BENEFIT/COST ANALYSIS OF GEOTHERMAL TECHNOLOGY R&D

Volume IV: Geochemical and Materials Engineering

The MITRE Corporation

NOTICE

Benefit/Cost Analysis of Geothermal Technology R&D

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ABSTRACT

This volume presents the benefit/cost analysis of 45 R&D projects sponsored by the Geochemical and Materials Engineering program of the Utilization Technology Branch, Division of Geothermal Energy, Department of Energy, as of F.Y. 1978.

Benefits of the R&D projects were estimated as potential cost savings in electricity production of geothermal power plants installed in the years 1979-2000 at 27 U.S. liquid-dominated geothermal prospects. The total cost saving was found to be from 3.9 to 8.5% making the overall benefit/cost ratio of the R&D projects fall somewhere between 18.3 and 39.8.

ACKNOWLEDGEMENTS

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The authors also wishes to express appreciation for much help in making computer runs and preparing many charts presented in this volume, from Richard T. Pfundstein and Mark Keimig.

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EXECUTIVE SUMMARY

This report (Volume IV of four volumes) describes the approach, methods, and results for benefit/cost analyses of 45 R&D projects sponsored by the Geochemical and Materials Engineering Program of the Utilization Technology Branch, Division of Geothermal Energy, Department of Energy.

Benefits of the R&D projects were estimated as potential future cost savings in electricity production at United States liquid-dominated geothermal prospects. The estimated benefits were based on the DGE hydrothermal electric development scenario for power plant installation at 27 United States liquid-dominated geothermal prospects in the years 1979-2000.

Important definitions for this summary are:

- R&D Subelement - A set of one or more R&D projects or contracts that promises to develop a practical commercializable product that will improve a geothermal energy system component or process.
- Sunk Costs - R&D costs incurred through FY1977 for the subelement, inflated at 10%/year to 1978 dollars.
- Planned Costs - Expected future (including FY1978) R&D costs to the Federal program. These include costs planned by DGE, and in many cases "additional" costs estimated by MITRE to be required to bring the anticipated products of the subelement to commercialization. Expressed in 1978 present value; discount rate = 10%.
- Date of Commercialization - Year in which the product of the subelement is expected to be available for commercial incorporation into geothermal wells or electric plants.
- Estimated Benefit - Savings in the costs of electricity production in the years 1979-2000 at the 27 U.S. liquid-dominated geothermal prospects included in the hydrothermal electricity development scenario. This benefit is based on technical considerations only, and is the modelled consequence of either a pessimistic or optimistic estimate of the degree to which the R&D subelement activities will alter technology performance and/or costs expressed in 1978 dollars; assumed discount rate of 10% per year.

- Degree of Success - A scaling factor between 0.0 and 1.0 that reflects MITRE's estimate of the degree to which the possible (estimated) benefit will be delivered commercially. The estimate of degree of success includes such considerations as probability of technical success in the R&D activities, competition between subelement products for shares of the same market, and sundry factors that could affect commercial use of the R&D product.

- Expected Benefit - Product of the estimated benefit and degree of success: final estimate of how much savings in the cost of electricity production is most likely to result from the R&D subelement.

- Figure of Merit - Expected benefit divided by planned R&D costs. This is the benefit/cost ratio for the R&D subelement. It disregards sunk costs, to provide a forward look of the relative merit of continued investment in the R&D subelement.

- Historical Figure of Merit - Expected benefit divided by sum of sunk plus planned costs. This value provides an estimate of the relative value of each subelement throughout its entire life-span.

The benefit/cost analysis required the creation of a comprehensive model of geothermal drilling technology in addition to existing power plant engineering and economic models. WELCST is a comprehensive computerized engineering cost model for geothermal wells, which includes accounting for most major drilling mishaps and all improvable cost items.

The current R&D projects of the Geochemical and Materials Engineering program were found to fall in four Standard Technical Areas: Precipitation and Geochemistry; Materials; Measurement, Testing, and Process Control Technology; and Waste Management. The results of the benefit/cost analyses of the projects in these areas are shown in Table S-1. The results for individual project or group of projects are presented in the main body of this volume, and are combined for the entire program here in Figure S-1.

The major conclusions of the analysis are:

- As an average across the U.S. scenario for geothermal electricity development, the expected electricity cost reduction is somewhere between 3.9 and 8.5%.

