)*FCTR(MTYPE)
      IF(NWO1-PWR) 4050,4051,4051
4050  GO TO 50
4051  TYPE(I)=1.
      NWO1=0.
      GOTO 50
3      L=M-5
      IF(L.LE.0) GO TO 50
      NWO(I,L)=NWO(I,L)+JVAL3(MTYPE)
      NWO1=NWO1+NWO(I,L)*FCTR(MTYPE)

```

```

      IF(NWO1-PWR) 5050,5051,5051
5050  GOTO 50
5051  TYPE(I)=2.
      NWO1=0.
50    CONTINUE
51    CONTINUE
9000  FORMAT(1X,23F5.0)
      WRITE(6,9002)
9002  FORMAT(///56X,'POWER-ON-LINE SCENARIO'//)
      WRITE(6,9000)((POL(I,J),J=1,23),I=1,37)
      WRITE(6,9003)
      WRITE(6,9001)((NWC(I,J),J=1,23),I=1,37)
9003  FORMAT('1',55X,'NUMBER OF WELLS REQUIRED'//58X,'TO SUPPORT SCENARI
      *O'///)
9001  FORMAT(1X,23I5)
C...  CHECK DEPTH OF WELL NEEDED & CALCULATE TOTAL FOOTAGE DRILLED
      WRITE(6,165)
165   FORMAT('1',57X,'WELL FOOTAGE NEEDED'//58X,'TO SUPPORT SCENARIO'//6
      *2X,'(10**3 FT)'//)
      DO 52 I=1,37
      DO 53 J=1,23
      WF(I,J)=NWO(I,J)*DEPTH(I)
53    CONTINUE
      WRITE(6,12)(WF(I,J),J=1,23)
12    FORMAT(23F5.0)
52    CONTINUE
      WRITE(6,48)
48    FORMAT('1',1X,'YEARLY NUMBER OF WELLS NEEDED'/6X,'TO SUPPORT SCENA
      *RIO'//5X,'YEAR',7X,'NUMBER OF'/18X,'WELLS')
      DO 41 J=1,23
      DO 42 I=1,37
      TWELS(J)=TWELS(J)+NWO(I,J)
42    CONTINUE
      YTWELS=YTWELS+TWELS(J)
      WRITE(6,43)J,TWELS(J)
43    FORMAT(6X,I2,8X,F10.4)
41    CONTINUE
      WRITE(6,49)YTWELS
      WRITE(6,47)
47    FORMAT('1',1X,'NUMBER OF WELLS NEEDED PER SITE'/7X,'TO SUPPORT SCE
      *NARIO'//6X,'SITE',7X,'NUMBER OF'/19X,'WELLS')
      DO 44 J=1,37
      DO 45 I=1,23
      WELST(J)=WELST(J)+NWO(J,I)
45    CONTINUE
      STWELS=STWELS+WELST(J)
      WRITE(6,46)J,WELST(J)
46    FORMAT(7X,I2,8X,F10.4)

```

```

44      CONTINUE
      WRITE(6,49) STWELS
49      FORMAT(5X,'TOTAL',7X,F10.4)
      WRITE(6,166)
166     FORMAT('1',1X,'TOTAL YEARLY FOOTAGE'/3X,'TO SUPPORT SCENARIO'///4
      *X,'YEAR',7X,'FOOTAGE'/13X,' (10**3 FT) '/')
      DO 54 J=1,23
      DO 55 I=1,37
      TF(J)=TF(J)+WF(I,J)
55      CONTINUE
      YTOTF=YTOTF+TF(J)
      WRITE(6,13) J,TF(J)
13      FORMAT(5X,I2,2X,G15.4)
54      CONTINUE
      WRITE(6,67) YTOTF
      WRITE(6,169)
169     FORMAT('1',2X,'TOTAL FOOTAGE PER SITE NEEDED'/6X,'TO SUPPORT SCENA
      *RIO'//8X,'SITE',7X,'FOOTAGE'/17X,' (10**3FT) '/')
      DO 61 J=1,37
      DO 62 I=1,23
      SF(J)=SF(J)+WF(J,I)
62      CONTINUE
      STOTF=STOTF+SF(J)
      WRITE(6,63) J,SF(J)
63      FORMAT(9X,I2,3X,G15.4)
61      CONTINUE
      WRITE(6,170) STOTF
170     FORMAT(7X,'TOTAL',2X,G15.4)
      WRITE(6,167)
167     FORMAT('1',2X,'TCTAL FOOTAGE COSTS'//8X,' ($/FT) '///4X,'SITE',7X,'C
      *OSTS'/)
      DO 60 I=1,37
C...   CALCULATE TOTAL FOOTAGE AS A FUNCTION OF DEPTH & HARDNESS
      IF(DEPTH(I)-5.) 56,56,57
56      K=1
      GOTO 58
57      K=2
58      N=HARD(I)
      COST(I)=COSTF(N,K)
      WRITE(6,14) I,COST(I)
14      FORMAT(4X,I2,2X,G15.4)
60      CONTINUE
      WRITE(6,168)
168     FORMAT('1',2X,'TOTAL SITE FOOTAGE COSTS'//11X,' ($*(10**3)) '///4X,'
      *SITE',9X,'COSTS'/)
      DO 64 J=1,37
      TSCOST(J)=COST(J)*SF(J)
      COSTTS=COSTTS+TSCOST(J)

```

