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An R&D Project Management and Selection System for the Utilization Technology Branch, Division of Geothermal Energy Volume III — Project Selection Procedure and Benefit/Cost Analysis

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**An R&D Project
Management and Selection
System for the Utilization
Technology Branch,
Division of Geothermal Energy
Volume III —
Project Selection Procedure
and Benefit/Cost Analysis**

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ABSTRACT

This report in three volumes describes an R&D project management and selection system developed for the Utilization Technology Branch of the Division of Geothermal Energy, Department of Energy. The proposed project management system (PMS) consists of a project data system (PDS) and a project selection procedure (PSP). The project data system consists of a series of project data forms and project status logs, and descriptions of information pathways. The PDS emphasizes timely monitoring of the technical and financial progress of projects, maintenance of the history of the project and rapid access to project information to facilitate responsive reporting to DGE and DOE Upper Management. The project selection procedure emphasizes a R&D product-oriented approach to benefit/cost analysis of individual projects. The report includes: (a) a description of the system, and recommendations for its implementation, (b) the PDS forms and explanation of their use, (c) a glossary of terms for use on the forms, (d) a description of the benefit/cost approach, (e) a data base for estimating R&D benefits, and (f) examples of test applications of the system to nine current DGE projects.

This volume describes a proposed procedure for R&D project selection. The benefit/cost analysis part of the procedure estimates financial savings expected to result from the commercial use of hardware or process products of R&D. Savings are estimated with respect to the geothermal power plants expected to come on line between 1978 and 2000.

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1.0 INTRODUCTION

The Project Selection Procedure (PSP) is a title for the varied activities that DGE uses or might use to identify projects or subelements that are worth pursuing. The PSP focuses specifically on one activity of the Project Management Sequence--the Detailed Evaluation of R&D Concept.

R&D concepts arise as original ideas of Program Managers, or from sources outside of DGE (e.g., from DOE laboratories or unsolicited proposals). The Program Manager conducts an initial screening of the concept to decide if the concept seems to have face validity. If the concept seems meritorious, a Detailed Evaluation is performed. The result of the Detailed Evaluation is a decision, made jointly by the Program Manager and the Branch Chief, either to pursue the concept by funding projects, or not to pursue the concept.

The Detailed Evaluation consists of two parts: an External Evaluation and a Benefit/Cost Analysis. While this volume emphasizes a proposed procedure for evaluating benefits and costs of the projects of the Utilization Technology Branch of DGE, the Benefit/Cost Evaluation is discussed in the context of the activity which it was designed to serve--project selection.

2.0 DETAILED EVALUATION PROCEDURE

The two parts of the Detailed Evaluation are typically to be conducted in parallel. The External Evaluation draws upon expert opinion outside of DGE headquarters to assess the general technical merits of the concept. The Benefit/Cost Evaluation estimates in numerical terms the degree to which the proposed R&D will contribute to the goals of the entire DGE program.

2.1 External Evaluation

As noted in the description of the Subelement Management Sequence in Volume I of this report, an External Evaluation typically is employed to assess the value of unsolicited proposals, but it is bypassed when the R&D concept originates within DGE or a DOE laboratory.

This evaluation is conducted in the traditional manner. That is, the Program Manager identifies persons that he feels have substantial expertise with respect to the technical aspects of the proposed project, specific knowledge about other projects of the same type, or awareness of the capabilities of the proposing contractor. Opinions are collected by letter or use of a proposal rating sheet. The evaluators are asked to provide an overall rating of the proposed work, and whether they recommend funding or alternative actions.

The Program Manager retrieves these evaluations in a timely manner. He prepares a resume of the recommendations. He also notes technical or managerial questions raised by the evaluators and, where necessary, contacts the proposing contractor to resolve

the questions. In some cases, the contractor may be asked to revise his proposal or submit appropriate addenda or clarifications.

It has been traditional to request from the external evaluators verbal descriptions of the value which they perceive from the proposed R&D work. It would be valuable, for purposes of benefit/cost evaluations, to have the evaluators make quantitative estimates of the improvement in technology which they feel would result from the project. The Program Manager's forwarding letter could contain a question phrased to this end. For example, "In the improved design for heat exchangers proposed here, what percentage increase in heat-exchange efficiency do you feel will most likely result from this project?" Or, "To what degree will the instantaneous penetration rate of this drill bit be increased?"

2.2 Benefit/Cost Evaluation

The purpose of the benefit/cost evaluation is to assign a "figure of merit" to each R&D concept, or subelement. This figure of merit (FOM) is the ratio of the benefits expected from the subelement to the R&D costs of the subelement. The FOM includes appropriate estimates of the expected degree of success of the project.

Most of the remainder of this volume is devoted to descriptions of how expected costs, benefits, and degree of success are to be estimated and integrated into a unitary figure of merit. In brief, the figure of merit reflects the Program Manager's estimate of the

degree to which DGE R&D dollars are expected to produce savings in the cost of producing geothermal power between now and the year 2000. The estimate of potential savings is based on an accounting of the technology that is expected to be employed to attain the DGE power-on-line goals as set forth by a DGE planning exercise in Spring 1977.

The approach to estimating benefits from R&D is tailored specifically to the needs of the Utilization Technology Branch of DGE. Therefore it emphasizes impacts of R&D on the costs of constructing or operating specific geothermal power-production technologies. It is likely that other approaches to estimating benefits might be required by other DGE Branches.

At the time of this writing, the only technology for which an adequate power-on-line scenario existed was that for hydrothermal and steam electrical plants, including those predicated for geopressured prospects. Provisions are made for adding other types of geothermal power production or utilization systems as power-on-line scenarios become established.

Estimates of the numbers and costs of future geothermal electrical power plants and wells, against which benefits are to be calculated, are presented in Appendix III-A. An example of how the figure of merit was estimated for one DGE project, the Terra Tek improved geothermal drill bit, is presented in Appendix III-B of this volume. The form for calculating and documenting the figure of merit is included in Appendix III-B.

It is proposed that evaluating the figure of merit for specific projects or subelements be the responsibility of the cognizant Program Manager. In many instances the Program Manager may have to have technical assistance to conduct the evaluations.

2.3 Project Selection

Once the External Evaluation and Benefit/Cost Evaluation have been completed, the Program Manager and Branch Chief decide jointly whether to seek approval of DGE upper management to fund the specific project. If the decision is positive, the current DGE procedures for preparing Contract Justification Memoranda, etc., are then followed to initiate the contracting process.

The decision to pursue particular R&D concepts will continue to be based on the informed judgment of the Program Manager and Branch Chief. There is no simple algorithm by which this sensitive process can be made entirely automatic.

3.0 THE APPROACH FOR BENEFIT/COST ANALYSIS

Both benefits and R&D costs are expressed in terms of dollars. Thus the figure of merit is the dimensionless ratio of benefits to costs. A figure of merit of 10 implies that ten dollars of benefit are expected to be recovered for every R&D dollar spent. Until a number of projects are analyzed, it seems reasonable to use this value of 10 as the threshold for selecting subelements as worthy of contract support.

The estimates of R&D costs and time are based on contractor-proposed costs and the experience of the Program Manager with similar projects. Such costs cover a variety of types and phases of R&D during the development of any technological product. Time estimates are used to determine the year in which the technological product of the subelement (an improved geothermal energy system component or process) will become available for commercial use. The procedure for estimating costs and time is described in Section 4.0.

The estimation of benefits for each subelement is based on the degree to which the technological product of the subelement will reduce the cost of delivering geothermal power from specific types of geothermal prospects. It is assumed that power could be delivered from each known prospect using systems built of available components, but these would bring power on line at high or even noneconomic costs. The products of R&D generate benefits equal to the reduction in the cost of geothermal power system construction and operation.

This approach to estimating benefits is proposed for use in estimating technological benefits of DGE projects because it provides a powerful set of linkages among five major components of the DGE program:

- (1) The power-on-line scenario goals for specific geothermal prospects which were set by the DGE Planning Exercise in April, 1977,
- (2) The prospect-specific characteristics (e.g., fluid temperature, depth, rock type, pressure, dissolved solids) which prescribe design points for the technology to be used to extract power from the prospect,
- (3) The design and assumed costs of current state-of-the-art technology that would be used to produce power if there were no further R&D,
- (4) The improved technical characteristics and potential cost savings of proposed products of R&D, along with the R&D-associated costs of each, and
- (5) Nontechnological factors associated with geothermal energy development activities (e.g., permitting, leasing, field unitizing, market penetration) that affect the utilization of new technology, especially insofar as these factors delay the use of improved products.

What would seem to be very important in any benefits-estimation procedure is a natural way for R&D Program Managers to relate proposed technological innovations to the DGE power-on-line goals. In the proposed procedure the Program Managers are given a forward look at the types of technologies that will be used to extract and deliver geothermal power, and given an indication of the time in the near to intermediate future (5 to 20 years) when each type of technology is most likely to be used. This forward look is provided by combining information about: (1) specific geothermal prospect characteristics, (2) power production systems based on current technology and designed around the most critical site-specific characteristics, and (3) potential R&D-originated improvements in those production systems. The integrating principle is costs. The integrating activity is the analysis of tradeoffs between R&D costs and future savings in delivering power from specific resources.

An overview of these relationships is presented in Figure 1. The following sections describe how R&D costs and benefits are estimated and documented. A Benefit/Cost Evaluation Form for structuring and recording these estimates is attached as Appendix III-B. This form is referred to in the following discussion.

FIGURE 1
OVERVIEW OF FIGURE-OF-MERIT EVALUATION APPROACH

4.0 ESTIMATES OF R&D COSTS AND TIME

Before benefits can be estimated, the Program Manager must project the time at which the product of the R&D subelement will be available for commercial use. This estimate is generated simultaneously with brief descriptions of the R&D work to be done and estimates of the cost of the work.

At the outset the Program Manager selects an overall strategy for the R&D subelement. Usually a subelement is synonymous with one project: the R&D work to be done by a single contractor during a few-year period. In those cases where multiple projects, either parallel or serial, are required to create a single technological product, one benefit/cost analysis is performed for the set of projects. Justification for the interrelationships of the projects should be provided to indicate why each project is necessary for the subelement.

Estimating work, cost, and time is facilitated by dividing the required work into six different (often sequential) types of R&D activities. These types of work are based in part on the Department of Defense Categories for describing defense R&D projects⁽¹⁾, with modifications to match special characteristics of DGE program policies.

The six types of work are:

- (i) Preliminary Study - Initial analysis and R&D technical planning efforts to determine the general merit of new R&D concepts. This may include literature searches,

gathering of expert opinion, technology forecasting, etc. The product of such studies is advice about what, if any, R&D efforts should be undertaken to develop the concept into a commercially useful product.

- (ii) Basic Research - Scientific study and experimentation directed toward increasing knowledge and understanding in those fields of science related to long-term geothermal energy production needs. It provides fundamental knowledge for the solution of identified technical and engineering problems. It also provides part of the base for exploration and development of advanced technology and new or improved functional capabilities.
- (iii) Exploratory Development - The dominant characteristic of this type of effort is that it is pointed toward specific geothermal technology problem areas and opportunities to develop proposed solutions, determining their parameters, and evaluating their feasibility and practicality. Such efforts vary from fairly fundamental applied research to quite sophisticated broad-based hardware, study, programming, and planning efforts. Such efforts thus may include minor engineering and development work to prove the feasibility of technical components of a proposed solution if carried out to assess the value of the system as a whole. The main output of such efforts are paper reports of designs and analyses of designs of new or improved technology for producing or utilizing geothermal energy. Evaluation of the value of these outputs relies on expert review and development of consensus within the technical branches of the Division of Geothermal Energy.
- (iv) Advanced Development - Includes all projects which have moved into the development of hardware for experimental and engineering tests. These projects result in hardware devices that are viewed as engineering prototypes whose size or performance scale falls short of that of products designed to be components of geothermal energy extraction or production systems. Evaluation of these prototype devices will typically be based on expert review of engineering performance data provided by the contractor who develops the device.
- (v) Engineering Development - These projects develop hardware devices with characteristics and performance on a scale deemed to be appropriate for components of commercial geothermal energy systems. Evaluation of

these devices will be based on operational tests conducted by contractors other than the developing contractor. The emphasis is on achieving performance that significantly reduces the overall cost of producing and utilizing geothermal energy.

- (vi) Demonstration and Commercialization - Activities and projects intended to induce the commercial sector to utilize new technology with proven performance/cost improvements. Evaluation of these activities is based on a combination of expert opinion and technology utilization assessment.

An appropriate accounting of each type of work should include the evaluation or operational testing required at the end of each phase of work, especially as these add to time (if not to costs). Section 6.0 of the Benefit/Cost Evaluation Form provides spaces for descriptions of work and evaluation requirements, plus estimates of time and costs.

Basic research will usually not be required, since most of the technical products to be developed will be based on new combinations of existing devices and information. The basic research category has been included to emphasize that, if basic research is done, the use of the results of that research should be projected through the entire R&D process. This allows formulations of estimates of total R&D costs and the ultimate commercial utility of the knowledge to be gained from basic R&D.

The demonstration and commercialization stage is included to emphasize the time lags between successful development of commercially viable products and their widespread use. Such lags should

be estimated as best possible, and included in the total time required before the R&D product can be incorporated as a component of future geothermal power delivery systems. The recognition of this time lag is also necessary for coordinating R&D activities with the projected scenarios for geothermal energy development.

5.0 ESTIMATE OF BENEFITS

5.1 The Benefits Model

As mentioned above, the benefits for each R&D subelement are defined to be future cost savings generated by the product of the subelement. Benefits are estimated by comparing the costs of producing power with technology that incorporates the new product to the costs of producing power with current technology (without R&D).

The baseline for estimating benefits is a model of the current technology that would be used to achieve the DGE resource-specific power-on-line projections between 1978 and 2000. This "Benefits Model" is a semi-exhaustive list of the types, unit costs, and number of units of all "current technology" systems that would have to be installed during successive two-year time periods in order to meet the power-on-line goals. Each new technology product (result of a successful subelement) then is estimated to produce benefits equal to the cost saving it would effect by replacing a "current technology" component. Figure 2 displays how the Benefits Model was constructed, and how it is used to estimate R&D benefits.