TABLE S-1

BENEFIT/COST RATIOS OF STANDARD TECHNICAL AREAS IN GEOCHEMICAL AND MATERIALS ENGINEERING PROGRAM

STANDARD TECHNICAL AREA	COST (10^3 \$78)[1]		EXPECTED BENEFIT[2] (10^6 \$78)		FIGURE OF MERIT[1]		HISTORICAL FIGURE OF MERIT[3]	
	SUNK ←FY77	PLANNED FY78→	PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC
Precipitation and Geochemistry	1314	3305	72.7	141.9	22.0	42.9	15.7	30.7
Materials	3776	10200	227.1	443.0	22.3	43.4	16.3	31.7
Measurement, Testing, & Process Control Technology	1021	3710	27.4	200.9	7.4	54.1	5.8	42.5
Waste Management	0	6113	100.0	141.7	16.4	23.2	16.4	23.2
ENTIRE PROGRAM	6111	23328	427.1	927.5	18.3	39.8	14.5	31.5

[1]Excluding costs of projects which have been completed or terminated.

[2]Product of calculated benefit and degree of success.

[3]Including sunk costs.

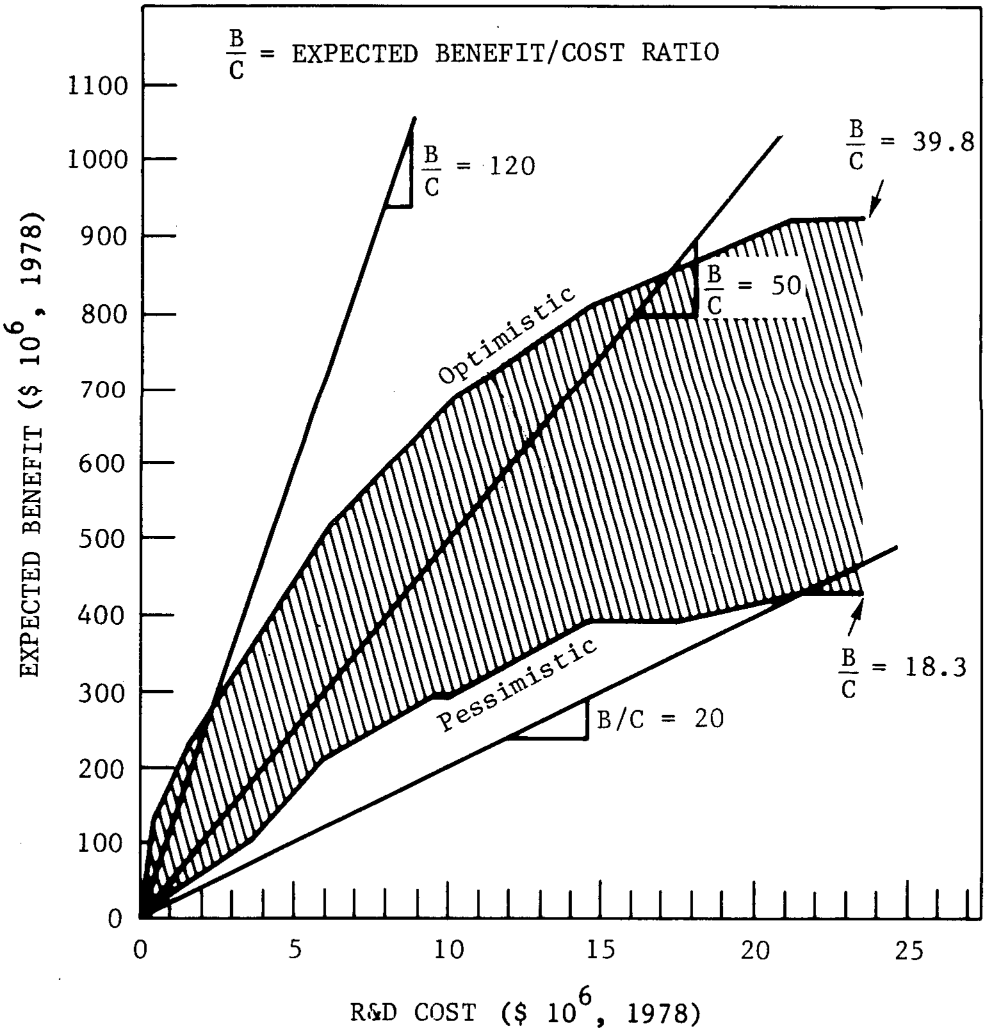


FIGURE S-1
EXPECTED BENEFIT VS. PLANNED PLUS ADDITIONAL R&D COST FOR THE GEOCHEMICAL & MATERIALS ENGINEERING PROGRAM

- R&D in materials development area yields highest impacts even when direct heat and geopressured applications are excluded.

- R&D activities in the area of precipitation and geochemistry show evidence of becoming more goal-orientated.