```

        WRITE(6,65) J,TSCOST(J)
65      FORMAT(5X,I2,3X,G15.4)
64      CONTINUE
        WRITE(6,67) COSTTS
67      FORMAT(3X,'TOTAL',2X,G15.4)
        DO 10 J=1,NI
        SRN(J)=SRO+X*J
        IF(J.GE.5) SRN(J)=SRN(5)
10      CONTINUE
        WRITE(6,1000)
1000     FORMAT('1',1X,'WELL FOOTAGE,DIFFERENCE IN WELL FOOTAGE, & BENEFIT'
*//11X,'DUE TO IMPROVED SUCCESS RATIO'///4X,'YEAR',6X,'WELL',6X,'DIF
*FERENCE',5X,'BENEFIT'/13X,'FOOTAGE',5X,'IN WELL'/25X,'FOOTAGE'/12
*X,'(10**3FT)',3X,'(10**3FT)',5X,'( $ )'/)
        DO 20 I=1,NI
        WN(I)=TF(I)*SRO/SRN(I)
C...   CALCULATE WELL FOOTAGE REQUIRED WITH IMPROVED SUCCESS RATIO
        DIFF(I)=TF(I)-WN(I)
        B(I)=(DIFF(I)*COST(I)*1000*(1.+ESC)**I)/(1+R)**I
        WRITE(6,1001) I,WN(I),DIFF(I),B(I)
1001    FORMAT(5X,I2,5X,G10.4,2X,G10.4,2X,G10.4)
20      CONTINUE
        DO 30 I=1,NI
C...   CALCULATE PRESENT WORTH OF SAVINGS (BENEFIT)
        TOTB=TOTB+B(I)
30      CONTINUE
        WRITE(6,2050)
2050    FORMAT('1',2X,'PARAMETERS FOR THIS RUN'//)
        WRITE(6,8000) SRM,ESC,R,SRO,MTYPE,PWR
        WRITE(6,2000) TOTB
        WRITE(2,2000) TOTB
2000    FORMAT(///2X,'TOTAL BENEFITS',11X,G10.4)
C...   CALCULATE PRESENT WORTH OF TOTAL RESEARCH BUDGET
        DO 40 I=1,MI
        TRB=TRB+(RB(I)/((1.+R)**I))
40      CONTINUE
        TRB=TRB*(10**6)
        WRITE(6,3000) TRB
        WRITE(2,3000) TRB
3000    FORMAT(2X,'TOTAL RESEARCH BUDGET',3X,G10.4)
C...   CALCULATE BENEFIT/COST RATIO
        BTCR=TOTB/TRB
        WRITE(6,4000) BTCR
        WRITE(2,4000) BTCR
4000    FORMAT(2X,'BENEFIT/COST RATIO',8X,G10.5)
        STOP
        END

```

APPENDIX B

INDUSTRY SURVEY QUESTIONNAIRE

APPENDIX B
INDUSTRY SURVEY QUESTIONNAIRE

Table B-1 is a respondent data sheet intended to provide information on the name, interest (i.e., steam, hydrothermal, geopressured or other type of geothermal field) and the nature of the responding organization, as well as, the areas of expertise of the individuals responsible for filling in the questionnaire. Such data were necessary to determine: (1) the weight of the respondent and, hence, the possible built-in bias in his/her responses, (2) the distribution of the respondents as to the interest and nature of the organization involved as compared to the distribution in the original survey sample who received the questionnaire. This is also an important indicator of the degree and trend of bias (if any) in the final results of the survey. Each item on the respondent data sheet is assigned an arbitrary weight that reflects its relative importance in determining the interest of the organization, its nature, or the expertise of the individual involved in filling the questionnaire. The highest score for any specific item in any given category (i.e., interest, nature of the organization or expertise of individual) is 5, and the overall score for any respondent is the sum of all scores checked on his sheet.

Table B-2 is intended to provide data that can help evaluate the impact of GERRA R&D program described in Appendix A, on the decision-making process in geothermal exploration. With this in mind the respondents are requested to evaluate, on a scale going from zero to twenty, the impact of the Federal R&D improvement in surface exploration techniques on the capability to:

TABLE B-1
Respondent Data Sheet

Name:

Organization:

Please check the appropriate boxes

(1) Your geothermal interests are in

- Steam Fields
- Hydrothermal Fields
- Geopressured Fields
- Hot Dry Rock Resource
- All

☐
☐
☐
☐
☐

(2) Nature of Your Organization

- Oil Company
- Utility
- Field Service Company
- Geothermal Field Developer
- University
- Consultant

☐
☐
☐
☐
☐
☐

(3) Experience of the individual completing this form

- Exploration
- Logging and Interpretation
- Reservoir Engineering
- Reservoir Modeling
- Environmental Effects
- Other

☐
☐
☐
☐
☐
☐

P.S. We would appreciate you mailing your response by July 18th, 1978 to:

Dr. Harpal S. Dhillon
Group Leader
Geothermal Energy Systems Group
Mail Stop W389
MITRE/Metrek Corporation
1820 Dolley Madison Avenue
McLean, Virginia 22101

Telephone (703) 827-6218

Company Name:
 Region of Development:
 Type of Field (steam, hydrothermal,
 geopressure, hot dry rock)

Date:

TABLE B-2⁺

EVALUATION OF IMPACT OF DOE/DGE RESEARCH PROGRAM

AREA OF IMPACT RESEARCH AREA	IMPROVE SUCCESS RATIO*	REDUCE EXPLORATION DECISION ERRORS**	REDUCE INVESTMENT RISK
	BETTER LOCATORS	BETTER INDICATION OF RESERVOIR PARAMETERS (TEMPERATURE, PERMEABILITY, SIZE, LONGEVITY)	(A) REDUCE # SHALLOW GRADIENT WELLS, CALIBRATION WELLS, # DEEP CONFIRMATION WELLS, (B) BETTER PREDICTION OF SUBSIDENCE AND INDUCED SEISMICITY
• Pre-Commercial Program			
• Industry Coupled Program			
• State Coupled Program			
• Reservoir Engi- neering			
• Surface Explora- tion Technology Development			
• Geothermal Log Interpretation			
• Subsidence and Induced Seis- micity			

Evaluation Scale: From zero to 20, with zero corresponding to useless and twenty corresponding to very effective.

* Success Ratio is defined as the ratio of number of producing wells to total number of wells drilled (i.e., dry well plus producing wells) in a certain site.

** Decision Errors refer to Type I error (i.e., false rejection of a good well) and Type II error (i.e., exploring in a non-productive area).

+ PLEASE FILL IN ONE COPY OF THIS FORM FOR EACH TYPE OF FIELD IN WHICH YOU ARE INVOLVED.