The model does not require an impossible accounting of all nuts and bolts to be used in the future. The model is constrained to a workable level of detail by assuming that a small number of standardized geothermal energy production systems can account for most of the power to be brought on line. These Geothermal Technology

FIGURE 2

MAIN COMPONENTS OF BENEFITS EVALUATION MODEL

Standard Systems (GTSS) are conceptualized around design points that cover the technology needs associated with known geothermal prospects.

For example, one important category of such systems is electricity-producing systems. For the current purposes the development and use of six model GTSSs for electricity production were postulated: flash systems for well-head temperatures of 180°C, 230°C, and 290°C, and binary systems for the same three temperatures. These six systems can be applied to about 85 percent of the estimated resources of useful geothermal fluids.⁽²⁾ These GTSSs would then be described and subdivided at the level of detail exemplified in Table I. The important elements of these descriptions are: (i) the major technical components, (ii) the capital costs of each component, and (iii) the operating and maintenance costs for each component.

It seems reasonable to use four major categories of standard systems. These are:

- (i) Exploration and Reservoir Assessment Activities - front end technical costs that cannot be directly associated with specific units of power production.
- (ii) Electric Systems - each designed to generate a net 50 megawatts of electricity (MWe).
- (iii) Nonelectric Systems - each delivering somewhere between 300 and 500 megawatts (thermal). This range is chosen because this is the approximate thermal power used to generate 50 MWe.

TABLE I
SYSTEM CHARACTERISTICS, CAPITAL AND O&M COSTS,
AND EQUIPMENT LIFETIMES FOR SELECTED HYDROTHERMAL
LIQUID-DOMINATED ELECTRICAL GENERATING SYSTEMS

	RESERVOIR TEMPERATURE AND UTILIZATION PLANT TYPE					
	180°C FLASH	230°C FLASH	290°C FLASH	180°C BINARY	230°C BINARY	290°C BINARY
Generator Rating (kw)	58,400	55,000	55,000	67,500	74,400	69,900
Net Plant Output (kw)	44,627	46,449	47,379	48,648	49,777	48,837
Net Plant Efficiency (%)	5.7	10.3	14.4	7.4	11.7	13.3
Plant Capital Cost (\$ (1976)/kw)	1380	720	520	1260	950	800
Percentage Breakdown of Capital Cost:						
1.0 Production	53.3	36.2	23.1	45.2	31.1	17.1
1.1 Wells	27.0	17.3	10.3	23.5	14.6	6.5
1.2 Gathering System	1.6	2.5	0.6	1.4	0.7	0.4
1.3 Process Mechanical	5.5	3.1	1.6	2.2	2.6	0.4
1.4 Instrumentation and Control	2.0	1.8	1.2	2.0	1.3	0.7
1.5 Waste Purification	1.2	0.8	0.6	1.2	0.7	0.6
1.6 Distribution System	1.7	0.7	0.6	1.4	1.1	0.5
1.7 Disposal Wells	9.4	6.7	6.2	9.4	7.3	6.5
1.8 Engineering and Administration	4.9	3.3	2.0	4.1	2.8	1.5
2.0 Generating Plant	46.7	63.8	76.9	54.8	68.9	82.9
2.1 Turbine Generator	18.6	21.4	24.9	9.5	14.0	15.2
2.2 Process Mechanical	1.6	2.5	3.3	5.6	5.8	9.6
2.3 Piping and Insulation	3.3	5.0	6.8	6.6	9.4	10.9
2.4 Instrumentation and Control	1.4	2.5	3.5	1.8	2.5	2.9
2.5 Electrical	1.8	3.1	4.3	2.1	3.0	3.4
2.6 Civil and Structural	8.3	12.9	14.0	6.8	9.7	11.3
2.7 Condenser and Heat Rejection	6.8	8.8	10.3	16.4	16.9	20.5
2.8 Switchyard	1.7	3.0	4.2	1.5	2.0	2.4
2.9 Engineering and Administration	3.2	4.6	5.6	4.5	5.6	6.7
3.0 Operations and Maintenance (% of capital cost per year)						
3.1 Materials and Supplies						
3.1.1 Production	0.053	0.036	0.023	0.045	0.031	0.017
3.1.2 Generating Plant	0.047	0.064	0.025	0.055	0.069	0.083
3.2 Manpower						
3.2.1 Production	0.053	0.036	0.023	0.045	0.031	0.017
3.2.2 Generating Plant	0.070	0.096	0.115	0.082	0.103	0.124
3.3 Well Maintenance						
3.3.1 Wells	*	*	*	*	*	*
3.3.2 Process Mechanical	1.540	---	---	1.320	1.300	---
3.4 Generating Plant Maintenance	0.234	0.319	0.385	0.660	0.805	1.021
3.5 Other Operations	*	*	*	*	*	*
4.0 Lifetimes (years)						
4.1 Wells	10	10	10	10	10	10
4.2 Production Plant	20	20	20	20	20	20
4.3 Generating Plant	30	30	30	30	30	30

* Dependent upon brine type.

- (iv) Environmental Protection Systems - modular in concept, to be added to systems of types (ii) and (iii) as necessary to control noncondensable gases, subsidence, scaling, etc.

Note that at the time of this writing the Benefits Model contains only the Second Category of GTSSs--Electric Systems. The other categories should be included as the component systems are defined.

The model specifies the number of each type of GTSS projected, on a prospect-specific basis, to come on line during two-year intervals. The GTSSs to be utilized will be matched to the characteristics of the specific prospects and regional needs for power. The model contains, for each two-year period between 1978 and 2000, the following data for each of 37 prospects:

- (i) Type of GTSS to be deployed on the prospect,
- (ii) Unit cost of the GTSS for the prospect, and
- (iii) Total cost of the units to be deployed in each period.

The tables that comprise the Benefits Model are attached as Appendix III-A. In sequence, the tables are:

1. Electric systems power-on-line scenario.
2. Prospect characteristics and unit costs.
3. Total cost per prospect per period, nondiscounted.
4. Total cost per prospect per period, discounted at 5 percent to 1977.
5. Electric systems wells-on-line scenario.

6. Well characteristics and unit costs.
7. Total well cost per prospect per period, nondiscounted.
8. Total well cost per prospect per period, discounted at 5 percent to 1977.
9. Discounting factors.

The well tables (Appendix III-A, Tables 5-8) consider a specific subset of the total technological scenario (Appendix III-A, Tables 1-4). A description of how each table was derived is included in the Appendix.

5.2 Procedure for Estimating Benefits

As mentioned above, to determine the benefits expected for a R&D subelement, the program manager calculates the cost savings that will occur if and when the product of the subelement replaces current technology. The components replaced could be an entire GTSS, one component of one GTSS, a number of components common to a number of GTSSs, and so forth.

The time at which the product of the subelement begins to be incorporated into commercial geothermal power applications, derived as explained in Section 3.0, is required to calculate benefits. This time controls the date at which projected GTSSs can be affected by the new technology. Cost savings will occur only for those GTSSs that are expected to come on line after that date, and the benefits calculated must reflect this. More intensive R&D, perhaps at higher total R&D costs, might deliver a product earlier to affect a larger proportion of the GTSSs to which the product applies.

The tradeoff between the time to complete the work of the subelement and the total benefit that can be realized is diagrammed in Figure 3. The curves in this figure show the fraction of the total number of GTSSs which, according to the power-on-line scenarios, remain to be installed during and after a certain year. A subelement technological product that can be commercially incorporated into GTSSs of type A within six years could be incorporated into about 65 percent of all such units. A product which is to be incorporated into GTSSs of type B would affect 65 percent of those units if commercialized 16 years from the start of the subelement. "Susceptibility curves" of this type can indicate to Program Managers how much R&D time is available in which to develop components that will impact on large proportions of anticipated installations of specific GTSSs.

In many cases, the savings achieved by the product of a subelement will be occasioned by the impact which that improved product component has on other kinds of components in the system. These are called the secondary impacts of technological improvements. For example, increased efficiency of a heat exchanging process might increase the heat-exchanger cost (a primary impact), but reduce the number of wells needed to drive one power plant (a secondary impact). A practical down-hole pump might increase the capital and O&M cost per well (primary), but reduce the number of wells needed (secondary) and reduce the size of the gathering systems (secondary). An increase in the durability of a drill bit, all other things being

*PRODUCT IMPACTING ON GTSS A REACHES COMMERCIALIZATION

FIGURE 3
TRADE-OFF BETWEEN NUMBER OF YEARS TO RD&D SUCCESS
AND MINIMUM ACHIEVABLE BENEFIT

equal, would reduce the number of bits needed (primary) and the number of drill string trips (secondary) and thus produce savings even if the new bit cost more than current bits (primary).

5.3 Predictions of Partial Success

The procedure described in Section 5.2 results in an estimate of the maximum possible benefits for the R&D subelement. This maximum benefit is based on the assumption that the performance goals specified for the product of the subelement will be realized. Because that ideal outcome will be achieved but rarely, only a fraction of the maximum benefit should be attributed to each R&D subelement.

Reductions in potential benefit might be caused by:

- (i) Low probability of technical success in early phases of R&D,
- (ii) Less than ideal performance of the developed component,
- (iii) Unanticipated efficiency-reducing interactions with other system components,
- (iv) Fractional market penetration, due to unanticipated factors.

The benefits estimation procedure provides a systematic approach for estimating such losses associated with each phase of R&D. These losses are estimated independently for each phase. The estimates are formulated as "degree of success expected for this phase," with values between 0.0 and 1.0. These estimates are then multiplied as if they were independent probabilities to estimate the final degree of success anticipated at the beginning of any specific phase.

6.0 FIGURE OF MERIT

The "figure of merit" (FOM) is proposed as the main parameter on which to base project selection.

6.1 Figure of Merit Calculation

The figure of merit is calculated as:

$$\text{FOM} = \frac{\text{Maximum Possible Benefit} \times \text{Degree of Success Expected From Start of Current Stage of R\&D Through Utilization}}{\text{R\&D Costs for Remaining Stages of R\&D}}$$

Sunk costs of the subelement are not included in the calculation in order to give selective advantage to subelements that are already in progress. Provision is made on the Benefit/Cost Evaluation Form for calculating a "historical" figure of merit (HFOM) that includes both sunk and budgeted costs.

6.2 Techniques for Handling Exceptional Cases

There are special situations that arise in the course of subelement selection. These include programs with very large funding requirements and those with low probability of complete success. Such programs may not be able to compete with other programs on the basis of the proposed figure of merit. If the probability of complete success is very low, it may be very risky to commit DGE's resources to the particular program subelement.

In such cases, the Program Manager should conduct (or arrange for) a preliminary study. If the preliminary study yields results that increase the expected degree of success of the program

subelement, the program subelement could turn out to be competitive on the basis of figure of merit. The preliminary study also might indicate that the expected degree of success would be lower and/or the cost would be higher than the original estimate. In this case, the program subelement may be discarded temporarily.

To identify the low expected degree of success, high cost projects, it would be necessary to:

- (i) Specify a lower bound on the expected degree of success for program subelements that are to be handled in the normal manner, provided they satisfy the cost constraint stated below,
- (ii) Place an upper bound on the cost of a program subelement that can be handled in the normal manner provided it satisfies the expected degree of success requirement stated above, and
- (iii) Set limits on the cost of preliminary studies, with approval needed at higher levels in the DGE organization as the cost of the study increases.

If there are significant doubts about the degree of success and/or benefits of a program subelement, the Program Manager should be asked to make a presentation to a screening committee of other Program Managers or technical experts. In this presentation the Program Manager must convince the panel that his estimates of the expected degree of success and benefits are realistic. The panel

members would then give estimates of the expected degree of success and benefits. These panel estimates could be used for generating an updated figure of merit for making decisions concerning program subelement selection.

Another special situation occurs with respect to projects and subelements that are already in progress. At predetermined check points or on an annual basis, ongoing program subelements will be evaluated for renewal/extension in accordance with the overall plans for the program subelement. The expected benefits, costs and the degree of success of each ongoing program will be reestimated at these check points.

The FOM for the balance of the program will be determined by using the revised benefits and the expected degree of success estimates. The cost used in the computation of the FOM will be the estimated cost of the balance of the subelement.

The exclusion of the already incurred costs (sunk costs) from the denominator of the FOM estimates will minimize the chance of a promising ongoing program subelement's being eliminated because of a low FOM. At the same time, if the expected benefits decrease, the expected degree of success decreases, and/or the estimated cost of the balance of the subelement increases sharply, the revised figure of merit for the subelement could turn out to be too low for the continuation of the program subelement.

7.0 FILLING OUT THE BENEFIT/COST EVALUATION FORM

7.1 General Instructions

The form should be filled out for each R&D subelement prior to seeking approval from DGE upper management for funding the subelement. An updated benefit/cost analysis and revised benefit/cost evaluation form should be prepared if any required reassessment of the subelement or its component projects indicates a sizable change in benefits, costs, or anticipated degree of success.

The suggested sequence for filling out the form is shown in Figure 4. The first page of the form (Items 1.0 through 5.0) is a summary of the results of the benefit/cost analysis. The remaining five pages of the form are worksheets for making and documenting estimates. In general, items on page 1 (the summary sheet) are filled out after the completion of associated items on the later pages.

An example of a completed benefit/cost analysis (for the Terra Tek Improved Geothermal Drill Bit project) is attached to this volume as Appendix III-B. The example illustrates the way in which one analysis was conducted. It also illustrates how the Benefit/Cost Evaluation Form should be filled out.

The remainder of this section consists of detailed instructions for the form. These should be read only if the Terra Tek example (Appendix III-B) leaves unanswered questions.

FIGURE 4
PROCESS FOR EVALUATING BENEFITS AND
COSTS FOR ONE R&D SUBELEMENT

7.2 Detailed Instructions

Item 1.0 is filled out first, by transferring the Technical Objective of the subelement from Item 6 of the R&D Concept Evaluation Form. The emphasis here is on a verbal description of what the subelement is intended to accomplish, in terms of developing new or improved geothermal energy system components or processes.

Item 6.0, the Subelement Development Plan, is filled out next. It consists of brief descriptions of the R&D work for each phase of the subelement. (Definitions of the kinds of work appropriate to each phase can be found in Section 4.0 of this volume, pp. 11-13). Separate blanks are provided for "Work" and "Evaluation", to account for time and costs required by routine or special evaluation of R&D products.

Consult the estimates made in Items 7 and 8 of the Concept Evaluation Form as guidance for the estimates to be made here. Once work and evaluation requirements are described, the number of calendar years required for each should be estimated and entered.