- Although there are high benefit projects, more goal-orientated definitions are needed in the measurement, testing and process control technology area.

- Not counting possible overlaps with projects in other R&D programs, the benefit/cost ratio of the whole program as planned falls somewhere between 18.3 and 39.8.

1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of the analysis reported in this volume was to assess the benefits and costs of 45 R&D projects of the Geochemical and Materials Engineering Program of the Division of Geothermal Energy, U.S. Department of Energy as of F.Y. 1978. The specific goals of the analysis were to:

- Provide a uniform basis on which to evaluate the probable impacts of disparate R&D projects upon the cost of producing electricity at 27 designated geothemal prospects in the U.S. between 1978 and 2000.
- Estimate the likely technological and economic impacts of 45 specific R&D projects.
- Estimate relative benefit/cost ratios for the R&D projects.
- Present the resulting estimates in a way that could assist DGE officials in monitoring the progress and potential changes in the relative importance of the various R&D projects to meeting DGE programmatic goals.

The uniform basis for project evaluation was required to extend across the three R&D programs of the Utilization Technology Branch:

- Geothermal Drilling Technology (Volume II of this report)
- Extraction and Conversion Technology (Volume III)
- Geochemical and Materials Engineering (Volume IV, this volume)

The scope of this volume of the report is limited to analysis of R&D projects related to the chemistry of geothermal brines, materials for geothermal systems, and brine utilization and disposal. The specific projects and the technical areas into which they all fall are detailed in Section 2.0.

The general scope of the benefits analysis as a whole was limited to effect on the economics of electricity production at 27 specific geothermal prospects. All of these prospects are moderate to high temperature (140-356^{o}C) liquid-dominated reservoirs of moderate depth (up to 3 kilometers, or about 10,000 feet). Volume I of this report, and Section 1.2 (below) may be consulted for further details on the scope of the analysis.

This benefit/cost analysis is, by design, project-oriented rather than program-oriented. The analysis considers, almost exclusively, the impacts of R&D activities upon the future cost of producing electricity from an assumed fixed scenario of power plant development at U.S. hydrothermal sites. This is intended to give the R&D Program Managers a forward look at the degree to which various R&D activities are most likely to impact on the types of technologies that will be used to produce geothermal electricity in the U.S.(1).

Since the analysis is not program-oriented, it specifically ignores some of the traditional aspects of federal programmatic benefit/cost analyses. For example, no attempt is made here to compare the future cost of geothermal electricity to electricity derived from other kinds of resources. Nor is there any attempt to predict the cost of electricity from specific prospects, or to predict market penetration shares at specific prospects. Such estimates will require additional analyses which could be based in part on the results presented here.

1.2 General Approach

"General" here refers to components of the approach that were common to the analysis of R&D Projects in all three of the Utilization Technology Branch research programs. Full details of the general approach used for the benefit/cost analysis of these projects can be found in Volume I of this report. Only a brief description of the general approach of the analysis is given here.

It was most important to identify the ways in which the expected results of the R&D projects could impact on geothermal power technology to reduce the cost of producing geothermal electricity. In some cases, e.g. "Silica Scaling Control", a single R&D project could produce a direct impact on costs. In other cases, projects had to be grouped together before they would result in a practical direct impact. To handle this diversity, the benefit/cost analyses were defined for R&D "subelements", where each subelement is a single project or a group of projects that holds promise of resulting in a commercializable improvement in a geothermal power system component or process.

For each R&D subelement, three independent quantitative factors were analyzed:

- Benefit - The total dollar savings that the technical impacts of the subelement could produce at electricity plants expected to be installed at 27 United States geothermal prospects in the years 1979-2000,

- R&D Cost - The total amount of DGE funds expected to be expended on the projects of the subelement from fiscal year 1978 through the estimated commercialization date of the product(s) of the subelement, and

- Degree of Success - An estimate of the likelihood that the total estimated benefit of the subelement will be realized, considering factors such as likelihood of technical success in the R&D work, market penetration barriers, etc.

The final result of each benefit/cost analysis is presented as a figure of merit for each subelement:

$$\text{Figure of Merit} = \frac{\text{Benefit x Degree of Success}}{\text{R\&D Cost}}$$

This figure of merit reflects only current and future costs. A parallel "Historical Figure of Merit" which includes sunk costs as well was also calculated to reflect the entire expected life-span of each R&D subelement. The analysis followed a series of steps:

STEP 1 - R&D project documentation was reviewed to identify the technical objectives, performance goals, latest test results, and any other information that could indicate likely quantitative impacts of each project on the cost of geothermal wells. Expected impacts on the performance and cost of geothermal plants and wells were identified. This information collection and impact identification effort included sending a letter to each R&D contractor requesting as much impact and benefit evaluation material as each could readily supply.