TABLE B-2 (Concluded)

With reference to Table B-2 please rank order the following impact areas, by weight percent, as to their importance to the geothermal exploration process:

IMPACT AREA	WEIGHT PERCENT
(1) Improvement in Exploratory Drilling Success Ratio (i.e., improvement in locating an economically producing wildcat drilling hole).	%
(2) Reduction in Exploration Decision Errors (i.e., reduction in false rejection of economic well and/exploring in non-productive or dry areas).	%
(3) Reduction in Investment Risk (i.e., reduction in the number of shallow gradient wells, deep confirmation wells, and better prediction of subsidence and induced seismicity).	%
	<div>TOTAL</div> <div>100%</div>

- (1) locate economic wildcat drilling holes more successfully (i.e., with minimum number of dry holes,)
- (2) reduce exploration decision errors of false rejection of a good drilling site or of actually drilling in an uneconomic or dry location,
- (3) reduce investment risk by enabling one to acquire the necessary exploration/assessment information with a smaller number of shallow gradient wells, and deep confirmation wells. For example, an improvement in surface exploration technique, as a result of the GERRA R&D program, may not in ones opinion add much to current capabilities in locating a wildcat drilling hole and, therefore, one could evaluate its expected effectiveness in improving success ratio as marginal and give it a score of (10). On the other hand, one may expect the improved surface exploration technique to give a better indication of reservoir parameters (e.g., temperature, permeability, etc.) and may, therefore, help reduce exploration decision error very effectively and, hence, a score of 20 is entered in Table B-2. In a similar way, the impact of the other research areas shown in Table B-2 could be evaluated with the resulting score appropriately entered.

In Table B-2, the respondent is also asked to evaluate the importance of the various impact areas in weight percent. For example, if an improvement in success ratio carries more weight in the geothermal exploration/assessment decision-making process, one would assign it a weight of say 50 percent with the remaining 50 percent perhaps equally divided between the impact areas of reduction in exploration decision errors and reduction in investment risk, respectively.

Table B-3, is intended for the evaluation of regional applicability of the various exploration/assessment techniques on a scale 0 to 4. Thus, if from one's experience, the electrical methods are indispensable as targeting tools in the Salton Trough, a score of 4 is entered for these methods in the Salton Trough column. The

TABLE B-3*

EVALUATION OF REGIONAL APPLICABILITY OF EXPLORATION/ASSESSMENT TECHNIQUE

PROVINCE TECHNIQUES	SALTON TROUGH	BASIN & RANGE	CASCADES	BASALTIC ISLAND REGIME	SNAKE RIVER PLAIN	WASATCH FRONT	RIO GRANDE RIFT	GEYSERS	ALEUTIAN ARC IS.	APPALA- CHIAN	EASTERN AND SE PLUTONS	GEOPRESSURED REGION
• Surface Geological Mapping												
• Liquid Geochemistry												
• Air Photogeology												
• Remote Sensing												
• Thermal Infra Red												
• Electrical Methods												
• Seismic Methods												
• Thermal Methods**												
• Gravimetry												
• Magnetism												
• Age Dating												
• Gas Geochemistry												
• Borehole Logging												
• Other***												

Ranking Grade: 0 = No known value, or not generally applicable
 1 = Perhaps some use, but not generally applicable
 2 = Useful information, but not diagnostic in itself
 3 = Relatively successful in itself, when intensity is high
 4 = Indispensable in narrowing target down

*Please fill in your response only for your area of interest and/or experience

**Thermal Methods include heat flow methods, temperature profile techniques, temperature gradient techniques, etc.

***Please feel free to list other relevant techniques as you see fit.

remaining techniques are similarly evaluated with the appropriate entries indicated in Table B-3.

In Table B-4, the respondents are asked, on a scale of 0 to 20, to evaluate the effectiveness of the various exploration/assessment techniques as to their diagnostic capabilities, applicability, dependability, immunity to background noise, the need for improvement and personal preference. Thus, if one thinks that liquid geochemistry has very high diagnostic capability, it would be given a score of 20 for that capability, and so on for the rest of the evaluation criteria.

In Table B-4, the respondents are requested to indicate importance, in weight percent, of each criterion (i.e., diagnostic capability, applicability, dependability, etc.) as a measure of effectiveness of exploration/assessment techniques. For example, if the diagnostic capability is the most important measure of effectiveness, it is assigned 60 percent with the remaining 40 percent divided appropriately among the other criteria of effectiveness in Table B-4.

Three entries in Table B-4 need more clarification. First, it should be noted that diagnostic capability refers to the capability of a given exploration technique to accurately indicate the key parameters of the reservoir (e.g., fluid temperature and flow rate, reservoir size, and longevity). Second, the higher the immunity of a given technique to background noise, the better it is, and third, personal preference reflects the respondent evaluation of the given exploration technique and his/her assessment of that technique based, for example, on the respondents own past experience with the technique or any other reason.