In the R&D costs column, actual costs are entered for completed phases, and budgeted or estimated costs are entered for future phases. Notation should be made (Yes/No) to indicate which phases have been completed. The grand totals are entered at the bottom of the page.

When Item 6.0 has been completed, the estimates are transferred to the appropriate blanks in Item 2.0, R&D Time and Costs Summary. At this point, sunk costs (those for completed work) are listed in

a different column from budgeted costs. Separate totals are made for budgeted and sunk costs. The time required for completed work is not entered in this Item; only the time required for unfinished work is entered. The time total thus is the number of calendar years between this benefit/cost evaluation and the time when the product of the subelement is expected to be commercialized.

The anticipated date of first commercial availability of the product is entered in blank 2d.

The next major step is to estimate the benefits expected from the subelement. This will often be a complex undertaking. It is suggested that final entries not be made in Section 7.0 until the benefits analysis for the subelement has been fairly well developed.

The benefits analysis consists of four steps:

1. Estimate the degree of improvement in component or process that is expected to result if the subelement is successful. Sources for this estimate include the proposer's estimate, laboratory test data, the Program Manager's estimate, and estimates based on engineering designs and analysis.

2. Devise a model for estimating how many dollars might be saved by using the R&D product in the context of specific geothermal prospects. The critical inputs to this model are: (a) the performance of the old technology, (b) the improved performance of the new technology, (c) the relative costs of the new and old technology, and (d) the characteristics of geothermal prospects that interact with

the technology. Existing models of geothermal wells, plants, and utilization processes should be used where available. The most important aspect of the model is that it be able to combine information about the technological change and known (or estimated) data about prospects, to derive a value of dollar savings per prospect.

3. Apply the model to each of the 37 prospects in the DGE power-on-line scenario to calculate the total savings to be expected between now and 2000 A.D. This is done by multiplying the savings per plant (or well) by the number of plants (or wells) to go on-line in each two-year period. The savings per period are discounted by 5 percent per year to emphasize the greater value of near-term benefits. The savings are further reduced by estimates of fractional market penetration in each period.

4. Fill out the benefits section (Item 7.0) of the Benefit/Cost Evaluation Form.

Section 7.1 of the B/C Form provides descriptions of the main inputs to the benefits calculation. This includes:

- (a) Description of the types of prospects to be affected.
- (b) Description of the technical subsystems or components to be affected. This should agree with Item 5 of the Concept Evaluation Form.
- (c) Estimate of expected quantitative improvement in performance of the affected components. This might be drawn from Items 6 and 8 of the Concept Evaluation form. However, it is

likely that additional study will be needed to make this estimate realistic.

(d) Cost of affected technological component or process.

The costs of both the new component and the components that it replaces or alters are entered here.

Section 7.2 of the form provides an explanation of the model used to calculate the savings expected at each prospect. In most cases extra pages will have to be attached to explain and document the model.

Section 7.3 is a worksheet for listing the parameters of the prospects that will affect the savings expected at each. Upon completion, the final column of this section should contain the dollar savings expected from each geothermal power plant or well at each prospect.

Section 7.4 is used to calculate the total savings expected across all prospects and time periods. Savings per unit, from Section 7.3, are entered in the first column. The remaining columns are filled by multiplying the savings per unit by the number of units expected to go on line in each period. The expected number of plants is found in Table 1 of Appendix II-A in this volume. The expected number of wells is found in Table 5, Appendix II-A.

Once the values are entered, sums are calculated for each period and entered in Total, Row a. These sums have to be discounted at 5 percent to the present year (1977 at this writing). Discounting

factors are given in Table 9 of Appendix III-A. The discounting factor for the first year of each period should be entered in Row b of Section 7.4. Row a is then multiplied by Row b to find the discounted savings, which are entered in Row c.

Row d provides spaces for the estimates of expected commercialization of the product. This is a factor between 0.0 and 1.00. It must be made equal to 0.0 during the periods when the product will not be ready for market, as defined in Item 2.0 d of the Benefit/Cost Evaluation Form. In estimating what share of the potential market will be captured by the product, thought should be given to the existence of competing products, the degree to which the improvement in the product will be apparent to its potential purchasers, the confidence of buyers in the producing firm, etc.

Row c is multiplied by Row d to derive the final estimate of benefits.

Rows a, c, and e are totalled. The totals are then entered in the appropriate blanks in Item 3.0 on page 1 of the Benefits/Cost Evaluation Form. This completes the work of estimating benefits.

The final estimates to be made are those of the relative degree of success of each phase of the subelement or project. These estimates are entered as numbers ranging from 0.00 to 1.00 in the first column of Item 8.0, page 6 of the form. Consult Section 5.3 of this volume for the kinds of factors that should be considered here.

The left column represents the degree of success estimated for each phase considered in isolation. The right column represents the overall degree of success expected from the subelement. For example, if the subelement being considered is to start at Phase 6.4 with an expected degree of success of 0.80, proceed through Phase 6.5 at 0.80, and terminate in a demonstration project (6.6) that produces 0.95 of its desired results, then the right column for Phase 6.6 would read 0.95, for Phase 6.5 would read 0.76 (0.95×0.80), and for Phase 6.4 would read 0.61 ($0.95 \times 0.80 \times 0.80$). The value 0.61 is taken to mean that of the maximum possible benefit at the start of Phase 6.4, 61 percent is deemed likely to be achieved.

This "current" overall degree of expected success is then entered in Item 4.0 of the Benefit/Cost Evaluation form.

The figure of merit is calculated next, in Item 5.0 of the form. Costs and benefits are both entered as \$ Millions. The figure of merit (FOM) does not include sunk costs. The "historical" figure of merit (HFOM) is included for comparative purposes.

Once the FOM has been calculated, it should be entered in Item 16 of the Concept Evaluation Form and Item 10 of the Subelement Status Monitoring Form. The R&D Costs, as estimated in Item 6.0, should be entered in Item 18, "Cost Plan", of the Contract Processing and Project Monitoring Form.

The final section of the Benefit/Cost Evaluation Form (Item 9.0, Review at End of Current Contract) is intended as input to deciding

whether a new B/C form should be filled out to justify continued funding of the project or subelement. If the expected performance of the product of the subelement has changed by plus or minus 50 percent, the subelement should probably be reevaluated, especially if the expected performance has decreased.

REFERENCES

1. Department of Defense Instruction, Number 7720.16. December 10, 1968.
2. Leigh, J. G., S.M.A. Pond, R.K. Trehan, "Cost-Benefit Analysis of the Federal Geothermal Energy Program," MTR-7326, The Mitre Corporation, Metrek Division, McLean, Virginia, 1977.

APPENDIX III-A

DATA TABLES FOR BENEFIT/COST ANALYSES

This Appendix presents nine tables of data for use in benefit/cost analyses. Tables A-I through A-IV depict the total cost of installing power at the 37 listed prospects. Tables A-V through A-VIII depict the costs of only the wells required.

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TABLE 1
ELECTRIC SYSTEMS POWER-ON-LINE SCENARIO

DEFINITION:

Table 1 contains the DGE projection of the number of 50 MW_e (net) power plants to come on line at each of 37 geothermal prospect areas in the years 1979-2000. Years are presented as two-year periods. Fractional entries represent plants of less than 50 MW_e net power.

REFERENCE:

A. Cohen, W. Jacobsen, J. Leigh, R. Trehan, "Site-Specific Analysis of Geothermal Development--Scenarios and Requirements," MTR-7586, Volume II, The Mitre Corporation/Metrek Division, McLean, Virginia, 1978.

TABLE A-I
ELECTRIC SYSTEMS POWER-ON-LINE SCENARIO

PROSPECT	TIME PERIODS											TOTAL
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	
	1979 -80	1981 -82	1983 -84	1985 -86	1987 -88	1989 -90	1991 -92	1993 -94	1995 -96	1997 -98	1999 -2000	
Geysers, CA (Steam)	9	9	8	2	--	--	--	--	--	--	--	28
Brazoria, TX	--	--	--	0.5	2	6	8	8	20	--	--	44.5
Salton Sea, CA	--	--	1	3.5	3.5	4	4	4	4	4	4	32
Valles Caldera, NM	--	--	1	2	2	2	4	4	4	4	4	27
Brady Hot Springs, NV	--	--	1	1	2	2	4	4	4	2	--	20
Brawley, CA	--	--	1	1	4	4	4	4	2	--	--	20
Roosevelt Hot Springs, UT	--	--	1	1	1	2	4	4	4	3	--	20
Beowawe, NV	--	--	1	1	1	2	4	4	4	3	--	20
Coso Hot Springs, CA	--	--	--	2	4	6	--	--	--	--	--	12
Mono-Long Valley, CA	--	--	--	1	2	2	--	--	--	--	--	5
Cove Fort-Sulfurdale, UT	--	--	--	1	1	2	4	4	4	4	4	24
Heber, CA	--	--	--	1	1	4	4	4	--	--	--	14
Geysers, CA (Hydrothermal)	--	--	--	4	4	4	4	4	--	--	--	20
East Mesa, CA	--	--	--	1	1	--	--	--	--	--	--	2
Steamboat Springs, NV	--	--	--	1	1	2	--	--	--	--	--	4
Surprise Valley, CA	--	--	--	1	1	4	4	4	4	4	4	26
Chandler, AZ	--	--	--	1	--	2	1	--	--	--	--	4
Leach, NV	--	--	--	--	1	1	4	4	4	4	4	22
Calcasieu Parish, LA	--	--	--	--	1	1	3	2	--	--	--	7
Bruneau-Grandview, ID	--	--	--	--	1	2	4	4	4	4	4	23
Lassen, CA	--	--	--	--	1	1	--	--	--	--	--	2
Kenedy County, TX	--	--	--	--	1	1	2	2	--	--	--	6
Alvord, OR	--	--	--	--	1	1	2	2	--	--	--	6
Matagorda County, TX	--	--	--	--	1	1	2	2	4	--	--	10
Cameron Parish, LA	--	--	--	--	1	1	2	2	2	2	--	10
Acadia Parish, LA	--	--	--	--	1	1	2	3	--	--	--	7
Corpus Christi, TX	--	--	--	--	1	1	2	3	4	4	6	21
Safford, AZ	--	--	--	--	1	--	--	--	1	--	--	2
Weiser-Crane Creek, ID	--	--	--	--	1	2	4	4	4	4	2	21
Vale Hot Springs, OR	--	--	--	--	1	1	2	2	2	2	2	12
Thermo, UT	--	--	--	--	1	--	2	4	3	--	--	10
Raft River, ID	--	--	--	--	1	1	--	--	--	--	--	2
Glass Mountain, CA	--	--	--	--	--	1	--	--	--	--	--	1
Puna, HI	--	--	--	--	--	2	8	8	2	--	--	20
Mt. Hood, OR	--	--	--	--	--	1	--	--	--	--	--	1
Baker Hot Springs, WA	--	--	--	--	--	1	--	--	--	--	--	1
West Yellowstone, MT	--	--	--	--	--	1	--	--	--	--	--	1
TOTAL	9	9	14	25	45.5	69	88	90	80	44	34	507.5

TABLE A-II
PROSPECT CHARACTERISTICS AND UNIT COSTS (\$ MILLIONS, 1977)

DEFINITION:

Table A-II is a list of data and estimates of important characteristics of the 37 geothermal prospects and of the power plants that are projected to be used to generate electricity at those prospects. The listed costs are for plants of 50 MW_e (net) installed capacity.

DERIVATION:

For prospects where no footnote is made in Table A-II, prospect characteristics and plant costs were taken from a computerized model of the cost prepared by Gupta, et. al., Reference 1. For footnoted prospects, prospect characteristics were taken from an analysis by Friedman and El-Sawy, Reference 2, except as explained in Footnote 3.

To facilitate the manual computation of benefits, O&M costs are included as if they are capitalized at the time when each plant comes on line, assuming a plant life of 30 years and a discount rate of 5%. This implicitly assumes, for present purposes, that the O&M costs for a particular plant will not be affected by R&D that is completed after that plant has been constructed. This assumption does not take into account potential improvements that might occur in the technology used to drill and complete replacement wells. From a table of present worth factors for the sum of a uniform annual series of costs,

$$\text{Capitalized O\&M Costs} = 13.41 \times \text{Annual O\&M costs in year 1.}$$