STEP 2 - The projects were grouped into Standard Technical Areas of projects that had many common or potentially overlapping technical/ economic impacts. For example, projects concerning geothermal fluid behavior were grouped into a Fluid Management area, and projects concerning the development of various types of materials were grouped into a Materials area.

The projects within each Standard Technical Area were then further subdivided into subelements. Each subelement contains one or more R&D project aiming toward common goals and the same commercializable practical impact. For example, the Materials Handbook subelement contains one project, while the Well Cements subelement contains four (see Figure 2).

STEP 3 - Quantitative estimates were made of likely technical/ economic impacts of each subelement, the year in which the product(s) of the subelement are likely to be commercially available, the past, present, and anticipated costs to DGE of the subelement, and the degree of success expected for each subelement. The estimates were based on information received from R&D project contractors, project reports and test results, and consultation with DGE program managers.

The quantitative estimates of the technical and economic impacts on electricity production systems were then mathematically transformed into appropriate terms as inputs to a general geothermal R&D benefits estimation model.

STEP 4 - The R&D benefits model, GEOBEN, was exercised. The benefits model calculates the total dollar savings that a given set of engineering/economic impacts would produce at electricity plants expected to be installed at 27 U.S. geothermal prospects in the years 1979-2000.

GEOBEN (for "Geothermal R&D Projects Benefits Analysis Code) is described in detail in Volume I of this report. GEOBEN is an expansion of GELCOM, the geothermal levelized busbar cost of electricity model developed at MITRE [(2)]. The benefits model has five main parts:

- A postulated geothermal electricity plant installation schedule for 27 prospects. This file includes estimates of primary physical characteristics of the sites (e.g., resource temperature, reservoir depth, brine salinity),
- Engineering cost models for geothermal wells and six types of geothermal electricity production plants,
- An R&D technical/economic impacts data file. Impacts derived in Step 3 above for one subelement are placed in this file, and are used by the program to adjust capital and O&M costs for plants expected to enter service after the commercialization date of the R&D subelement products,
- A levelized busbar cost model (GELCOM). This model uses the three above files, as well as pertinent financial factor estimates to calculate the levelized busbar cost of electricity at a particular plant in a particular year. And, finally,
- A summation and discount program. This code stores the electricity costs calculated for all the plants in the scenario, and then sums them for the years 1979 to 2000. The calculations include the fiscal impacts of the 1978 Federal Energy Act. The summation of costs is performed for two cases: With and without the R&D impacts, and discounted to present value (1978 dollars).

The electricity cost difference between the "with R&D" and "without R&D" cases is the estimated economic benefit of the R&D subelement.

As described above, the benefit is then combined with estimates of R&D cost, and degree of success to derive a benefit/cost ratio for each subelement.

As described above, the benefit is then combined with estimates of R&D cost, and degree of success to derive a benefit/cost ratio for each subelement.

Implicit in the analysis is an assumption that the reference set of schedules for the growth of electricity production at 27 representative geothermal prospects, herein generally called the "hydrothermal development scenario", is a reasonable basis for estimating benefits of R&D. While hydrothermal-electric development is unlikely to materialize precisely as postulated in the schedules, this site-specific basis for R&D impact assessment is more realistic than generic resource utilization projections.

1.3 Organization of this volume

The body of this volume contains general information on the R&D projects of the Geochemical and Materials Engineering program (Section 2.0). Section 2.0 also contains classifications of the projects into Standard Technical Areas and Subelements. Section 3.0 discusses specific methods used in the analysis for project benefit/cost ratios and figures of merit. The results of the analysis are presented in section 4.0. Conclusions are in Section 5.0. Appendix A contains the details of the analyses of individual R&D subelements.

2.0 TECHNICAL AREAS AND PROJECT CLASSIFICATION

The Geochemical and Materials Engineering program is concerned with all aspects of geothermal systems operations. Its primary objective is to improve the reliability, economics and environmental acceptance of geothermal resource utilization. To achieve the objectives the program is designed to study geothermal fluid chemistry so that adverse effects encountered in extracting the fluid and the heat it carries can be formulated and dealt with. To deal with those adverse effects, suitable materials for system components that are in contact with the fluid must be developed, wastes discharged from the utilization systems must be properly managed, and other operational problems such as measurements, process control, and testing procedures must be solved.

The 45 projects of this program were grouped into 4 standard technical areas on the basis of discussion with the Geochemical and Materials Engineering Program manager.