TABLE B-4

EVALUATION OF EFFECTIVENESS OF EXPLORATION/ASSESSMENT TECHNIQUES (RANKING)

EXPLORATION/ ASSESSMENT TECHNIQUES	EVALUATION PARAMETER	DIAGNOSTIC CAPABILITY	APPLICABILITY				DEPENDABILITY		INSENSITIVITY			NEED FOR IMPROVEMENT NO MID HIGH	PERSONAL PREFERENCE AND WHY?
			GENERAL	SPECIFIC	KNOWN RES.	HIDDEN RES.	PRIMARY TECH.	BACK-UP TECH.	TOPOGRAPHY	DEPTH	BACKGROUND NOISE		
• Surface Geological Mapping													
• Liquid Geochemistry													
• Air Photogeology													
• Remote Sensing													
• Thermal Infra Red													
• Electrical Methods													
• Seismic Methods													
• Thermal Methods													
• Gravimetry													
• Magnetism													
• Age Dating													
• Gas Geochemistry													
• Borehole Logging													
• Other													

Evaluation Scale: 0 (useless) to 20 (very effective).

TABLE B-4 (Concluded)

With reference to Table B-4, please rank order the following measures of effectiveness by weight percent as to their importance in evaluating the effectiveness of the various exploration/assessment techniques.

MEASURE OF EFFECTIVENESS	WEIGHT PERCENT
Diagnostic Capability	%
Applicability	%
Defendability	%
Insensitivity	%
Need for Improvement	%
	<div>TOTAL</div> <div>100%</div>

Individual questions are rated by respondents on the basis of different arbitrary uniform scales of measurement (either 0 to 20 or 0 to 4). In each case, the range covered by a given scale is fixed with due regard to the typically expected differences in opinion over the issues involved.

APPENDIX C

USERS GUIDE FOR INDUSTRY
SURVEY ANALYSIS PROGRAM

APPENDIX C

A. USERS GUIDE FOR INDUSTRY SURVEY ANALYSIS PROGRAM

1.0 PURPOSE

This appendix is a guide to the computer program SURVEY used in the analysis of the industry survey questionnaire in Section 4.0. It describes the logic, data base structure, program access procedure, and the main features of the SURVEY Program.

2.0 PROGRAM LOGIC

The basic logic used in this program is shown in Figures C-1 through C-5. The program input data is compiled from the responses in each participant's questionnaire. Each table in the questionnaire is analyzed as a separate entity.

The Respondent Data sheet is used to determine the mix of participants who responded to the questionnaire on the basis of:

- o Type of Geothermal Interests,
- o Type of Organization, and
- o Expertise of the Respondent.

As shown in Figures (C3 through C5), entries in tables (B-2 through B-4) of the questionnaire are used to generate three corresponding composite tables showing the weighted averages of all respondents for each entry in each of the tables B2 through B4, respectively. These composite tables form the basis of the statistical analysis in Section 4. Furthermore, subroutine SORT is called by the main program to rank order the data in each of the composite tables according to various criteria as detailed in Section 4.

FIGURE C-1
LOGIC OF QUESTIONNAIRE ANALYSIS

FIGURE C-2
LOGIC USED IN ANALYSIS OF RESPONDENT DATA SHEET

FIGURE C-3
LOGIC OF TABLE 1 ANALYSIS

FIGURE C-4
LOGIC OF TABLE 2 ANALYSIS

FIGURE C-5
LOGIC OF TABLE 3 ANALYSIS

3.0 STRUCTURE OF DATA BASE

The data from the survey is input to the program in the form of a data base called SURVEY DATA. In this data base each respondent's data is structured as shown in Table C-1.

4.0 PROGRAM ACCESS PROCEDURE

The SURVEY program consists of a main program that calls a subroutine SORT. The whole program is accessed by typing the program name SURVEY. A complete listing of SURVEY program is given in exhibit C-1 below.

5.0 PROGRAM FEATURES

5.1 Definition of Variables

All symbols used as address locators of different variables used within the program are defined in Table C-2.

5.2 Dimension Statement

The program has several arrays defined in the dimension statement which have the number of respondents as one of their dimensions (presently 24). In order to change the program to handle a different number of respondents, the dimension statement and value of the variable NR must be changed accordingly.

TABLE C-1
STRUCTURE OF SURVEY DATA

<u>CARD</u>	<u>COLUMNS</u>	<u>INPUT</u>	<u>FORMAT</u>
1	1-17	Respondant Name	A
1	18-34	Respondant Co. Name	A
1	35-79	Respondant Data Sheet Data	F3.0
2	1-9	Respondant Data Sheet Data	F3.0
2	10-72	Steam Resource Data From Table 1	F3.0
2	73-78	Hydrothermal Resource Data From Table 1	F3.0
3	1-57	Hydrothermal Resource Data From Table 1	F3.0
3	58-78	Geopressure Resource Data From Table 1	F3.0
4	1-42	Geopressure Resource Data From Table 1	F3.0
4	43-78	Hot Dry Rock Resource Data From Table 1	F3.0
5	1-27	Hot Dry Rock Resource Data From Table 1	F3.0
5	28-36	Weight Percents For Table 1	F3.2
5	37-80	Table 2 Data	F2.0
6-8	1-80	Table 2 Data	F2.0
9	1-52	Table 2 Data	F2.0
9	53-79	Table 3 Data	F3.0

TABLE C-1 (Continued)
STRUCTURE OF SURVEY DATA

<u>CARD</u>	<u>COLUMNS</u>	<u>INPUT</u>	<u>FORMAT</u>
10-14	1-78	Table 3 Data	F3.0
15	1-3	Table 3 Data	F3.0
15	4-18	Weight Percents For Table 3	F3.2

EXHIBIT C-1

SURVEY PROGRAM LISTING