A-7

PROSPECT		FIRST PLANT ON LINE	CYCLE TEMPERATURE, °C	CYCLE TYPE	A. PRODUCER CAPITAL	B. UTILITY CAPITAL	C. TOTAL CAPITAL	D. PRODUCER ANNUAL O&M	E. UTILITY ANNUAL O&M	F. TOTAL ANNUAL O&M	G. CAPITALIZED O&M (= 13.41 x F)	H. TOTAL COSTS (= C+G)
	(Notes)											
Geysers, CA (Steam)	(6)	--	240	STEAM	9.16	16.15	25.31	0.38	0.17	0.55	7.37	32.68
Brazoria, TX	(2)	1986	146	BINARY	198.20	50.80	249.00	1.38	1.45	2.83	37.95	286.95
Salton Sea, CA	(1)	1983	340	FLASH	9.74	20.27	30.01	0.56	0.61	1.17	15.68	45.69
Valles Caldera, NM		1983	240	FLASH	42.99	24.44	67.43	0.58	0.71	1.29	17.29	84.72
Brady Hot Springs, NV		1983	214	FLASH	43.13	27.10	70.23	0.57	0.76	1.33	17.83	88.06
Brawley, CA	(1)	1983	260	FLASH	26.95	23.08	50.04	0.81	0.69	1.50	20.11	70.15
Roosevelt Hot Springs, UT		1983	230	FLASH	23.36	25.31	48.68	0.30	0.73	1.03	13.81	62.49
Beowawe, NV		1983	240	FLASH	43.00	24.44	67.44	0.58	0.71	1.29	17.29	84.73
Coso Hot Springs, CA		1985	220	FLASH	37.22	26.37	63.59	0.49	0.77	1.26	16.89	80.48
Mono-Long Valley, CA		1985	220	FLASH	37.22	26.37	63.59	0.49	0.77	1.26	16.89	80.48
Cove Fort-Sulfurdale, UT		1985	200	BINARY	70.47	37.21	107.68	1.66	1.34	3.00	40.23	147.91
Heber, CA		1983	190	BINARY	43.36	37.57	80.93	1.33	1.35	2.68	35.93	116.86
Geysers, CA (Hydrothermal)	(3)	1985	200	BINARY	90.45	35.44	125.90	1.89	1.28	3.17	42.46	168.36
East Mesa, CA		1985	180	BINARY	50.48	40.00	88.48	1.48	1.36	2.84	38.08	126.56
Steamboat Springs, NV		1985	210	FLASH	27.67	27.64	55.31	0.37	0.80	1.17	15.68	70.99
Surprise Valley, CA		1986	175	BINARY	71.77	38.24	110.01	1.81	1.37	3.18	42.64	152.65
Chandler, AZ		1986	178	BINARY	114.41	38.09	152.50	2.35	1.36	3.71	49.75	202.25
Leach, NV		1987	170	BINARY	168.04	38.50	206.54	3.14	1.38	4.52	60.61	267.15
Calcasieu Parish, LA	(2)	1987	156	BINARY	198.20	50.80	249.00	1.38	1.45	2.83	37.95	286.95
Bruneau-Grandview, ID		1987	210	BINARY	80.59	36.90	117.49	1.76	1.33	3.09	41.43	158.92
Lassen, CA		1987	240	FLASH	29.16	24.44	53.60	0.39	0.71	1.10	14.75	68.35
Kenedy County, TX	(2)	1987	168	BINARY	198.20	50.80	249.00	1.38	1.45	2.83	37.95	286.95
Alvord, OR		1987	200	BINARY	106.88	37.21	144.09	2.14	1.34	3.48	46.66	190.75
Matagorda County, TX	(2)	1987	146	BINARY	198.20	50.80	249.00	1.38	1.45	2.83	37.95	286.95
Cameron Parish, LA	(2)	1987	140	BINARY	198.20	50.80	249.00	1.38	1.45	2.83	37.95	286.95
Acadia Parish, LA	(2)	1987	164	BINARY	198.20	50.80	249.00	1.38	1.45	2.83	37.95	286.95
Corpus Christi, TX	(2)	1987	169	BINARY	198.20	50.80	249.00	1.38	1.45	2.83	37.95	286.95
Safford, AZ		1987	210	BINARY	80.59	36.90	117.49	1.76	1.33	3.09	41.43	158.92
Weiser-Crane Creek, ID		1988	160	BINARY	98.92	39.12	138.04	2.32	1.40	3.72	49.88	187.92
Vale Hot Springs, OR		1988	160	BINARY	69.34	39.12	108.46	1.92	1.40	3.32	44.52	152.98
Thermo, UT		1988	200	BINARY	58.34	37.21	95.55	1.49	1.34	2.83	37.95	133.50
Raft River, ID		1988	140	BINARY	132.26	40.82	173.08	3.17	1.46	4.63	62.08	235.16
Glass Mountain, CA		1988	210	FLASH	86.81	27.65	114.47	1.15	0.81	1.96	26.28	140.75
Puna, HI		1990	356	FLASH	22.63	19.97	42.60	0.30	0.59	0.89	11.93	54.53
Mt. Hood, OR	(4)	1990	125									
Baker Hot Springs, WA		1990	165	BINARY	187.52	38.79	226.31	3.45	1.40	4.85	65.03	291.34
West Yellowstone, MT	(5)	1990

REFERENCES:

1. J. Gupta, J. Leigh, and R. Trehan, "Estimated Costs of Electric Power from Twenty-Six U. S. Liquid Dominated Hydrothermal Prospects," WP-12644, The Mitre Corporation/Metrek Division, McLean, Virginia, 1977.
2. E.J. Friedman and A. El-Sawy, "Prospects for Improvements in Geothermal Well Technology and Their Expected Benefits," MTR-7613, The Mitre Corporation/Metrek Division, McLean, Virginia, 1977.

FOOTNOTES:

- (1) The first plant at Salton Sea, CA, and at Brawley, CA, might be either binary cycle or flash cycle. Flash cycle is assumed here for all plants at these two locations because it is significantly less costly than the comparative binary cycle plant.
- (2) All geopressured sites have the same cost estimates, based on the report of Brown and Root, Inc., "Gulf Coast Geopressured Geothermal Energy Study," Proceedings of Second Geothermal Energy Conference, Volume III, Surface Technology and Resource Utilization, The University of Texas at Austin (1976).
- (3) For lack of other information, the resource temperature for The Geysers (hydrothermal) was assumed to be somewhat (40°C) lower than that for The Geysers (steam).
- (4) Costs for Mt. Hood were not estimated because the estimated resource temperature, 125°C, exceeds the lower bound of the Metrek Geothermal Plant Costs model.
- (5) Costs for West Yellowstone were not estimated because an estimate of the resource temperature was not available.
- (6) Costs estimated from a communication from Pacific Gas and Electric and from T. Larsen, "The Costs of Geothermal Energy Development," Geothermal Energy, Volume 5, #3, March 1977.

TABLE A-III
TOTAL COST PER PROSPECT PER PERIOD, NON-DISCOUNTED (\$ MILLIONS, 1977)

DEFINITION:

A projection of the cost of all geothermal electric power plants projected to be installed in the U.S.A. between 1979 and 2000, on a prospect-specific basis. The values listed are 1977 dollars. Operating and Maintenance (O&M) costs are included by assuming that they are capitalized in the year each power plant goes on line.

DERIVATION:

The costs listed in Table A-III are the product of the cost per 50 MW_e plant (from Table A-II) and the number of plants per prospect per time period (from Table A-I).

TABLE A-III

TOTAL COST PER PROSPECT PER PERIOD, NON-DISCOUNTED
(\$ MILLIONS, 1977)

PROSPECT	TIME PERIODS											TOTAL
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	
	1979 -80	1981 -82	1983 -84	1985 -86	1987 -88	1989 -90	1991 -92	1993 -94	1995 -96	1997 -98	1999 -2000	
Geysers, CA (Steam)	294	294	261	65	--	--	--	--	--	--	--	915
Brazoria, TX	--	--	--	143	574	1722	2296	2296	5739	--	--	12770
Salton Sea, CA	--	--	46	160	160	183	183	183	183	183	183	1462
Valles Caldera, NM	--	--	85	169	169	169	339	339	339	339	339	2287
Brady Hot Springs, NV	--	--	88	88	176	176	352	352	352	176	--	1761
Brawley, CA	--	--	70	70	281	281	281	281	140	--	--	1403
Roosevelt Hot Springs, UT	--	--	62	62	62	125	250	250	250	187	--	1250
Beowawe, NV	--	--	85	85	85	169	339	339	339	254	--	1695
Coso Hot Springs, CA	--	--	--	161	322	483	--	--	--	--	--	966
Mono-Long Valley, CA	--	--	--	80	161	161	--	--	--	--	--	402
Cove Fort-Sulfurdale, UT	--	--	--	148	148	296	592	592	592	592	--	3550
Heber, CA	--	--	--	117	117	467	467	467	--	--	--	1636
Geysers, CA (Hydrothermal)	--	--	--	673	673	673	673	673	--	--	--	3367
East Mesa, CA	--	--	--	127	127	--	--	--	--	--	--	253
Steamboat Springs, NV	--	--	--	71	71	142	--	--	--	--	--	284
Surprise Valley, CA	--	--	--	153	153	611	611	611	611	611	611	3969
Chandler, AZ	--	--	--	202	--	405	202	--	--	--	--	809
Leach, NV	--	--	--	--	267	267	1069	1069	1069	1069	1069	5877
Calcasieu Parish, LA	--	--	--	--	287	287	861	574	--	--	--	2009
Bruneau-Grandview, ID	--	--	--	--	159	318	636	636	636	636	636	3655
Lassen, CA	--	--	--	--	68	68	--	--	--	--	--	137
Kenedy County, TX	--	--	--	--	287	287	574	574	--	--	--	1722
Alvord, OR	--	--	--	--	191	191	382	382	--	--	--	1145
Matagorda County, TX	--	--	--	--	287	287	574	574	1148	--	--	2870
Cameron Parish, LA	--	--	--	--	287	287	574	574	574	574	--	2870
Acadia Parish, LA	--	--	--	--	287	287	574	861	--	--	--	2009
Corpus Christi, TX	--	--	--	--	287	287	574	861	1148	1148	1722	6027
Safford, AZ	--	--	--	--	159	--	--	--	159	--	--	318
Weiser-Crane Creek, ID	--	--	--	--	188	376	752	752	752	752	376	3946
Vale Hot Springs, OR	--	--	--	--	153	153	306	306	306	306	306	1836
Thermo, UT	--	--	--	--	134	--	267	534	401	--	--	1335
Raft River, ID	--	--	--	--	235	235	--	--	--	--	--	470
Glass Mountain, CA	--	--	--	--	--	141	--	--	--	--	--	141
Puna, HI	--	--	--	--	--	109	436	436	109	--	--	1091
Mt. Hood, OR	--	--	--	--	--	--	--	--	--	--	--	--
Baker Hot Springs, WA	--	--	--	--	--	291	--	--	--	--	--	291
West Yellowstone, MT	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	294	294	697	2576	6554	9934	14161	14513	14844	6825	5832	76524

TABLE A-IV
TOTAL COST PER PROSPECT PER PERIOD, DISCOUNTED AT 5% TO 1977

DEFINITION:

Cost projection from Table A-III discounted to 1977 at a rate of 5%.

DERIVATION:

Costs from each two-year period are discounted to 1977 as if they were incurred at the start of the period. For example, \$1000 incurred in the 1980-81 period is discounted over three years to a present worth of \$864.

$$\$1000 \times \frac{1}{(1.05)^3} = \$864$$

TABLE A-IV

TOTAL COST PER PROSPECT PER PERIOD, DISCOUNTED AT 5% TO 1977

PROSPECT	TIME PERIODS											TOTAL
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	
	1979 -80	1981 -82	1983 -84	1985 -86	1987 -88	1989 -90	1991 -92	1993 -94	1995 -96	1997 -98	1999 -2000	
Geysers, CA (Steam)	267	242	195	44	--	--	--	--	--	--	--	748
Brazoria, TX	--	--	--	97	352	959	1159	1051	2387	--	--	6007
Salton Sea, CA	--	--	34	105	98	101	92	84	76	69	63	723
Valles Caldera, NM	--	--	63	115	104	94	171	155	141	128	116	1087
Brady Hot Springs, NV	--	--	66	60	108	98	178	161	147	66	--	884
Brawley, CA	--	--	52	47	172	156	142	129	58	--	--	757
Roosevelt Hot Springs, UT	--	--	47	42	38	70	126	114	104	71	--	612
Beowawe, NV	--	--	63	57	52	94	171	155	141	96	--	830
Coso Hot Springs, CA	--	--	--	109	198	269	--	--	--	--	--	576
Mono-Long Valley, CA	--	--	--	54	99	90	--	--	--	--	--	243
Cove Fort-Sulfurdale, UT	--	--	--	100	91	165	299	271	246	223	202	1597
Heber, CA	--	--	--	79	72	260	236	214	--	--	--	861
Geysers, CA (Hydrothermal)	--	--	--	456	200	182	165	149	--	--	--	1893
East Mesa, CA	--	--	--	86	78	--	--	--	--	--	--	163
Steamboat Springs, NV	--	--	--	48	44	79	--	--	--	--	--	171
Surprise Valley, CA	--	--	--	103	94	340	308	280	254	230	208	1818
Chandler, AZ	--	--	--	137	--	225	102	--	--	--	--	464
Leach, NV	--	--	--	--	164	149	540	489	445	403	365	2555
Calcasieu Parish, LA	--	--	--	--	176	160	435	263	--	--	--	1034
Bruneau-Grandview, ID	--	--	--	--	98	177	321	291	264	240	217	1608
Lassen, CA	--	--	--	--	42	38	--	--	--	--	--	80
Kenedy County, TX	--	--	--	--	176	160	290	263	--	--	--	889
Alvord, OR	--	--	--	--	117	106	193	175	--	--	--	591
Matagorda County, TX	--	--	--	--	176	160	290	263	477	--	--	1366
Cameron Parish, LA	--	--	--	--	176	160	290	263	239	216	--	1344
Acadia Parish, LA	--	--	--	--	176	160	290	394	--	--	--	1020
Corpus Christi, TX	--	--	--	--	176	160	290	394	477	433	589	2519
Safford, AZ	--	--	--	--	98	--	--	--	66	--	--	164
Weiser-Crane Creek, ID	--	--	--	--	115	209	380	344	313	283	129	1773
Vale Hot Springs, OR	--	--	--	--	94	85	155	140	127	115	105	821
Thermo, UT	--	--	--	--	82	--	135	245	167	--	--	628
Raft River, ID	--	--	--	--	144	131	--	--	--	--	--	275
Glass Mountain, CA	--	--	--	--	--	78	--	--	--	--	--	78
Puna, HI	--	--	--	--	--	61	230	200	45	--	--	536
Mt. Hood, OR	--	--	--	--	--	--	--	--	--	--	--	--
Baker Hot Springs, WA	--	--	--	--	--	162	--	--	--	--	--	162
West Yellowstone, MT	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL	267	242	520	1741	4024	5533	7162	6647	6175	2573	1993	36877

TABLE A-V
ELECTRIC SYSTEMS WELLS-ON-LINE SCENARIO

DEFINITION:

Table A-V is a projection, prepared by Mitre/Metrek, of the number of geothermal wells required to support the geothermal electric plants postulated in Table A-I. The scenario includes exploratory, production, reinjection, and replacement wells required in each time period between 1979 and 2000 at each of 37 prospects.

DERIVATION:

The number of wells per prospect is based on the assumptions and results of the analysis by E.J. Friedman and A. El-Sawy, "Prospects for Improvements in Geothermal Well Technology and Their Expected Benefits", MTR-7613, The Mitre Corporation/Metrek Division, McLean, Virginia, 1977.