Each standard technical area contains a number of projects, each of which has its own objective. The objective of many projects would result in direct impacts on geothermal power systems. However there are some projects which had to be combined with other projects before the combined objective could generate identifiable impacts on the geothermal systems. In such cases, related projects were grouped to perform benefit analyses. In both cases the unit to be analyzed is called a "subelement" of the program. In other words, a subelement consists of one or more R&D projects that when analyzed, hold promise of delivering specific practicable impacts.

In the process of organizing the projects, a coding system was developed and used throughout the four volumes of this report. The three programs of the UTB are coded with numbers 1 to 3 with program 3 being the Geochemical and Materials Engineering program. The Standard Technical Area number is next to but separated by a hyphen from the program number. The project number is last. For example project 3-2-09 is the ninth project in area 2 of the Geochemical and Materials Engineering program. A subelement is designated with a letter in place of the project number, (e.g., subelement 3-2-C).

2.1 Standard Technical Area

The four standard technical areas of the Geochemical and Materials Engineering program are described below.

2.1.1 Standard Technical Area 3-1: Precipitation and Geochemistry

The projects in the precipitation and geochemistry area are currently concerned with precipitation problems in the fluid transport and heat exchange systems. The primary function of these R&D activities is to arrive at methods to predict and control precipitate formation. These projects are listed in Table 1.

In the precipitation process, the amount and types of precipitates can be identified by comparing the fluid constituents with their solubility data. Given the solubility information, controlling

TABLE 1

STANDARD TECHNICAL AREA 3-1: PRECIPITATION AND GEOCHEMISTRY

MITRE CODE	PROJECT TITLE	CONTRACTOR	CONTRACT NUMBER	TECHNICAL OBJECTIVE
3-1-01	Scale Formation Modeling	Los Alamos Sci. Lab.	05ENG36	To develop computer models to predict scale formation in heat exchanger and piping systems.
3-1-02	Mineral Solubility Data - RFP	Los Alamos Sci. Lab.	05ENG36	To generate, through laboratory experiments, support data on scaling and precipitation for the modeling of brine.
3-1-03	Hydrodynamic/Kinetic Reaction Engineering R&D - RFP	Los Alamos Scientific Laboratory	05ENG36	To determine systems and processes affecting scale morphology and precipitation of dissolved and suspended solids in support of brine modeling.
3-1-04	Brine Chemistry Studies	Lawrence Livermore Laboratory	05ENG48	To conduct support studies on interactions between brine chemistry and the Total Flow System.
3-1-05	Scale Formation and Control	Lawrence Livermore Laboratory	05ENG48	To study scale formation and its control in support for the Total Flow System.
3-1-06	Precipitation and Scaling in Dynamic Geothermal Systems	Oak Ridge National Laboratory	05ENG26	To obtain, through experimentation on a test loop, chemical engineering data on parameters important for scale formation and control.
3-1-07	Empirical Kinetic Reaction Model	Lawrence Berkeley Laboratory	05ENG48	To develop, through literature research and theoretical study, basic understanding of various mechanisms of silica precipitation under different temperature and compositions.
3-1-08	Silica Scaling Study	EIC Corp.	C022607	To study condensation of silica from water supersaturated with silicic acid.
3-1-09	Scale Formation and Suppression	DOW Chemical	C022833	To test the effectiveness of commercially available chemical scale control additives and electro-magnetic devices proported to reduce scale formation.
3-1-10	Scale Inhibition Test	Vetter Associates	--	To conduct field tests of various scale inhibitors.

techniques with acceptable economics can then be developed. However under the dynamic conditions of geothermal utilization processes, precipitation problems become complicated. Dynamic precipitation can happen in a variety of steady and transient modes of operation even when the solubility limits have not been reached. Thus solubility data for geothermal fluid, must be compiled, and equilibrium and dynamic precipitations must be studied before effective control methods can be developed. The R&D activities in this area therefore include a range of work from basic research to practical studies.

Mineral solubility data and modeling of precipitation studies are carried out in the Los Alamos Scientific Laboratory (LASL). These studies include precipitation kinetics and precipitate structure characteristics under various hydrodynamic conditions. A dynamic test loop is under operation at the Oak Ridge National Laboratory (ORNL) to generate precipitation data. Other specific studies such as silica precipitation - a major problem in many geothermal sites - studied by Lawrence Berkeley Laboratories (LBL) and EIC Corporation, and precipitation in Total Flow System studied by Lawrence Livermore Laboratories (LLL) are also included in this area. Projects which are concerned with practical problems such as precipitation control and suppression are carried out by Dow Chemicals and Vetter Associates.