```

    DIMENSION RDATA (24,18),SIDATA (24,21),HIDATA (24,21),GIDATA (24,21),R
    *IDATA (24,21),XIAP (24,3),REATA (24,14,12),EEAT (24,14,10),WPET (24,5),
    *RSUM (24),WP (24),COUNT (18),SUMWP (3),AVIP (3),EIDATA (24,21),TOTAL (24,
    *3),AVE (3),POAI (3),RATOT (24,7),RAVE (7),EVTOT (14,12),AOAT (14),WPSUM (
    *24),DIFF (24),WPETN (24,4),WPTOT (4),WPAVE (4),EEATN (24,14,4),EFFRKNK (1
    *4,4),OAFET (14),AVEEFF (4)
    INTEGER POINTR (14)
    DATA RSUM/24*0./,WP/24*0./,COUNT/18*0./,SUMWP/3*0./,AVIP/3*0./,EID
    *ATA/504*0./,EVTOT/168*0./,AOAT/14*0./,WPSUM/24*0./,DIFF/24*0./,WPE
    *TN/96*0./,WPTOT/4*0./,WPAVE/4*0./,EEATN/1344*0./,EFFRKNK/56*0./,OAF
    *ET/14*0./,AVEEFF/4*0./
    ICOUNT=0
    KOUNT=0
    RTOT=0.
    NR=23
    HSCORE=20.
    DO 66 I=1,NR
    READ (5,3000) (RDATA (I,J),J=1,18),
    * (SIDATA (I,J),HIDATA (I,J),GIDATA (I,J),RIDATA (I,J),J=1,21),
    * (XIAP (I,J),J=1,3),
    * ((REATA (I,J,K),K=1,12),J=1,14),
    * ((EEAT (I,J,K),K=1,10),J=1,14),
    * (WPET (I,J),J=1,5)
3000  FORMAT (34X,15F3.0/3F3.0,
    *21F3.0,2F3.0/19F3.0,7F3.0/14F3.0,12F3.0/9F3.0,3F3.2,
    *22F2.0/40F2.0/40F2.0/40F2.0/26F2.0,
    *9F3.0/26F3.0/26F3.0/26F3.0/26F3.0/26F3.0/F3.0,5F3.2)
66    CONTINUE
    WRITE (2,3050)
    WRITE (6,3050)
3050  FORMAT (1X,'DATA HAS BEEN READ - ANALYSIS OF RESPONDANT DATA BEGINS
    *')
C...
C...  ANALYSIS OF RESPONDANT DATA SHEET
C...
    DO 10 I=1,NR
    DO 11 J=1,18
    RSUM (J)=RSUM (J)+RDATA (I,J)
11    CONTINUE
    RTOT=RTOT+RSUM (J)
10    CONTINUE
    WRITE (6,100) (I,RSUM (I),RTOT,I=1,NR)
100  FORMAT (2X,'I=',I2,2X,'RSUM(I)=' ,F5.2,' RTOT=' ,F10.2)
    DO 12 I=1,NR
    WP (I)=(RSUM (I)/RTOT)*100.
12    CONTINUE
    WRITE (6,110) (I,WP (I),I=1,NR)
110  FORMAT (2X,'I=',I2,' WP(I)=' ,F5.2)

```

EXHIBIT C-1 (Continued)

SURVEY PROGRAM LISTING

```

DO 13 I=1,NR
DO 14 J=1,18
IF(RDATA(I,J).EQ.0.)GOTO 14
COUNT(J)=COUNT(J)+1.
14 CONTINUE
WRITE(6,120) (I,J,COUNT(J),J=1,18)
120 FORMAT(2X,'I=',I2,' J=',I2,' COUNT(J)=',F4.0)
13 CONTINUE
WRITE(2,3060)
WRITE(6,3060)
3060 FORMAT(1X,'RESPONDANT DATA ANALYZED - BEGIN TABLE 1 ANALYSIS')
C...
C... TABLE ANALYSIS - WEIGHT PERCENT AVERAGES
C...
DO 15 I=1,NR
DO 16 J=1,3
SUMWP(J)=SUMWP(J)+XIAP(I,J)
AVIP(J)=SUMWP(J)/NR
16 CONTINUE
WRITE(6,130) (J,SUMWP(J),AVIP(J),J=1,3)
130 FORMAT(2X,'J=',I2,' SUMWP(J)=',F8.3,' AVIP(J)=',F5.2)
15 CONTINUE
C...
C... ANALYSIS OF TABLE 1 - MAIN ANALYSIS
C...
DO 26 I=1,NR
DO 27 J=1,21
EIDATA(I,J)=SIDATA(I,J)
27 CONTINUE
26 CONTINUE
1000 DO 70 I=1,NR
DO 71 K=1,3
TOTAL(I,K)=0.
AVE(K)=0.
POAI(K)=0.
71 CONTINUE
70 CONTINUE
OAI=0.
DO 17 I=1,NR
DO 18 J=1,7
DO 19 K=1,3
L=(J-1)*3+K
TOTAL(I,K)=TOTAL(I,K)+EIDATA(I,L)
19 CONTINUE
18 CONTINUE
DO 20 K=1,3
TOTAL(I,K)=(TOTAL(I,K)/7.)*AVIP(K)
AVE(K)=AVE(K)+TOTAL(I,K)/NR

```

EXHIBIT C-1 (Continued)

SURVEY PROGRAM LISTING

```
20      CONTINUE
      WRITE(6,140) I, (TOTAL(I,K), K=1,3)
140     FORMAT(2X, 'I=', I2, ' TOTAL(I,K) = ', 3G10.4)
17      CONTINUE
      OAI=AVE(1)+AVE(2)+AVE(3)
      DO 21 J=1,3
      POAI(J) = (AVE(J)/OAI)
21      CONTINUE
      WRITE(6,150) (K, AVE(K), POAI(K), K=1,3)
150     FORMAT(2X, 'K=', I2, ' AVE(K) = ', F10.2, ' POAI(K) = ', F10.2)
      WRITE(6,180) ICOUNT
180     FORMAT(2X, 'ICOUNT=', I2)
      ICOUNT=ICOUNT+1
      IF(ICOUNT.EQ.2) GOTO 1050
      IF(ICOUNT.EQ.3) GOTO 1060
      IF(ICOUNT.GT.3) GOTO 1070
      DO 28 I=1, NR
      DO 29 J=1, 21
      EIDATA(I,J)=HIDATA(I,J)
29      CONTINUE
28      CONTINUE
      GOTO 1000
1050    DO 30 I=1, NR
      DO 31 J=1, 21
      EIDATA(I,J)=GIDATA(I,J)
31      CONTINUE
30      CONTINUE
      GOTO 1000
1060    DO 32 I=1, NR
      DO 33 J=1, 21
      EIDATA(I,J)=RIDATA(I,J)
33      CONTINUE
32      CONTINUE
      GOTO 1000
1070    DO 34 I=1, NR
      DO 35 J=1, 21
      EIDATA(I,J)=SIDATA(I,J)
35      CONTINUE
34      CONTINUE
1080    DO 72 I=1, NR
      DO 73 J=1, 7
      RAVE(J)=0.
      RATOT(I,J)=0.
73      CONTINUE
72      CONTINUE
      DO 22 I=1, NR
      DO 23 J=1, 7
      DO 24 K=1, 3
```

EXHIBIT C-1 (Continued)

SURVEY PROGRAM LISTING