TABLE A-V

ELECTRIC SYSTEMS WELLS-ON-LINE SCENARIO

PROSPECT	TIME PERIODS											TOTAL
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	
	1979 -80	1981 -82	1983 -84	1985 -86	1987 -88	1989 -90	1991 -92	1993 -94	1995 -96	1997 -98	1999 -2000	
Geysers, CA (Steam)	130	121	66	46	46	46	46	46	46	46	46	685
Brazoria, TX	--	10	35	131	276	516	548	1290	158	176	176	3316
Salton Sea, CA	--	17	35	38	45	49	46	49	53	45	25	402
Valles Caldera, NM	--	21	39	41	50	86	96	104	114	132	58	741
Brady Hot Springs, NV	--	27	31	55	65	115	124	132	95	60	60	764
Brawley, CA	--	15	22	54	57	61	60	41	24	24	24	382
Roosevelt Hot Springs, UT	--	18	20	21	41	69	73	79	61	37	28	447
Beowawe, NV	--	21	23	24	47	82	92	100	83	43	44	559
Cost Hot Springs, CA	10	5	50	93	130	26	34	34	34	34	34	484
Mono-Long Valley, CA	10	--	25	47	48	11	14	14	14	14	14	211
Cove Fort-Sulfurdale, UT	10	--	24	31	52	93	104	115	125	125	60	739
Heber, CA	--	--	28	37	110	119	121	41	44	44	44	588
Geysers, CA (Hydrothermal)	5	5	76	81	86	92	97	26	26	26	26	546
East Mesa, CA	--	--	32	31	6	8	8	8	8	8	8	117
Steamboat Springs, NV	10	--	28	32	52	11	12	12	12	12	12	193
Surprise Valley, CA	--	10	35	42	136	150	168	184	202	208	105	1240
Chandler, AZ	--	10	28	7	65	36	16	16	16	16	16	226
Leach, NV	--	10	--	39	48	152	170	189	209	217	101	1135
Calcasieu Parish, LA	--	10	--	65	74	191	136	28	28	28	28	588
Bruneau-Grandview, ID	--	10	--	24	50	91	101	112	123	123	57	691
Lassen, CA	--	10	--	21	18	3	4	4	4	4	4	72
Kenedy County, TX	--	10	--	65	74	136	134	22	24	24	24	513
Alvord, OR	--	10	--	24	31	51	57	14	16	16	16	235
Matagorda County, TX	--	10	--	65	74	136	144	262	36	40	40	807
Cameron Parish, LA	--	10	--	65	74	136	144	147	150	40	40	806
Acadia Parish, LA	--	10	--	65	74	136	194	24	28	28	28	587
Corpus Christi, TX	--	10	--	65	74	136	204	274	290	416	76	1545
Safford, AZ	--	10	--	19	2	2	7	21	6	6	6	79
Weiser-Crane Creek, ID	--	--	10	47	97	190	214	238	257	192	126	1371
Vale Hot Springs, OR	--	--	10	47	55	103	115	127	139	141	69	806
Thermo, UT	--	--	10	19	6	50	91	72	25	26	26	325
Raft River, ID	--	--	5	81	82	18	22	22	22	22	22	296
Glass Mountain, CA	--	--	--	10	24	2	4	4	4	4	4	56
Puna, HI	--	--	--	10	34	108	114	49	32	32	32	411
Mt. Hood, OR	--	--	--	10	72	5	10	10	10	10	10	137
Baker Hot Springs, WA	--	--	--	10	38	3	6	6	6	6	6	81
West Yellowstone, MT	--	--	--	10	72	5	10	10	10	10	10	137
TOTAL	175	390	632	1572	2485	3224	3540	3926	2534	2435	1505	22418

TABLE A-VI
WELL CHARACTERISTICS AND UNIT COSTS

DEFINITION:

Table A-VI contains data and estimates of a few main parameters and of projected costs for single geothermal wells at each of 37 prospects. Costs are expressed in 1977 dollars.

DERIVATION:

The cost of wells is taken from the Mitre/Metrek report, "Prospects for Improvements in Geothermal Well Technology and Their Expected Benefits", MTR-7613, 1977. Where that report listed different costs for extraction and injection wells, those costs were averaged into the single value used here.

TABLE A-VI

WELL CHARACTERISTICS AND UNIT COSTS

PROSPECT	WELL DEPTH (KM)	ROCK HARDNESS	RESOURCE TEMPERATURE (°C)	COST PER WELL (\$1000, 1977)
Geysers, CA (Steam)	2.5	M	240	1003
Brazoria, TX	4.5	S	146	1962
Salton Sea, CA	1.5	S	340	400
Valles Caldera, NM	1.5	H	240	984
Brady Hot Springs, NV	1.0	H	214	656
Brawley, CA	2.0	S	260	400
Roosevelt Hot Springs, UT	1.3	M-H	230	533
Beowawe, NV	1.5	H	240	984
Coso Hot Springs, CA	1.5	M-H	220	615
Mono-Long Valley, CA	1.5	M-H	220	615
Cove Fort-Sulfurdale, UT	2.0	M-H	200	1269
Heber, CA	1.5	S	190	500
Geysers, CA (Hydrothermal)	2.5	M-H	200	1782
East Mesa, CA	1.5	S	180	500
Steamboat Springs, NV	0.8	M-H	210	328
Surprise Valley, CA	1.5	M-H	175	769
Chandler, AZ	2.5	M	178	1425
Leach, NV	2.5	M-H	170	1782
Calcasieu Parish, LA	4.5	S	156	1962
Bruneau-Grandview, ID	2.5	M-H	210	1782
Lassen, CA	1.5	M-H	240	615
Kenedy County, TX	4.5	S	168	2590
Alvord, OR	2.0	H	200	2031
Matagorda County, TX	4.5	S	146	1962
Cameron Parish, LA	4.5	S	140	2662
Acadia Parish, LA	4.5	S	164	1962
Corpus Christi, TX	4.5	S	169	2000
Safford, AZ	2.5	M-H	210	1782
Weiser-Crane Creek, ID	1.5	M-H	160	679
Vale Hot Springs, OR	1.5	S	160	492
Thermo, UT	2.0	M	200	1016
Raft River, ID	2.0	S	140	758
Glass Mountain, CA	2.5	M-H	210	1426
Puna, HI	2.5	H	356	2281
Mt. Hood, OR	1.5	M	125	615
Baker Hot Springs, WA	2.5	M-H	165	1782
West Yellowstone, MT	2.5	S	--	912

TABLE A-VII
TOTAL WELL COST PER PERIOD, NON-DISCOUNTED (\$ MILLIONS, 1977)

DEFINITION:

A projection of the cost of all wells listed in the Electric Systems Wells-On-Line Scenario (Table A-V).

DERIVATION:

The values in Table A-VII were calculated by multiplying the cost per well at each prospect (Table A-VI) by the number of wells expected per time period and prospect (Table A-V).

TABLE A-VII

TOTAL WELL COST PER PERIOD, NON-DISCOUNTED
(\$ MILLIONS, 1977)

PROSPECT	TIME PERIODS											TOTAL
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	
	1979 -80	1981 -82	1983 -84	1985 -86	1987 -88	1989 -90	1991 -92	1993 -94	1995 -96	1997 -98	1999 -2000	
Geysers, CA (Steam)	130.4	121.4	66.2	46.1	46.1	46.1	46.1	46.1	46.1	46.1	46.1	687.1
Brazoria, TX	--	19.6	68.7	257.0	541.5	1012.4	1075.2	2531.0	310.0	345.3	345.3	6506.0
Salton Sea, CA	--	6.8	14.0	15.2	18.0	19.6	18.4	19.6	21.2	18.0	10.0	160.8
Valles Caldera, NM	--	20.7	38.4	40.3	49.2	84.6	94.5	102.3	112.2	129.9	57.1	729.1
Brady Hot Springs, NV	--	17.7	20.3	36.1	42.6	75.4	81.3	86.6	62.3	39.4	39.4	501.2
Brawley, CA	--	6.0	8.8	21.6	22.8	24.4	24.0	16.4	9.6	9.6	9.6	152.8
Roosevelt Hot Springs, UT	--	9.6	10.7	11.2	21.9	36.8	38.9	42.1	32.5	19.7	14.9	238.3
Beowawe, NV	--	20.7	22.6	23.6	46.2	80.7	90.5	98.4	81.7	42.3	43.3	550.1
Coso Hot Springs, CA	6.2	3.1	30.8	57.2	80.0	16.0	20.9	20.9	20.9	20.9	20.9	297.7
Mono-Long Valley, CA	6.2	--	15.4	28.9	29.5	6.8	8.6	8.6	8.6	8.6	8.6	129.8
Cove Fort-Sulfurdale, UT	12.7	--	30.5	39.3	66.0	118.0	132.0	145.9	158.6	158.6	76.1	937.8
Heber, CA	--	--	14.0	18.5	55.0	59.5	60.5	20.5	22.0	22.0	22.0	294.0
Geysers, CA (Hydrothermal)	8.9	8.9	135.4	144.3	153.3	163.9	172.9	46.3	46.3	46.3	46.3	973.0
East Mesa, CA	--	--	16.0	15.5	3.0	4.0	4.0	4.0	4.0	4.0	4.0	58.5
Steamboat Springs, NV	3.3	--	9.2	10.5	17.1	3.6	3.9	3.9	3.9	3.9	3.9	63.3
Surprise Valley, CA	--	7.7	26.9	32.3	104.6	115.4	129.2	141.5	155.3	160.0	80.7	953.6
Chandler, AZ	--	14.2	39.9	10.0	92.6	51.3	22.8	22.8	22.8	22.8	22.8	322.0
Leach, NV	--	17.8	--	69.5	85.5	270.9	302.9	336.8	372.4	386.7	180.0	2022.6
Calcasieu Parish, LA	--	19.6	--	127.5	145.2	374.7	266.8	54.9	54.9	54.9	54.9	1153.7
Bruneau-Grandview, ID	--	17.8	--	42.8	89.1	162.2	180.0	200.0	219.2	219.2	101.6	1231.4
Lassen, CA	--	6.2	--	12.9	11.1	1.8	2.5	2.5	2.5	2.5	2.5	44.3
Kenedy County, TX	--	25.9	--	168.4	191.7	352.2	347.1	57.0	62.2	62.2	62.2	1328.7
Alvord, OR	--	20.3	--	48.7	63.0	103.6	115.8	28.4	32.5	32.5	32.5	477.3
Matagorda County, TX	--	19.6	--	127.5	145.2	266.8	282.5	514.0	70.6	78.5	78.5	1583.3
Cameron Parish, LA	--	26.6	--	173.0	197.0	362.0	383.3	391.3	399.3	106.5	106.5	2145.6
Acadia Parish, LA	--	19.6	--	127.5	145.2	266.8	380.6	47.1	54.9	54.9	54.9	1151.7
Corpus Christi, TX	--	20.0	--	130.0	148.0	272.0	408.0	528.0	580.0	832.0	152.0	3090.0
Safford, AZ	--	17.8	--	33.9	3.6	3.6	12.5	37.4	10.7	10.7	10.7	140.8
Weiser-Crane Creek, ID	--	--	6.8	31.9	65.9	129.0	145.3	161.6	174.5	130.4	85.6	930.9
Vale Hot Springs, OR	--	--	4.9	23.1	27.1	50.7	56.6	62.5	68.4	69.4	33.9	396.6
Thermo, UT	--	--	10.2	16.3	6.1	50.8	92.5	73.2	25.4	26.4	26.4	330.2
Raft River, ID	--	--	3.8	61.4	62.2	13.6	16.7	16.7	16.7	16.7	16.7	224.4
Glass Mountain, CA	--	--	--	14.3	34.2	2.9	5.7	5.7	5.7	5.7	5.7	79.9
Puna, HI	--	--	--	22.8	77.6	246.4	260.0	111.8	73.0	73.0	73.0	937.5
Mt. Hood, OR	--	--	--	6.2	44.3	3.1	6.2	6.2	6.2	6.2	6.2	84.3
Baker Hot Springs, WA	--	--	--	17.8	67.7	5.3	10.7	10.7	10.7	10.7	10.7	144.3
West Yellowstone, MT	--	--	--	9.1	65.7	4.6	9.1	9.1	9.1	9.1	9.1	124.9
TOTAL	167.7	476.6	593.5	2072.2	3064.8	4861.5	5308.5	6011.8	3366.9	3285.6	1954.6	31154.7

TABLE A-VIII
TOTAL WELL COST PER PROSPECT PER PERIOD, DISCOUNTED AT 5% TO 1977

DEFINITION:

Cost projections from Table A-VII discounted to 1977 at a rate of 5%.

DERIVATION:

See Derivation for Table A-IV, this Appendix.