Table 1 also contains information about project contractors, contract numbers, and technical objectives. Detailed project costs are included in Appendix A.

2.1.2 Standard Technical Area 3-2: Materials

The projects in the Materials area concentrate on the selection and development of suitable materials for use in contact with the geothermal fluid which, in general, has high temperature and high undesirable solids content. The main objective of these projects is to increase the life spans and reduce capital and operating and maintenance (O&M) costs of geothermal hardware.

Because of the special conditions (high temperature and salinity and corrosive environments) encountered in geothermal applications, virtually all the common engineering materials used need to be evaluated for suitability. In addition, because of economic reasons many of these materials need to be redeveloped for additional desired properties. The materials currently under consideration include cement, elastomers, polymer-concrete, and metals. There are 19 projects in this area. They are listed in Table 2 and briefly described below.

High temperature cements or mixtures of polymers and cements for use in geothermal well completion are being developed and tested by Brookhaven National Laboratory (BNL). This cement program is supported by the screening and testing efforts of National Bureau of Standards (NBS) and by the Dowell Division of Dow Chemical efforts for developing an improved cement slurry formulation. The field testing of different types of cement will start in FY 79 and will be managed by the regional offices of the Division of Geothermal Energy

TABLE 2

STANDARD TECHNICAL AREA 3-2: MATERIALS

MITRE CODE	PROJECT TITLE	CONTRACTOR	CONTRACT NUMBER	TECHNICAL OBJECTIVE
3-2-01	Materials Design Handbook	Radian Corp.	C043904	To prepare and maintain a materials selection and operational guideline handbook for geothermal energy conversion systems.
WELL CEMENT				
3-2-02	High Temperature Polymer Well Cement and Management	Brookhaven National Laboratory	C020016	To conduct in-house research to develop polymer well cement for downhole applications up to 330°C, and to manage other R&D subcontracts on inorganic cements.
3-2-03	Geothermal Cement Evaluation	Nat. Bur. Standards	A016010	To test and screen cements prior to downhole testing in a downhole test facility.
3-2-04	Well Completion Evaluation	Dowell of Dow Chem.	C024190	To develop an improved cement slurry formulation for the completion of wells.
3-2-05	Cement Downhole Tests	Unknown	--	To establish materials and performance standards for well cements by basket testing and to carry out non-destructive tests on cement in completed wells.
NON-METALLIC CONSTRUCTION MATERIALS				
3-2-06	Alternate Materials of Construction and Management	Brookhaven National Laboratory	C020016	To identify areas in geothermal processes where non-metallic materials such as plastics, concrete polymer composites and refractory cements can be utilized as a replacement for metals in a cost-effective manner and to develop and test these materials under laboratory and field conditions.
3-2-07	Alternate Materials for Non-Electric Applications	Brookhaven National Laboratory	C020016	To provide technical basis for subcontracts or alternate materials for use in non-electric applications.
3-2-08	DAI Intensity Polymer Concrete Erosion	Brookhaven National Laboratory	C020016	To evaluate the erosion and scale intensity on polymer concrete coated vessels and pipes, and determine the margins of safety of the coating, and also test various cleaning techniques.
SEAL MATERIALS				
3-2-09	High Temperature Elastomers R&D	NASA/JPL	A361011	To develop improved elastomeric materials for use as packers, 'O' ring, cable insulation and blowout preventers in downhole operations.
3-2-10	Alternate High Temperature Seal Materials - RFP	Brookhaven National Laboratory	-- --	To conduct R&D and make available seals for long term use between 250 and 500°F.

TABLE 2 (CONTINUED)