```

      L=(J-1)*3+K
      RATOT(I,J)=RATOT(I,J)+EIDATA(I,L)*AVIP(K)
24    CONTINUE
23    CONTINUE
      DO 25 J=1,7
      RATOT(I,J)=RATOT(I,J)/(3.*HSCORE)
      RAVE(J)=RAVE(J)+RATOT(I,J)/NR
25    CONTINUE
      WRITE(6,160) (I,(RATOT(I,J),J=1,7))
160   FORMAT(2X,'I=',I2,' RATOT(I,J)=' ,7F10.2)
22    CONTINUE
      WRITE(6,170) (J,RAVE(J),J=1,7)
170   FORMAT(2X,'J=',I2,' RAVE(J)=' ,F10.2)
      CALL SORT(RAVE,7,POINTR)
      WRITE(6,300) (POINTR(I),RAVE(POINTR(I)),I=1,7)
300   FORMAT(2X,'I=',RAVE(RANKED)=' ,7(I2,1X,F10.4))
      WRITE(6,190) KOUNT
190   FORMAT(2X,'KOUNT=' ,I2)
      KOUNT=KOUNT+1
      IF(KOUNT.EQ.2) GOTO 2000
      IF(KOUNT.EQ.3) GOTO 2010
      IF(KOUNT.GT.3) GOTO 2020
      DO 36 I=1,NR
      DO 37 J=1,21
      EIDATA(I,J)=HIDATA(I,J)
37    CONTINUE
36    CONTINUE
      GOTO 1080
2000  DO 38 I=1,NR
      DO 39 J=1,21
      EIDATA(I,J)=GIDATA(I,J)
39    CONTINUE
38    CONTINUE
      GOTO 1080
2010  DO 40 I=1,NR
      DO 41 J=1,21
      EIDATA(I,J)=RIDATA(I,J)
41    CONTINUE
40    CONTINUE
      GOTO 1080
2020  CONTINUE
      WRITE(2,3070)
      WRITE(6,3070)
3070  FORMAT(1X,'TABLE 1 ANALYZED - BEGIN TABLE 2 ANALYSIS')
C...
C...  ANALYSIS OF TABLE 2
C...
      DO 42 I=1,NR

```

EXHIBIT C-1 (Continued)

SURVEY PROGRAM LISTING

```

DO 43 J=1,14
DO 44 K=1,12
EVTOT(J,K)=EVTOT(J,K)+REATA(I,J,K)
44 CONTINUE
43 CONTINUE
42 CONTINUE
DO 45 I=1,14
DO 46 J=1,12
EVTOT(I,J)=EVTOT(I,J)/NR
46 CONTINUE
WRITE(6,200) I, (EVTOT(I,J), J=1,12)
200 FORMAT(2X,'I=',I2,' EVTOT(I,J)=' ,12F6.3)
45 CONTINUE
C...
C... RANK ORDER TECHNIQUES IN EACH REGION
C...
DO 67 J=1,12
CALL SORT(EVTOT(1,J),14,POINTR)
WRITE(6,210) J, (EVTOT(POINTR(I),J), I=1,14)
210 FORMAT(2X,'J=',I2,2X,' EVTOT(RANKED)=' ,14F6.3)
67 CONTINUE
C...
C... AVERAGE OVERALL APPLICABILITY FOR EACH TECHNIQUE
C...
DO 47 I=1,14
DO 48 J=1,12
AOAT(I)=AOAT(I)+EVTOT(I,J)/12.
48 CONTINUE
WRITE(6,230) I,AOAT(I)
230 FORMAT(2X,'I=',I2,' AOAT(I)=' ,14F5.1)
47 CONTINUE
C...
C... RANK ORDER THE AVERAGE OVERALL APPLICABILITY FOR EACH TECHNOLOGY
C...
CALL SORT(AOAT,14,POINTR)
WRITE(6,220) (POINTR(I),AOAT(POINTR(I)), I=1,14)
220 FORMAT(2X,'I= AOAT(RANKED)=' ,7(I2,2X,F5.1)/18X,7(I2,2X,F5.1) )
WRITE(2,3080)
WRITE(6,3080)
3080 FORMAT(1X,'TABLE 2 ANALYZED - BEGIN TABLE 3 ANALYSIS')
C...
C... ANALYSIS OF TABLE 3 - AVERAGE OF WEIGHT PERCENTAGES
C...
DO 49 I=1,NR
DO 50 J=1,4
WPSUM(I)=WPSUM(I)+WPET(I,J)
WRITE(6,550) I,J,WPSUM(I),WPET(I,J)
550 FORMAT(1X,'I=',I2,1X,'J=',I2,1X,'WPSUM(I)=' ,F8.4,1X,'WPET(I,J)=' ,F

```

EXHIBIT C-1 (Continued)

SURVEY PROGRAM LISTING