TABLE A-VIII

TOTAL WELL COST PER PROSPECT PER PERIOD, DISCOUNTED AT 5% TO 1977

PROSPECT	TIME PERIODS											TOTAL
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	
	1979 -80	1981 -82	1983 -84	1985 -86	1987 -88	1989 -90	1991 -92	1993 -94	1995 -96	1997 -98	1999 -2000	
Geysers, CA (Steam)	118.3	99.9	49.4	31.2	28.3	25.7	23.3	21.1	19.2	17.4	15.8	449.6
Brazoria, TX	--	16.1	51.3	173.9	332.4	563.7	543.1	1159.5	128.8	130.1	118.0	3216.9
Salton Sea, CA	--	5.6	10.4	10.3	11.1	10.9	9.3	9.0	8.8	6.8	3.4	85.6
Valles Caldera, NM	--	17.0	28.7	27.3	30.2	47.1	47.7	46.9	46.6	49.0	19.5	360.0
Brady Hot Springs, NV	--	14.6	15.2	24.4	26.2	42.0	41.1	39.7	25.9	14.8	13.5	257.4
Brawley, CA	--	4.9	6.6	14.6	14.0	13.6	12.1	7.5	4.0	3.6	3.3	84.2
Roosevelt Hot Springs, UT	--	7.9	8.0	7.6	13.4	20.5	19.6	19.3	13.5	7.4	5.1	122.3
Beowawe, NV	--	17.0	16.9	16.0	28.4	44.9	45.7	45.1	33.9	15.9	14.8	278.6
Coso Hot Springs, CA	5.6	2.6	23.0	38.7	49.1	8.9	10.6	9.6	8.7	7.9	7.1	171.8
Mono-Long Valley, CA	5.6	--	11.5	19.6	18.1	3.8	4.3	3.9	3.6	3.2	2.9	76.5
Cove Fort-Sulfurdale, UT	11.5	--	22.8	26.6	40.5	65.7	66.7	66.8	65.9	59.8	26.0	452.3
Heber, CA	--	--	10.4	12.5	33.8	33.1	30.6	9.4	9.1	8.3	7.5	154.7
Geysers, CA (Hydrothermal)	8.1	7.3	101.0	97.7	94.1	91.3	87.3	21.2	19.2	17.5	15.8	560.5
East Mesa, CA	--	--	11.9	10.5	1.8	2.2	2.0	1.8	1.7	1.5	1.4	34.8
Steamboat Springs, NV	3.0	--	6.9	7.1	10.5	2.0	2.0	1.8	1.6	1.5	1.3	37.7
Surprise Valley, CA	--	5.8	20.1	21.9	64.2	64.2	65.3	64.8	64.5	60.3	27.6	458.7
Chandler, AZ	--	11.7	29.8	6.8	56.8	28.6	11.5	10.4	9.5	8.6	7.8	181.5
Leach, NV	--	14.6	--	47.0	52.5	150.8	153.0	154.3	154.7	145.7	61.5	934.1
Calcasieu Parish, LA	--	16.1	--	86.3	89.1	208.6	134.8	25.1	22.8	20.7	18.8	622.3
Bruneau-Grandview, ID	--	14.6	--	29.0	54.7	90.3	90.9	91.6	91.1	82.6	34.7	579.5
Lassen, CA	--	5.1	--	8.7	6.8	1.0	1.3	1.1	1.0	0.9	0.9	26.8
Kenedy County, TX	--	21.3	--	114.0	117.7	196.1	175.3	26.1	25.8	23.4	21.3	721.0
Alvord, OR	--	16.7	--	33.0	38.7	57.7	58.5	13.0	13.5	12.2	11.1	254.4
Matagorda County, TX	--	16.1	--	86.3	89.1	148.6	142.7	235.5	29.3	29.6	26.8	804.0
Cameron Parish, LA	--	21.9	--	117.1	120.9	201.6	193.6	179.3	165.9	40.1	36.4	1076.8
Acadia Parish, LA	--	16.1	--	86.3	89.1	148.6	192.2	21.6	22.8	20.7	18.8	616.2
Corpus Christi, TX	--	16.5	--	88.0	90.9	151.4	206.1	241.9	241.0	313.6	52.0	1401.4
Safford, AZ	--	14.6	--	22.9	2.2	2.0	6.3	17.1	4.4	4.0	3.7	77.2
Weiser-Crane Creek, ID	--	--	5.1	21.6	40.5	71.8	73.4	74.0	72.5	49.1	29.3	437.3
Vale Hot Springs, OR	--	--	3.7	15.6	16.6	28.2	28.6	28.4	28.4	26.2	11.6	187.5
Thermo, UT	--	--	7.6	11.0	3.7	28.3	46.7	33.5	10.6	10.0	9.0	160.4
Raft River, ID	--	--	2.8	41.6	38.2	7.6	8.4	7.7	6.9	6.3	5.7	125.2
Glass Mountain, CA	--	--	--	9.7	21.0	1.6	2.9	2.6	2.4	2.2	1.9	44.3
Puna, HI	--	--	--	15.4	47.6	137.2	131.3	51.2	30.3	27.5	25.0	465.5
Mt. Hood, OR	--	--	--	4.2	27.2	1.7	5.1	2.8	2.6	2.3	2.1	46.0
Baker Hot Springs, WA	--	--	--	12.0	41.6	3.0	5.4	4.9	4.4	4.0	3.7	79.0
West Yellowstone, MT	--	--	--	6.2	40.3	2.6	4.6	4.2	3.8	3.4	3.1	68.2
TOTAL	152.1	384.0	443.1	1402.6	1881.3	2706.9	2681.3	2754.0	1398.9	1238.3	6681.1	15,710.6

TABLE IX
DISCOUNTING FACTORS

USE:

Present value of an amount is calculated by multiplying the benefit (or cost) expected in years from now by the tabular value under a selected discounting rate. For example, the 1977 present value of \$100 to be received in 1987, at the 5% rate, is $\$100 \times 0.6139$, or \$61.39.

TABLE A-IX
DISCOUNTING FACTORS

YEARS	DISCOUNTING RATE, %						
	3%	4%	5%	6%	7%	8%	10%
1	0.9709	0.9615	0.9524	0.9434	0.9346	0.9259	0.9091
2	0.9426	0.9246	0.9070	0.8900	0.8734	0.8573	0.8264
3	0.9151	0.8890	0.8638	0.8396	0.8163	0.7938	0.7513
4	0.8885	0.8548	0.8227	0.7921	0.7629	0.7350	0.6830
5	0.8626	0.8219	0.7835	0.7473	0.7130	0.6806	0.6209
6	0.8375	0.7903	0.7462	0.7050	0.6663	0.6302	0.5645
7	0.8131	0.7599	0.7107	0.6651	0.6227	0.5835	0.5132
8	0.7894	0.7307	0.6768	0.6274	0.5820	0.5403	0.4665
9	0.7664	0.7026	0.6446	0.5919	0.5439	0.5002	0.4241
10	0.7441	0.6756	0.6139	0.5584	0.5083	0.4632	0.3855
11	0.7224	0.6496	0.5847	0.5268	0.4751	0.4289	0.3505
12	0.7014	0.6246	0.5568	0.4970	0.4440	0.3971	0.3186
13	0.6810	0.6006	0.5303	0.4688	0.4150	0.3677	0.2897
14	0.6611	0.5775	0.5051	0.4423	0.3878	0.3405	0.2633
15	0.6419	0.5553	0.4810	0.4173	0.3624	0.3152	0.2394
16	0.6232	0.5339	0.4581	0.3936	0.3387	0.2919	0.2176
17	0.6050	0.5134	0.4363	0.3714	0.3166	0.2703	0.1978
18	0.5874	0.4936	0.4155	0.3503	0.2959	0.2502	0.1799
19	0.5703	0.4746	0.3957	0.3305	0.2765	0.2317	0.1635
20	0.5537	0.4564	0.3769	0.3118	0.2584	0.2145	0.1486
21	0.5375	0.4388	0.3589	0.2942	0.2415	0.1987	0.1351
22	0.5219	0.4220	0.3418	0.2775	0.2257	0.1839	0.1228
23	0.5067	0.4057	0.3256	0.2618	0.2109	0.1703	0.1117
24	0.4919	0.3901	0.3101	0.2470	0.1971	0.1577	0.1015
25	0.4776	0.3751	0.2953	0.2330	0.1842	0.1460	0.0923

APPENDIX III-B

BENEFIT/COST ANALYSIS OF THE
TERRA TEK IMPROVED GEOTHERMAL
DRILL BIT PROJECT

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1.0 INTRODUCTION

This Appendix describes an analysis of the Figure of Merit of one of the current R&D projects of the Division of Geothermal Energy, Department of Energy. While the analysis is intended to be technically accurate, the reader should note that the analysis was prepared for the primary purpose of illustrating to DGE staff an approach for estimating benefits to be expected from DGE R&D projects. Thus these pages describe one way in which expected benefits might be estimated for a particular project.

The analysis should not be construed to be either sophisticated or accurate with respect to either the technical or cost aspects of current geothermal drilling technology.

The project to be analyzed is Phase III of Terra Tek's work on improving the lifetime of unsealed bits at the higher than usual temperatures encountered in drilling geothermal wells. The analysis ignores the costs and benefits of some other work included in this project, namely the study of improved high temperature seals and lubricants.

The analysis is worded as if it were being done as input to the DGE decision to fund or not to fund the third year of the project. (Phase III was actually funded by DGE in April 1977.) The analysis is presented as if the author is a DGE Program Manager, making required estimates of expected improvements in technology, probability of technical success, etc.

The principal result to be derived is the amount of savings in well costs that might be expected if the Terra Tek project is successful. Savings are sought for wells to be drilled in the years 1978-2000 in the 37 geothermal prospect areas listed in the Geothermal Wells Scenario (see Volume III, Appendix III-A, Table 5), which supports the DGE power-on-line scenario.

The approach of the analysis consists of four steps:

1. Quantify the technical improvements in drill bit performance that will be realized if the project is successful.
2. Devise a model for estimating how many dollars might be saved by using the new bit to drill single wells of specific depth in geothermal prospects with a specific temperature and rock formation hardness.
3. Apply the model to each of the 37 prospects in the DGE power-on-line scenario to estimate the total savings to be expected between now and 2000 A.D.
4. Fill out the cost/benefit analysis form to derive a figure of merit for the project.

The analysis, as presented in the next sections is somewhat longer and more explicit than is required by DGE purposes, because tutorial comments are included. At the conclusion of the analysis, additional comments are made about alternative ways to calculate the benefits from this project.

2.0 QUANTIFICATION OF EXPECTED TECHNICAL IMPROVEMENTS

The Terra Tek "Improved Geothermal Drill Bit" is an unsealed tricone rotary bit of conventional geometric design. The "improvement" sought by this R&D project is an increased lifetime of the bit at the relatively high temperatures encountered during geothermal drilling.

Examination of the Terra Tek proposals for Phases I-III, and various progress reports from Phases I and II indicate that the following conditions appear to hold:

1. While drilling in the geothermal formation (hereinafter called "hot rock") at the Geysers, unsealed drill bits have about 1/5 of the lifetime expected when drilling in the colder rock encountered when drilling for oil.
2. Analysis of bits from the Geysers indicated that abrasive wear of the cone bearing races was the most common mode of failure of these bits. The temperatures to which the bits are exposed at the Geysers (about 240°C) are higher than the temperature used to anneal these conventional bits during manufacture (about 180°C). Consequently the hardness of the race surfaces decreases above 180°C, accelerating bearing race wear and premature failure.
3. The technical approach of the Terra Tek project is to select improved steels, and to anneal the steel at higher temperatures after carburizing the surfaces of the lug and cone.
4. Engineering tests of two "improved" bits during Phase II of the project indicates that bearing wear at 316°C is reduced to about 1/5 of that of conventional bits at that temperature. Consequently bearing life and bit life might be raised by a factor of 5 at 316°C.
5. The annealing temperature was 316°C for these bits. It can consequently be assumed that the improved bit will begin to lose its hardness at that temperature.

———— LIFE OF CONVENTIONAL BIT
- - - - - LIFE OF TERRA TEK MKII BIT

FIGURE B-1
INFERRED RELATIONSHIP BETWEEN BIT BEARING LIFE
AND DRILLING TEMPERATURE

These facts and assumptions were combined to infer the most likely relationship between bit bearing life and drilling temperature, as shown in Figure B-1. The solid curve indicates relative lifetime of bearings for conventional bits, the dashed line for the Terra Tek bit.

The curve was constructed as follows:

- Point A - Estimated lifetime of conventional unsealed bits at The Geysers (240°C) relative to expected lifetime at lower temperatures. (From Terra Tek Phase I proposal)
- Point B - Bearing wear on conventional bits relative to Terra Tek bits in tests in April 1977. (Note: Additional tests in August 1977 gave about the same result).
- Point C - Assumed relative lifetime point for conventional bits. Point C is the numerical average of points A and B.
- Point D - Annealing temperature for conventional bits (180°C). Conventional bit lifetime is assumed to begin to degrade linearly toward point C, starting at point D.
- Point E - Point at which Terra Tek bit lifetime is assumed to begin to degrade (280°C). This point could be set at 316°C (the temperature of the tests), but was reduced to the same temperature as Point C to be conservative in this analysis.
- Line F - The slope of temperature-related degradation of Terra Tek bit lifetime is assumed (for lack of better information) to be the same as the slope for the conventional bit (Line C-D).
- Line C-B: It was assumed that there was some limit to the degradation in life time of either type of bit. (This was done for computational convenience, rather than because of some assumed physical reality.)

It was further assumed that bit life is directly proportional to bearing life. It should be recognized that the Terra Tek engineering

test data on which Figure B-1 is based are quite limited, but are nonetheless the best data available.

3.0 MODEL FOR SAVINGS PER SINGLE WELL IN SPECIFIC GEOTHERMAL RESOURCE AREA

The model has to predict the dollar savings that would occur if the improved bit were used to drill a geothermal well of specific depth, formation hardness, and resource temperature. Because the economic basis of the model has to be consistent with the "cost of wells" portion of the power-on-line scenario, the cost basis of this model was drawn from Mitre report MTR-7613 (1977), "Prospects for Improvements in Geothermal Well Technology and Their Expected Benefits", by E.J. Friedman and A. El-Sawy.

The Friedman-El-Sawy analysis postulated the dependence of well cost on rock hardness and depth (Table B-I). That report did not discuss relationships between well costs and temperature. It did, however, include enough information about one well drilled at the Geysers to allow the estimation of many drilling cost parameters. (See Table B-II.)

TABLE B-I

FOOTAGE COSTS FOR GEOTHERMAL DRILLING AS A FUNCTION
OF ROCK TYPE AND WELL DEPTH

ROCK HARDNESS	COST/FOOT (1977 DOLLARS)	
	< 5,000 FEET	> 5,000 FEET
SOFT	80	160
MEDIUM	100	200
MEDIUM-HARD	125	250
HARD	200	400

TABLE B-II

COST PER FOOT AS A FUNCTION OF BIT CHARACTERISTICS

THE COST PER FOOT IS GIVEN BY:

$$F = \frac{C \left[L + V \left(D + \frac{Z}{2} \right) \right] + B}{RL}$$

WHERE:

C = operating time cost factor, including rig rental, materials, labor, and all other costs except bits (in dollars)

L = bit lifetime (in hours)

V = average tripping rate (in hours per foot of round trip: pull string, replace bit, lower string)

D = starting depth for drilling below ground level (in feet)

Z = total depth drilled (in feet)

B = bit cost (in dollars)

R = instantaneous penetration rate (in feet per hour).

FOR A TYPICAL WELL AT THE GEYSERS, C = \$400; L = 55 HOURS IN COLD ROCK; V = 1.1 HOUR PER 1,000 FEET, D = 0, Z = 7,000 FEET, B = \$2,000, AND R = 20 FEET/HOUR (ROCK HARDNESS = MEDIUM). (CALCULATED FROM DATA ON GEYSERS WELL #37, AS GIVEN IN MTR-7613.)

The relationship among well cost, bit performance and the factors of rock hardness and resource temperature was based on the following assumptions:

1. The drilling portion of the cost of each well can be estimated from the usual footage cost model, as explained in Table B-II. The estimated value of C (\$400/hr) should be viewed as a conservative estimate of operational

expenses associated with one hour's worth of active drilling. In certain situations much higher costs have been experienced.