STANDARD TECHNICAL AREA 3-2: MATERIALS

MITRE CODE	PROJECT TITLE	CONTRACTOR	CONTRACT NUMBER	TECHNICAL OBJECTIVE
3-2-11	High Temperature Elastomers	L'Garde Inc.	C031308	To develop elastomer compounds for the high temperature geothermal casing packers,'O' ring and other static application. Goal requirements are 24 hours at 260°C brine.
3-2-12	Development of Well Logging Elastomers	Hughes Aircraft	C031325	Similar to preceeding project except that trials are performed on different chemical bases.
3-2-13	Geothermal Seal Symposium - Boston	Am. Soc. Test. Mats.	-- --	To review state of the art of seal research and seal problems in geothermal applications to arrive at recommendations for solutions. It takes place early October 1978.
METALS				
3-2-14	Iron-Base Alloys Versus Alternate Materials	Pacific Northwest Labs.	4511830	To characterize the corrosivity of varying geothermal brines on iron-base alloys as compared to several corrosion-resistant alloys, and to establish the brine temperature and chemistry limitations at which economical iron-base alloys will be useful.
3-2-15	Corrosivity of Brine	Oak Ridge Nat. Lab.	05ENG26	To conduct research on the corrosivity with respect to metals of synthetic brines.
3-2-16	Casing and Drill Pipe Materials	Case Western Reserve	5022602	To improve performance of casing, tubing, drill pipe and other downhole components in sour aggressive environments. Goal is to increase reliability in service against sulphide stress cracking and/or chloride cracking.
3-2-17	Pitting Resistant Alloys Development and Management	Brookhaven National Laboratory	C020016	To develop pitting and localized corrosion resistant materials for pipes and pressure vessels and to manage other metal R&D subcontracts.
3-2-18	Materials Testing and Development Subcontracts - RFP	Brookhaven National Laboratory	C020016	To develop high temperature (350-400°C), fracture toughness, and fatigue resistant materials for dynamic parts in pumps and borehole technology.
3-2-19	Geopressured HIP Materials Development, Commercialization and Subcontracts	Brookhaven National Laboratory	C020016	To develop low cost, clad (hot isostatic pressed, HIP), corrosion resistant casing materials for, primarily, geopressured applications.

The development and evaluation of non-metallic construction materials such as concrete, polymer-concrete and polymer lining in polymer-lined pressure vessels for use in both electric generation and non-electric applications are also managed by BNL.

High temperature, high strength seal-materials for use in drilling and well completion operations, and well logging equipment such as 'O' rings, packers, blowout preventers, etc. are being developed and tested by Jet Propulsion Laboratories (JPL), L'Garde, and Hughes Aircraft. The involvement of these aerospace laboratories is beneficial because of their known familiarity with seal materials under adverse conditions. Although seals are used only in relatively small quantities, their development requires such a high level of molding and treatment technology, along with such tedious procedures as trial and error combinations of numerous ingredients that the R&D success rate is quite low. The JPL, L'Garde, and Hughes projects have not been successful and will therefore be discontinued at the end of FY78. The development of alternate seal materials (other than elastomer-rich) program will be initiated in FY79 and will be managed by BNL.

Among the different kinds of materials used in geothermal applications, metals are predominant. Thus, the development work in this sub-area could be expected to have substantial pay-offs. The general effort in the development of geothermal materials for commercialization is managed by BNL. The applicability of iron-based alloys, which are the most common and therefore the first choice unless proven otherwise, is examined against alternative more exotic materials by Pacific Northwest Laboratory (PNL). A theoretical study completed in Fiscal Year 1977 (FY77) on the corrosivity of brine has been carried out at the Oak Ridge National Laboratory. The functional aspects of metals as applied to well casing and drill pipe are being studied by Case Western Reserve University. The efforts in metal development cited so far are thought to be inadequate; hence, three additional projects are planned for future years. Structural materials, small component materials, and materials for geopressured applications will be managed by BNL starting in FY80.

The results from all the above efforts will be condensed in a Materials Design Handbook which is being compiled and edited by the Radian Corporation.

Table 2 also contains information about project contractors, contract numbers, and technical objectives. Detailed project costs are included in Appendix A.

2.1.3 Standard Technical Area 3-3: Measurement, Testing and Process Control

There are eight current and future projects in this area. Their primary objective is to develop sensors and compatible instruments for use in high temperature and corrosive environments, and to develop methods for chemical analysis of the brine. The projects are listed in Table 3.

The Pacific Northwest Laboratories (PNL) is managing the

TABLE 3

TECHNICAL AREA 3-3:
MEASUREMENT, TESTING AND PROCESS CONTROL

MITRE CODE	PROJECT TITLE	CONTRACTOR	CONTRACT NUMBER	TECHNICAL OBJECTIVE
3-3-01	Sampling and Analysis Techniques	Pacific NW Labs.	4511830	To develop recommended methods and publish a manual for sampling and analysis of geothermal fluids and gases in order to assure accuracy, reliability and inter-comparability of reported results.
3-3-02	Assessment of Geothermal Brine	National Academy of Sci.	C012551	To form committee to study and recommend the types of instrumentation which can be used in geothermal wells to monitor changes in the brine characteristics as a function of time.
3-3-03	Geochemical Controls and Instruments Application	Pacific Northwest Labs.	4511830	To develop electrical and electrochemical probes that can measure CO_2, pH, oxidation-reduction potential, conductivity, corrosivity, sulfide ion concentration, heat transport, and scale thickness under high temperature, high pressure conditions of geothermal well and associated piping.
3-3-04	Reservoir In-Line Monitor R&D Subcontracts - RFP	Pacific Northwest Labs.	4511830	To subcontract industries in R&D to identify various instrumentation techniques that are suitable to monitor reservoir and well bore conditions.
3-3-05	Monitor Instrument Field Experiment	Pacific NW Labs.	--	To conduct field tests and to commercialize measuring instruments for continuous monitoring of reservoir and well conditions.
3-3-06	Cable Tests Subcontract	Sandia Labs	C040789	To test existing cable materials in short lengths for capability in data and current transmission.
3-3-07	High Temperature Cable Materials R&D	Brookhaven National Labs.	--	To provide materials to upgrade state of the art cables for high temperature downhole applications.
3-3-08	Non-Destructive Evaluation for Drill Pipe	Daedalean Associates Inc.	C014045	To determine the practicality of using non-destructive technique for detecting incipient cracks of drill pipes.