```

*8.4)
50  CONTINUE
    DIFF(I)=1.0-WPSUM(I)
    WRITE(6,551) I,DIFF(I)
551  FORMAT(1X,'I=',I2,1X,'DIFF(I)=' ,F8.4)
49  CONTINUE
    DO 51 I=1,NR
    IF(WPSUM(I).EQ.0.) GOTO 51
    DO 52 J=1,4
    WPETN(I,J)=WPET(I,J)+((WPET(I,J)/WPSUM(I))*DIFF(I))
52  CONTINUE
51  CONTINUE
    DO 53 I=1,NR
    DO 54 J=1,4
    WPTOT(J)=WPTOT(J)+WPETN(I,J)
54  CONTINUE
53  CONTINUE
    DO 55 J=1,4
    WPAVE(J)=WPTOT(J)/NR
55  CONTINUE
    WRITE(6,240) (J,WPAVE(J),J=1,4)
240  FORMAT(2X,'J=',I2,' WPAVE(J)=' ,F10.4)
C...
C...  ANALYSIS OF TABLE 3 - MAIN ANALYSIS
C...
    DO 56 I=1,NR
    DO 57 J=1,14
    EEATN(I,J,1)=EEAT(I,J,1)
    EEATN(I,J,2)=(EEAT(I,J,2)+EEAT(I,J,3)+EEAT(I,J,4)+EEAT(I,J,5))/4.
    EEATN(I,J,3)=(EEAT(I,J,6)+EEAT(I,J,7))/2.
    EEATN(I,J,4)=(EEAT(I,J,8)+EEAT(I,J,9)+EEAT(I,J,10))/3.
57  CONTINUE
56  CONTINUE
    DO 59 I=1,NR
    DO 60 J=1,14
    DO 61 K=1,4
    EFFRNK(J,K)=EFFRNK(J,K)+((EEATN(I,J,K)*WPAVE(K))/NR)
61  CONTINUE
60  CONTINUE
59  CONTINUE
    DO 62 J=1,14
    DO 63 K=1,4
    AVEEFF(K)=AVEEFF(K)+EFFRNK(J,K)/14.
63  CONTINUE
62  CONTINUE
    WRITE(6,250) (K,AVEEFF(K),K=1,4)
250  FORMAT(2X,'K=',I2,' AVEEFF(K)=' ,F10.4)
C...

```


EXHIBIT C-1 (Continued)

SURVEY PROGRAM LISTING

```

C...  RANK ORDER TECHNIQUES IN EACH EVALUATION PARAMETER
C...
      DO 68 K=1,4
      CALL SORT(EFFRNK(1,K),14,POINTR)
      WRITE(6,260) (K,POINTR(I),EFFRNK(POINTR(I),K),I=1,14)
68      CONTINUE
260     FORMAT(2X,'K=',I2,1X,'I=',I2,' EFFRNK(RANKED)=' ,F5.1/)
C...
C... COMPUTE OVERALL AVERAGE FOR EACH TECHNIQUE
C...
      DO 64 I=1,14
      DO 65 J=1,4
      OAFET(I)=OAFET(I)+EFFRNK(I,J)/4.
65      CONTINUE
64      CONTINUE
      WRITE(6,270) (I,OAFET(I),I=1,14)
270     FORMAT(2X,'I=',I2,' OAFET(I)=' ,F10.4)
C...
C...  RANK ORDER OVERAL AVERAGES FOR EACH TECHNIQUE
C...
      CALL SORT(OAFET,14,POINTR)
      WRITE(6,280) (POINTR(I),OAFET(POINTR(I)),I=1,14)
280     FORMAT(2X,'I=',I2,' OAFET(RANKED)=' ,F4.1)
      WRITE(2,3090)
      WRITE(6,3090)
3090    FORMAT(1X,'ANALYSIS COMPLETED')
      STOP
      END

```

EXHIBIT C-1 (Concluded)

SURVEY PROGRAM LISTING

5.3 Subroutine SORT