2. The average lifetime of conventional unsealed bits during low-temperature drilling is assumed to be 55 hours. (The average lifetime and instantaneous penetration rate were estimated by correlating well costs and rock type, using the data in MTR-7613. These correlations are tentative, and are used here because time did not allow gathering of primary data.)
3. The main effect of rock hardness is to alter R, the instantaneous penetration rate, in proportion to the footage costs given in Table B-I. R would be 25 feet/hour in soft rock, 20 feet/hour in medium rock, 16 feet/hour in medium-hard rock, and 10 feet/hour in hard rock.
4. To a first approximation, air drilling will be used only for the portion of the hole that penetrates the geothermal formation. This is postulated by the DGE wells scenario to be the bottom 0.5 kilometer of each hole. Therefore, potential savings from the Terra Tek bit will occur only in that part of the drilling.
5. The operating temperature of the bit while in the hot formation is prospect-specific, and is postulated to be the formation temperature listed for each resource in MTR-7613.
6. Mud drilling will be used within the formation of geopressured prospects (to counter-balance the formation pressure), and in prospects where the formation is soft or poorly consolidated. Thus no savings are expected from the Terra Tek bit in resources of these types.

The data and assumptions from this section and section 2.0 lead to the following model for calculating benefits:

1. Savings per well, S, are estimated to be the difference in cost between conventional bits and Terra Tek bits. From the equation in Table B-II:

$$S = Z \left[\frac{C[L_1 + V(D + Z/2)] + B_1}{RL_1} - \frac{C[L_2 + V(D + Z/2)] + B_2}{RL_2} \right]$$

where subscript "1" indicates the conventional bit, and "2" the Terra Tek bit. If $L_1 = H \cdot L_2$, then the equation reduces to:

$$S = \frac{Z}{RL_2} \left[CV (D + Z/2) \left(\frac{1}{H} - 1 \right) + \left(\frac{B_1}{H} - B_2 \right) \right] .$$

S can be viewed as consisting of two components. S_1 is due to fewer bits of the new type being needed:

$$S_1 = \frac{Z}{RL_2} \left[(B_1/H) - B_2 \right]$$

S_2 is due to reduced time being spent on round-tripping fewer bits:

$$S_2 = \frac{Z}{RL_2} CV (D + Z/2) \left(\frac{1}{H} - 1 \right) .$$

Note that in this analysis, the instantaneous penetration rate (R) is taken to be a function of rock hardness only, while the lifetime of bits (L_1 and L_2) depend only on operating temperature.

2. Terra Tek has not projected a price for the new bit. The price is estimated to be \$2500, a 25% increase over the 1977 price of conventional bits of similar geometry.
3. Instantaneous penetration rate, R, is the function of rock hardness given by the parameters listed in Assumption 3 of this section (above).
4. The lifetimes of the bits are taken from the curves in Figure B-I in the following form: L_2 is assumed to be 55 hours in cold rock. "G" is the fractional lifetime expected for the Terra Tek bit at various elevated temperatures. "H" is the ratio of the lifetime of conventional bits to the lifetime of the Terra Tek bit, as a function of operating temperature.

For calculations, the parameters G and H were estimated from the curves of Figure B-I at 100°C intervals over the range of 180 to 390°C. The values are shown in Table B-III.

TABLE B-III

RELATIONSHIP BETWEEN TEMPERATURE OF DRILLING AND BIT LIFETIME

BIT TEMPERATURE, °C	LIFETIME FACTOR ¹		RELATIVE LIFETIME (H)
	CONVENTIONAL BIT	TERRA TEK BIT (G)	
180	1.00	1.00	1.00
190	0.92	1.00	0.92
200	0.84	1.00	0.84
210	0.76	1.00	0.76
220	0.68	1.00	0.68
230	0.60	1.00	0.60
240	0.52	1.00	0.52
250	0.44	1.00	0.44
260	0.36	1.00	0.36
270	0.28	1.00	0.28
280	0.20	1.00	0.20
290	0.20	0.92	0.22
300	0.20	0.84	0.24
310	0.20	0.76	0.26
320	0.20	0.68	0.29
330	0.20	0.60	0.33
340	0.20	0.52	0.38
350	0.20	0.44	0.45
360	0.20	0.36	0.56
370	0.20	0.28	0.71
380	0.20	0.20	1.00
390	0.20	0.20	1.00
¹ From Figure B-I			

TABLE B-IV

WORKSHEET FOR CALCULATING THE SAVINGS EXPECTED FROM THE TERRA TEK BIT
AT EACH RESOURCE

1. RESOURCE VALLES CALDERA, NM
2. FIXED PARAMETERS:
 Z = Footage to be drilled = 1640 feet
 B_1 = Cost of conventional bit = \$2000
 B_2 = Cost of Terra Tek bit = \$2500
 C = Operating time cost factor = \$400/hour
 V = Round tripping rate = 1.1/1000 feet/hour.
3. VARIABLE PARAMETERS (From Table B-III):
 R = Instantaneous Penetration Rate = 10 feet/hour
 H = Relative bit lifetime factor = 0.52
 G = Terra Tek bit lifetime factor = 1.00
 D = Depth to top of formation = 3280 feet
4. LIFETIME OF TERRA TEK BIT:
 $L_2 = G \cdot 55 = \underline{1.0} \cdot 55 = \underline{55}$ hours
5. NUMBER OF TERRA TEK BITS NEEDED:
 $A = Z/RL_2 = 1640 / (\underline{10}) (\underline{55}) = \underline{3.0}$
6. S_1 = SAVINGS DUE TO FEWER BITS:

$$S_1 = A \cdot [(B_1/H) - B_2] = \underline{3.0} \cdot \left[\left(\frac{2000}{\underline{0.52}} \right) - 2500 \right]$$

$$= 3.0 \times 1346 =$$

$$S_1 = \$ \underline{4040}$$
7. S_2 = SAVINGS DUE TO REDUCED TRIPPING:

$$S_2 = A \cdot C \cdot V \cdot (D + Z/2) ((1/H) - 1)$$

$$= \underline{3.0} \cdot 400 \cdot \left[\frac{1.1}{1000} \cdot (\underline{3280} + 820) \cdot ((1/\underline{0.52}) - 1) \right]$$

$$S_2 = \$ \underline{4980}$$
8. S = TOTAL SAVINGS PER WELL = $S_1 + S_2 = \$ \underline{9020}$

A worksheet was prepared for calculating the savings per well at each affected resource. The worksheet (with calculations for the Valles Caldera, New Mexico, resource) is shown in Table B-IV. Note that space was provided on the worksheet for intermediate calculations.

Prior to calculating savings the parameters assumed for each well were collected into a single table. This table is shown in Item 7.3 of the Benefit/Cost Evaluation Form, in Section 5.0 below. The values of parameters were drawn from MTR-7613, or derived as explained above. If the resource formation is expected to be drilled using fluid, or if the resource temperature is projected at 180°C or less, the model predicts no savings. This is indicated in the third column. The calculated savings per well are incorporated as the last three columns of Item 7.3.

TABLE B-V
NUMBER OF WELLS REQUIRED

PROSPECT	TIME PERIODS											TOTAL
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	
	1979 -80	1981 -82	1983 -84	1985 -86	1987 -88	1989 -90	1991 -92	1993 -94	1995 -96	1997 -98	1999 -2000	
Geysers, CA (Steam)	130	121	66	46	46	46	46	46	46	46	46	685
Brazoria, TX	--	10	35	131	276	516	548	1290	158	176	176	3316
Salton Sea, CA	--	17	35	38	45	49	46	49	53	45	25	402
Valles Caldera, NM	--	21	39	41	50	86	96	104	114	132	58	741
Brady Hot Springs, NV	--	27	31	55	65	115	124	132	95	60	60	764
Brawley, CA	--	15	22	54	57	61	60	41	24	24	24	382
Roosevelt Hot Springs, UT	--	18	20	21	41	69	73	79	61	37	28	447
Beowawe, NV	--	21	23	24	47	82	92	100	83	43	44	559
Cost Hot Springs, CA	10	5	50	93	130	26	34	34	34	34	34	484
Mono-Long Valley, CA	10	--	25	47	48	11	14	14	14	14	14	211
Cove Fort-Sulfurdale, UT	10	--	24	31	52	93	104	115	125	125	60	739
Heber, CA	--	--	28	37	110	119	121	41	44	44	44	588
Geysers, CA (Hydrothermal)	5	5	76	81	86	92	97	26	26	26	26	546
East Mesa, CA	--	--	32	31	6	8	8	8	8	8	8	117
Steamboat Springs, NV	10	--	28	32	52	11	12	12	12	12	12	193
Surprise Valley, CA	--	10	35	42	136	150	168	184	202	208	105	1240
Chandler, AZ	--	10	28	7	65	36	16	16	16	16	16	226
Leach, NV	--	10	--	39	48	152	170	189	209	217	101	1135
Calcasieu Parish, LA	--	10	--	65	74	191	136	28	28	28	28	588
Bruneau-Grandview, ID	--	10	--	24	50	91	101	112	123	123	57	691
Lassen, CA	--	10	--	21	18	3	4	4	4	4	4	72
Kenedy County, TX	--	10	--	65	74	136	134	22	24	24	24	513
Alvord, OR	--	10	--	24	31	51	57	14	16	16	16	235
Matagorda County, TX	--	10	--	65	74	136	144	262	36	40	40	807
Cameron Parish, LA	--	10	--	65	74	136	144	147	150	40	40	806
Acadia Parish, LA	--	10	--	65	74	136	194	24	28	28	28	587
Corpus Christi, TX	--	10	--	65	74	136	204	274	290	416	76	1545
Safford, AZ	--	10	--	19	2	2	7	21	6	6	6	79
Weiser-Crane Creek, ID	--	--	10	47	97	190	214	238	257	192	126	1371
Vale Hot Springs, OR	--	--	10	47	55	103	115	127	139	141	69	806
Thermo, UT	--	--	10	19	6	50	91	72	25	26	26	325
Raft River, ID	--	--	5	81	82	18	22	22	22	22	22	296
Glass Mountain, CA	--	--	--	10	24	2	4	4	4	4	4	56
Puna, HI	--	--	--	10	34	108	114	49	32	32	32	411
Mt. Hood, OR	--	--	--	10	72	5	10	10	10	10	10	137
Baker Hot Springs, WA	--	--	--	10	38	3	6	6	6	6	6	81
West Yellowstone, MT	--	--	--	10	72	5	10	10	10	10	10	137
TOTAL	175	390	632	1572	2485	3224	3540	3926	2534	2435	1505	22418

4.0 CALCULATION OF TOTAL SAVINGS EXPECTED

The savings per well was multiplied by the "number of wells" scenario (Table B-V) to find the savings per resource in each 2-year time period between 1978 and 2000. The results of the calculation are shown in Item 7.4 of the Benefit/Cost Form, Section 5.0 below.

The savings per period were summed. The "Total" row in Item 7.4 represents a maximum expected benefit of \$43,152,000 in 1977 constant dollars. The period sums were then discounted by 5% to 1977 to place appropriate relative emphasis on the near-term potential benefits. The total discounted benefit is \$22.6 million.

The Terra Tek bit cannot be assumed to penetrate totally its entire market. The bit will not be commercialized in Period I. It seems reasonable to assume that the bit will penetrate 5% of its market in 1981-82, 20% in 1983-1984, and 50% in 1985-2000. The discounted savings were multiplied by these penetration factors to give a final estimate of the most probable benefit shown in the bottom column of Item 7.4, Section 5.0.

Thus, the expected savings from the Terra Tek unsealed geothermal drill bit is \$9.84 million.

FIGURE B-2
PROCESS FOR EVALUATING COSTS AND BENEFITS OF SUBELEMENT

5.0 BENEFIT/COST EVALUATION FORM

A filled out Benefit/Cost analysis form is included in this section. Figure B-2 is a flow chart of the sequence for filling out sections of the form.

Item 6.0, the "Subelement Development Plan", is filled out first. Only those costs estimated to pertain to the development of the unsealed geothermal bit are shown. Phases I and II of the Terra Tek project have completed advanced development work. Phase III is mainly field-testing of full-sized bits, at a proposed cost of \$202,000. A total budget of \$302,000 to completion of commercialization is estimated.

Item 7.0 is used to describe the benefits. A single algorithm was used to calculate both primary benefits (fewer bits needed per hole) and secondary benefits (reduced tripping time). The expected cost savings is \$9.84 million.

In Item 8.0 an "Expected Degree of Success" is estimated. The Phase III work is judged to have a 50-50 chance of reaching completion as scheduled, and delivering a bit with the expected technical performance. The expected degree of commercialization was calculated as part of estimating the benefits in Item 7.0.

The summary values from Items 6-8 are entered in Items 2-4. Note that the sunk costs for Phases I and II of this project (already completed) are not included in the estimate of total R&D costs.

The overall Figure of Merit is calculated in Item 5.0. For this project, the F.O.M. is 16.3. This is interpreted to mean that about \$16 of geothermal power on line costs might be saved for each \$1 spent on this project.

It should be noted that while the Figure of Merit derived above is interpreted as the "best" estimate, other considerations might lead one to predict different values. For example, the Terra Tek bit could conceivably be used to drill as much as three times the footage estimated in the analysis. This would raise the F.O.M. to about 48, a reasonable upper bound. On the other hand, the technical performance of the bit might turn out to be only half as good as indicated in Figure B-1. This would reduce the F.O.M. to about 8.

When sunk costs from Phases I and II are included in the total R&D budget, the total budget becomes \$839K. The Figure of Merit for the total lifetime of the project is then 5.9.

BENEFIT/COST EVALUATION FORM

SUBELEMENT I.D.# 9 TITLE: Terra Tek Improved Geothermal Drill Bit

EVALUATOR: D. Entingh (MITRE/METREK) EVALUATION DATE: October, 1977

1.0 TECHNICAL OBJECTIVE (FROM ITEM 6, R&D CONCEPT EVALUATION FORM):

Improve lifetime of unsealed drill bit at high drilling temperatures. Continue search for improved materials and design of seals of high temperature sealed bits

2.0 R&D TIMING AND COSTS SUMMARY (FROM ITEM * 6, THIS FORM):

WORK REQUIRED, AS SPECIFIED BY SUBELEMENT DEVELOPMENT PLAN	COMPLETED? (YES/NO)	TIME, YEARS*	SUNK COSTS \$1000s	BUDGET \$1000s*
6.1 Preliminary Study	----	--	----	----
6.2 Basic Research	----	--	----	----
6.3 Exploratory Development	Yes	--	\$322	----
6.4 Advanced Development	Yes	--	\$215	----
6.5 Engineering Development	No	1.0	----	\$202
6.6 Demonstration and Commercialization	No	3.0	----	\$100
TOTALS: * For unfinished work, only.		(a) 4.0	(b) \$537	(c) \$302
(d) Anticipated Commercialization Date (Year):				1981

3.0 BENEFITS SUMMARY (FROM ITEM 7.4, THIS FORM):

(a) Non-discounted Total (\$ Millions)	\$43.15M
(b) Discounted @ 5% (\$ Millions)	\$22.62M
(c) Adjusted for Commercialization (\$ Millions)	\$ 9.84M

4.0 EXPECTED DEGREE OF SUCCESS AT START OF CURRENT PROJECT (FROM ITEM 8, THIS FORM):

(a) Degree of Success = DOS =	0.50
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5.0 FIGURE OF MERIT (ENTER BENEFIT AND R&D COSTS AS \$ MILLIONS)

(a) Current (Without Sunk Costs)	FOM=
$FOM = \frac{\text{BENEFIT (3c)} \times \text{DOS (4a)}}{\text{BUDGET (2c)}} = \frac{(9.84) \times (0.50)}{(0.302)} =$	
(b) Historical (With Sunk Costs)	HFOM=
$HFOM = \frac{\text{BENEFIT (3c)} \times \text{DOS (4a)}}{\text{SUNK COSTS (3b)} \times \text{BUDGET (2c)}} = \frac{(9.84) \times (0.50)}{(0.302) + (0.537)} =$	

6.0 SUBELEMENT DEVELOPMENT PLAN

DESCRIPTION OF RESEARCH, DEVELOPMENT, OR EVALUATION WORK	COMPLETED? (YES/NO)	YEARS	R&D COSTS (\$1000s)
--	------------------------	-------	------------------------

6.1 Preliminary Study			
WORK: None			
EVALUATION: None			
TOTAL:		----	-----

6.2 Basic Research			
WORK: None			
EVALUATION: None			
TOTAL:		----	-----

6.3 Exploratory Development (Terra Tek Phase I)			
WORK: Improve bit testing rig. Design and fabricate small test bits.	Yes	1.0	\$322
EVALUATION: Failure analysis of bits from Geysers	Yes	---	----
TOTAL:		1.0	\$322

6.4 Advanced Development (Terra Tek Phase II)			
WORK: Fabricate second-generation experimental bits.	Yes	1.0	\$215
EVALUATION: Test first & second generation exper. bits.	2nd gen. test in Phase III	----	----
TOTAL:		1.0	\$215

6.5 Engineering Development (Terra Tek Phase III)			
WORK: Final design and fabrication of third generation bits.	No	0.5	\$101
EVALUATION: Laboratory tests of second generation bits. Field tests of third generation bits.	No	0.5	\$101
TOTAL:		1.0	\$202

6.6 Demonstration and Commercialization			
WORK: Completion of field tests	No	1	\$100
EVALUATION: Continued work by Terra Tek commercialization	No	2	0
TOTAL:		3	\$100

(Transfer Totals to Item 2, Page 1)

GRAND TOTAL:	6.0	\$839
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7.0 ESTIMATE OF BENEFITS

7.1 Inputs to Benefits Model

(a) Type(s) of Prospects to be Affected: Only Prospects where air drilling will be used in the formation, and the formation temperature is greater than 180°C.	
(b) Subsystem or Component(s) to be Affected: Primary Impact: Increased lifetime for unsealed bits through increased hardness of bit bearing surfaces. Will reduce number of bits needed and reduce tripping time at the affected prospects.	
(c) Expected Quantitative Improvement in Performance of Component(s): Will depend on temperature to which bit is exposed while drilling. Maximum improvement is a 4 fold increase in bit lifetime at about 280°C.	
(d) Cost of Affected Technological Component or Process:	
Cost of New Component:	\$ 2500. (est)
Cost of Current Component:	\$ 2000.
Cost Ratio (New/Old):	1.25

7.2 Model for Savings Per Prospect

Explain how savings are estimated for specific prospects. Attach extra pages if needed.
<p>A. Bit lifetimes at various temperatures were estimated from experience at the Geyers and from results of Terra Tek's Phase II laboratory testing of prototype bits.</p> <p>B. A parametric model for estimating drilling costs as a function of (1) Prospect temperature, (2) Rock hardness, and (3) Depth of well, was constructed. This allowed the determination of an estimated savings per well at each prospect where the Terra Tek bit might be used.</p> <p>(See Volume IV of this report for the full description of the benefit/cost analysis of the Terra Tek project.)</p>

PROSPECT	AIR OR LIQUID DRILLING?	TEMPERATURE, °C	BENEFITS EXPECTED?	DEPTH TO TOP OF FORMATION, FEET (D)	ROCK HARDNESS	PENETRATION RATE (R)	TERRA TEK BIT LIFETIME FACTOR (G)	RELATIVE BIT LIFETIME FACTOR (H)	SAVINGS DUE TO FEWER BITS, \$ (S ₁)	SAVINGS DUE TO REDUCED TRIPPING, \$ (S ₂)	TOTAL SAVINGS PER WELL, \$ (S=S ₁ +S ₂)
Geysers, CA (Steam)	Air	240	Yes	6560	M	20	1.00	0.52	2000	4480	6480
Brazoria, TX	L (1)	---	No								0
Salton Sea, CA	Air	340	Yes	3280	S	25	0.52	0.38	6355	6765	13,120
Valles Caldera, NM	Air	240	Yes	3280	H	10	1.00	0.52	4040	4980	9020
Brady Hot Springs, NV	Air	214	Yes	1640	H	10	1.00	0.72	834	1266	2100
Brawley, CA	L (2)	---	No								0
Roosevelt Hot Springs, UT	Air	230	Yes	2624	MH	16	1.00	0.60	1580	1920	3500
Beowawe, NV	Air	240	Yes	3280	H	10	1.00	0.52	4040	4980	9020
Coso Hot Springs, CA	Air	220	Yes	3280	MH	16	1.00	0.68	838	1612	2450
Mono-Long Valley, CA	Air	220	Yes	3280	MH	16	1.00	0.68	838	1612	2450
Cove Fort-Sulfurdale, UT	Air	200	Yes	4920	MH	16	1.00	0.84	-222	892	670
Heber, CA	L (2)	---	No								0
Geysers, CA (Hydrothermal)	Air	200	Yes	6560	MH	16	1.00	0.84	-222	1172	950
East Mesa, CA	L (2)	---	No								0
Steamboat Springs, NV	Air	210	Yes	984	MH	16	1.00	0.76	250	480	730
Surprise Valley, CA	Air	175	No								0
Chandler, AZ	Air	178	No								0
Leach, NV	Air	170	No								0
Calcasieu Parish, LA	L (1)	---	No								0
Bruneau-Grandview, ID	Air	210	Yes	6560	MH	16	1.00	0.76	250	1970	2220
Lassen, CA	Air	240	Yes	3280	MH	16	1.00	0.52	2557	3153	5710
Kenedy County, TX	L (1)	---	No								0
Alvord, OR	Air	200	Yes	4920	H	10	1.00	0.84	-358	1438	1080
Matagorda County, TX	L (1)	---	No								0
Cameron Parish, LA	L (1)	---	No								0
Acadia Parish, LA	L (1)	---	No								0
Corpus Christi, TX	L (1)	---	No								0
Safford, AZ	Air	210	Yes	3280	MH	16	1.00	0.76	250	1100	1360
Weiser-Crane Creek, ID	Air	160	No								0
Vale Hot Springs, OR	L (2)	---	No								0
Thermo, UT	L (2)	---	No								0
Raft River, ID	L (2)	---	No								0
Glass Mountain, CA	Air	210	Yes	6560	MH	16	1.00	0.76	246	7974	8220
Puna, HI	Air	356	Yes	6560	H	10	0.39	0.51	8333	13267	26600
Mt. Hood, OR	Air	125	No								0
Baker Hot Springs, WA	Air	165	No								0
West Yellowstone, MT	L (2)	---	No								0

7.3 SAVINGS PER PLANT OR WELL AT EACH PROSPECT (WORKSHEET)

EXPECTED SAVINGS (\$ MILLIONS)

PROSPECT	TIME PERIODS												TOTAL
	SAVINGS PER UNIT (\$)	I 1979 -80	II 1981 -82	III 1983 -84	IV 1985 -86	V 1987 -88	VI 1989 -90	VII 1991 -92	VIII 1993 -94	IX 1995 -96	X 1997 -98	XI 1999 -2000	
Geysers, CA (Steam)	6840	.889	.828	.441	.314	.314	.314	.314	.314	.314	.314	.314	4.67M
Brazoria, TX	0	---	---	---	---	---	---	---	---	---	---	---	---
Salton Sea, CA	13120	---	.223	.459	.499	.590	.643	.604	.643	.695	.590	.328	5.27
Valles Caldera, NM	9020	---	.189	.352	.370	.451	.776	.866	.938	1.028	1.190	.523	6.68
Brady Hot Springs, NV	2100	---	.057	.065	.116	.136	.242	.260	.277	.200	.126	.126	1.60
Brawley, CA	0	---	---	---	---	---	---	---	---	---	---	---	---
Roosevelt Hot Springs, UT	3500	---	.063	.070	.047	.144	.242	.256	.277	.214	.130	.098	1.57
Beowawe, NV	9020	---	.189	.207	.216	.424	.740	.830	.902	.749	.388	.397	5.04
Coso Hot Springs, CA	2450	.024	.012	.122	.228	.318	.064	.083	.083	.083	.083	.083	1.18
Mono-Long Valley, CA	2450	.024	---	.061	.115	.118	.027	.034	.034	.034	.034	.034	0.52
Cove Fort-Sulfurdale, UT	670	.007	---	.016	.021	.035	.062	.070	.077	.084	.084	.040	0.50
Heber, CA	0	---	---	---	---	---	---	---	---	---	---	---	---
Geysers, CA (Hydrothermal)	950	.005	.005	.072	.077	.082	.087	.092	.025	.025	.025	.025	0.52
East Mesa, CA	0	---	---	---	---	---	---	---	---	---	---	---	---
Steamboat Springs, NV	730	.007	---	.020	.023	.023	.038	.008	.009	.009	.009	.009	0.14
Surprise Valley, CA	0	---	---	---	---	---	---	---	---	---	---	---	---
Chandler, AZ	0	---	---	---	---	---	---	---	---	---	---	---	---
Leach, NV	0	---	---	---	---	---	---	---	---	---	---	---	---
Calcasieu Parish, LA	0	---	---	---	---	---	---	---	---	---	---	---	---
Bruneau-Grandview, ID	2200	---	.022	---	.053	.111	.202	.224	.249	.273	.273	.127	1.53
Lassen, CA	5710	---	.057	---	.120	.103	.017	.023	.023	.023	.023	.023	0.41
Kenedy County, TX	0	---	---	---	---	---	---	---	---	---	---	---	---
Alvord, OR	1080	---	.011	---	.026	.033	.055	.062	.015	.017	.017	.017	0.25
Matagorda County, TX	0	---	---	---	---	---	---	---	---	---	---	---	---
Cameron Parish, LA	0	---	---	---	---	---	---	---	---	---	---	---	---
Acadia Parish, LA	0	---	---	---	---	---	---	---	---	---	---	---	---
Corpus Christi, TX	0	---	---	---	---	---	---	---	---	---	---	---	---
Safford, AZ	1360	---	---	.014	.064	.132	.258	.291	.324	.350	.261	.171	1.86
Weiser-Crane Creek, ID	0	---	---	---	---	---	---	---	---	---	---	---	---
Vale Hot Springs, OR	0	---	---	---	---	---	---	---	---	---	---	---	---
Thermo, UT	0	---	---	---	---	---	---	---	---	---	---	---	---
Raft River, ID	0	---	---	---	---	---	---	---	---	---	---	---	---
Glass Mountain, CA	8220	---	---	---	.082	.197	.016	.033	.033	.033	.033	.033	0.46
Puna, HI	26600	---	---	---	.266	.904	2.873	3.032	1.303	.851	.851	.851	10.93
Mt. Hood, OR	0	---	---	---	---	---	---	---	---	---	---	---	---
Baker Hot Springs, WA	0	---	---	---	---	---	---	---	---	---	---	---	---
West Yellowstone, MT	0	---	---	---	---	---	---	---	---	---	---	---	---
(a) TOTAL:	---	.956	1.656	1.899	2.664	4.130	6.626	7.083	5.526	4.982	4.431	3.199	43.15
(b) DISCOUNTING FACTORS:	---	---	---	---	---	---	---	---	---	---	---	---	---
(c) DISCOUNTED TOTAL:	---	.867	1.362	1.417	1.803	2.535	3.689	3.578	2.531	2.070	1.670	1.099	22.62
(d) COMMERCIALIZATION:	---	0	5	20	50	50	50	50	50	50	50	50	---
(e) FINAL TOTAL:	---	0	.068	.283	.902	1.268	1.844	1.789	1.266	1.035	.835	.550	9.84

7.4 TOTAL SAVINGS ACROSS PROSPECTS AND TIME PERIODS

8.0 EXPECTED DEGREE OF SUCCESS

TYPE OF RD&D EFFORT		PROBABILITY OF ATTAINING TEST CRITERIA	OVERALL DEGREE OF SUCCESS
6.2 Basic Research	→	-----	Done
6.3 Exploratory Development	→	-----	Done
6.4 Advanced Development	→	-----	Done
6.5 Engineering Development	→	0.50	0.50
6.6 Demonstration*	→	1.00	1.00
Total Benefit Delivered	→	1.00	XXXXXXXXXX
Type of Current Project	→ 6.5	XXXXXXXXXX	XXXXXXXXXX
(a) Currently Expected Degree of Success →			0.50

(* Partial commercialization is accounted for in Item 7.4)

9.0 REVIEW AT END OF CURRENT CONTRACT (To be filled out in Spring, 1978.)

(a) Current estimate of performance of device or process; in same terms as original estimate of performance.	
(b) Ratio of Current Performance Estimate to Previous: →	
(c) Actual RD&D Costs (\$1000s), this stage: →	
(d) Has expected benefit been altered by RD&D schedule change or changed performance of component? Explain:	
(e) Current estimate of benefit (\$1000s): →	
(f) Achieved Figure of Merit: = (9e) / Current Cost Estimate = () / () =	