```

SUBROUTINE SORT (ARRAY, NNUMB, POINTR)
REAL ARRAY (NNUMB), DUMMY (14)
INTEGER POINTR (NNUMB)
DO 90 I=1, NNUMB
POINTR (I) =I
DUMMY (I) =ARRAY (I)
90  CONTINUE
LIMIT=NNUMB-1
DO 91 JJ=1, LIMIT
ITEST=0
DO 92 J=1, LIMIT
IF (DUMMY (J) .GE. DUMMY (J+1) ) GOTO 92
YTEMP=DUMMY (J)
DUMMY (J) =DUMMY (J+1)
DUMMY (J+1) =YTEMP
ITEMP=POINTR (J)
POINTR (J) =POINTR (J+1)
POINTR (J+1) =ITEMP
ITEST=1
92  CONTINUE
IF (ITEST.EQ.0) GOTO 400
91  CONTINUE
400  RETURN
END
```

TABLE C-2
DEFINITION OF VARIABLES

VARIABLE NAME	DEFINITION
NR	Number of respondents
RDATA	Respondent sheet data
SIDATA	Steam resource data (Table 1)
HIDATA	Hydrothermal resource data (Table 1)
GIDATA	Geopressure resource data (Table 1)
RIDATA	Hot dry rock resource data (Table 1)
XIAP	Weight percent (Table 1)
REATA	Table 2 data
EEAT	Table 3 data
WPET	Weight percent (Table 3)
RSUM	Sum of respondent data
RTOT	Total of all respondent data sums
WP	Respondent weight percent of total (RTOT)
COUNT (1-18)	Categories on respondent data sheet (1-18) top to bottom
SUMWP	Weight percent sum (Table 1)
AVIP	Average weight percent (Table 1)
TOTAL	Column total (Table 1)
AVE	Column average (Table 1)

TABLE C-2 (Concluded)

VARIABLE NAME	DEFINITION
POAI	Column weight percent (Table 1)
RATOT	Research area (row) total (Table 1)
RAVE	Research area (row) average (Table 1)
EVTOT	Composite matrix (Table 2)
AOAT	Research area (row) averages
WPSUM	Weight percent total (Table 3)
DIFF	Difference between 1.0 and WPSUM (Table 3)
NWPET	New weight percent (Table 3)
WPTOT	New weight percent total (all responses) (Table 3)
WPAVE	Weight percent average (all responses) (Table 3)
NEEAT	Combined columns (Table 3)
EFFRNK	Composite matrix (Table 3)
OAFET	Average of rows in composite matrix (Table 3)
AVEEFF	Average of columns in composite matrix (Table 3)

B. STATISTICAL SIGNIFICANCE OF SURVEY RESULTS

6.0 STATISTICAL SIGNIFICANCE

The main sources of error in any survey are improper sample size, the built-in bias, and the randomness of responses. It is, therefore, necessary to evaluate the impact of these errors on the final results of a survey.

As already indicated, the size of sample of individuals/organizations that received the questionnaire (i.e., 72) and the number of respondents (i.e., 30) is greater than or equal to thirty. This size of sample is adequate²⁴ and will, hence, lead to statistically valid conclusions.

Even with an adequate survey sample size, a misrepresentation of the various categories included in this sample may lead to an undesirable bias in the final results of that survey. For the case in hand, Table C-3 indicates that both the original users' survey sample, and the set of respondents represent an appropriate cross section of the geothermal industry. Oil companies, the utilities, field service companies, and field developers are shown in Table 14 to constitute more than 57 percent of the survey respondent sample. This gives more weight to the opinion of the representatives of that segment of geothermal industry which would benefit most from a successful GERRA R&D program. A built-in bias, if any, would, therefore, be in the proper direction.

It could also be shown that²⁵, the theoretical chi-square value

TABLE C-3

PROFILE OF USERS SURVEY SAMPLE

CATEGORY OF USER	ORIGINAL MAIL SURVEY (PERCENT)	RESPONSES RECEIVED (PERCENT)
Oil Company	16.7	18.2
Utility	2.8	3.0
Field Service Company	15.3	15.2
Field Developer	12.5	21.2
University	16.7	3.0
Consultant	11.1	24.2
Other	25.0	15.2
TOTAL	100.0	100.0

for a level of significance of 0.01 (i.e., theoretical χ^2 0.01) is less than the calculated chi-square value based on the responses entered in Tables B-2, B-3 and B-4 of the questionnaire. This verifies that all responses to the questionnaire were significantly deliberate (non-random responses), thus confirming the validity of all results and conclusions discussed below.

6.1 Profile of Respondents

Figure C-6a depicts the distribution of interest of respondents based on the statistical frequency analysis of their identification data in Table B-1 of the questionnaire (i.e., Respondent Data Sheet). In this figure, it can be seen that the majority of the respondents organization are interested in steam and hydrothermal resources. This is not surprising since these two resource types are most likely to be developed in the near future.

Similarly, inspection of Figure C-6b indicates that field developers, field service companies, oil companies, and other Federal (U.S.G.S.) and state organizations, which are more heavily involved in exploration and resource assessment, constitute the largest percentage (70 percent) of the participants in the survey. This is desirable, since, it will give more weight to the opinion of those who are expected to be the primary beneficiaries of the outcome of a successful GERRA R&D program. Responses were also weighted by the type and extent of experience of the respondent. As depicted in Figure C-6c, the major areas of experience of respondents are exploration, logging

FIGURE C-6a
DISTRIBUTION OF GEOTHERMAL INTERESTS
OF THE PARTICIPANTS

FIGURE C-6b
DISTRIBUTION OF ORGANIZATION TYPES
OF SURVEY PARTICIPANTS

FIGURE C-6c
DISTRIBUTION OF EXPERIENCE (AREA OF EXPERTISE)
OF THE PARTICIPANTS

FIGURE C-6
PROFILE OF RESPONDENTS AS TO GEOTHERMAL INTEREST,
ORGANIZATION TYPES, AREA OF EXPERTISE

and interpretation, and reservoir engineering and modeling. Eighty-seven percent of the respondents are involved in one or more of these areas of experience. This is also a desirable feature of the profile of respondents, since, it gives more weight to the opinion of those who are most familiar with R&D needs of geothermal resource exploration and assessment.

APPENDIX D

LIST OF MAIL RESPONDENTS
AND PARTICIPANTS IN
IN-PERSON INTERVIEWS

APPENDIX D

LIST OF MAIL RESPONDENTS AND PARTICIPANTS IN IN-PERSON INTERVIEWS

<u>NAME</u>	<u>COMPANY</u>
1. Ronald C. Barr	Earth Power Corporation
2. C. W. Berge	Phillips Petroleum
3. David Butler	Micro Geophysics
4.	California Energy Company
5. Jim Combs	Geothermal Services, Inc.
6. W. L. D'Olier	Thermal Power Company
7. Dr. William Dolan	Amax Exploration, Inc.
8. Acey L. Floyd	City of Burbank, California
9. B. Greider	Energy Corporation Intercontinental
10. John Husler	The University of New Mexico
11. C. B. Jenkins	Aminoil USA
12. Nile O. Jones	Arizona Bureau of Geology
13. Dr. Paul Kasemeyer	Lawrence Livermore Labs
14. Frank C. Kresse	Harding-Lawson Associates
15. Mr. Arthur Lange	Amax Exploration, Inc.
16. Guy W. Leach	Oil Development Company of Texas
17. Don Mabey	USGS
18. Tsvi Meidav	Consultant
19. Donald S. Miller	Rensselaer Polytechnic Institute
20. Dr. Patrick Muffler	U.S. Geological Survey
21. Robert B. McEuen	Woodward-Clyde Consultants

22.	Carel Otte	Union 76
23.	Richard H. Pearl	Colorado Geological Survey
24.		Petroleum Information
25.	Dean Pilkington	Amax Exploration, Inc.
26.	D. E. Powley	Amoco
27.	Mr. Jacob M. Rudisill	Thermal Power Company
28.	John M. Savino	Systems, Science and Software
29.	Kathy Skokan	Colorado School of Mines
30.	J. L. Smith	Republic Geothermal, Inc.
31.	John L. Sonderegger	Montana Bureau of Mines and Geology
32.	Charles Swift	Chevron Resources
33.	Dennis T. Trexler	Nevada Bureau of Mines and Geology
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APPENDIX E
USERS SURVEY MAILING LIST

APPENDIX E

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