development of sensors, probes and in-line monitor instruments, and preparing documentation for standardization of chemical analysis and sampling techniques. The instrumentation activities of PNL are supported by a study performed by the National Academy of Sciences (NAS). Other projects in this area include a technology transfer study on a non-destructive evaluation technique by Daedalean Associates, Inc. (DAI), a test study on the existing data and current transmission cable materials by Sandia Laboratories, and upgrading these cable materials by Brookhaven National Laboratory (BNL).

Table 3 also contains information about project contractors, contract numbers, and technical objectives. Detailed project costs are included in Appendix A.

2.1.4 Standard Technical Area 3-4: Waste Management

Projects and potential projects in the Waste Management area cover three areas of concern: (i) recovery and disposal of gases and minerals, (ii) waste water and waste heat utilization, and (iii) fluid injection operations. The waste management activities were initiated in FY1978 and hence in some instances are not yet completely planned or not yet under contract.

The funding in FY78 for the Waste Management area supports only 5 projects. Recovery and utilization of wastes, including the preparation of a geochemical engineering and process handbook, are authorized but contractors have not yet been selected. Chemicals for use in the injection well stimulation are being investigated by Vetter

Associates and Oklahoma University. The important characteristics of the injection fluid are studied by PNL.

Three additional future projects such as waste utilization process subcontracting, inter-regional coordination in waste disposal, and construction of a 1 MW test unit are planned or under consideration. Contractors for these projects are yet to be identified.

The eight projects in this area are listed in Table 4 together with their known contractos, contract numbers, and technical objectives. Current and future costs of these projects are included in Appendix A.

2.2 Project Classification, Subelements

Projects in the four standard technical areas were re-examined in terms of specific objectives or goals. It was found that some projects alone will not generate practical impacts upon their completion. They have to be associated with other projects before practical impacts can be realized. For example, project 3-1-01, Scale Formation Modeling, requires inputs from projects "Mineral Solubility Data" (3-1-02) and "Hydrodynamic/Kinetic Reaction Engineering R&D" (3-1-03). Hence these projects were combined into a subelement with an identifiable common goal, namely the development of a scaling prediction method.

The interdependence of the projects in the above example is illustrated in Figure 1. Since the resulting subelement is the first unit in the Standard Technical Area 3-1, it is coded as subelement 3-1-A.

Aggregation with respect to common goals was done across the 45

TABLE 4

TECHNICAL AREA 3-4: WASTE MANAGEMENT

MITRE CODE	PROJECT TITLE	CONTRACTOR	CONTRACT NUMBER	TECHNICAL OBJECTIVE
3-4-01	Injection Fluid Characteristics	Pacific Northwest Labs.	4511830	To characterize injection fluid on site by site basis.
3-4-02	Injection and Stimulation Chemicals	Vetter/U. Oklahoma	--	To evaluate case history of well clogging and develop methods for reviving plugged wells and increasing dry well permeability.
3-4-03	Geochemical Engineering and Process Handbook	Unknown	--	To prepare a handbook which identifies energy systems and chemical processes and equipment for geothermal waste utilization.
3-4-04	Gas and Waste Utilization	Unknown	--	To develop chemical engineering systems to control and recover useful gaseous and solid constituents of geothermal fluids.
3-4-05	Waste Utilization Process Subcontracts	Unknown	--	To subcontract to industry to develop, through R&D, chemical engineering systems to control and recover gaseous and solid constituents.
3-4-06	Spent Fluid Disposal	Unknown	--	To investigate existing technology to develop alternate disposal methods for and pretreatment of injection fluid.
3-4-07	Waste Disposal Inter-regional Coordination	Unknown	--	To coordinate regional efforts in solving waste disposal problems.
3-4-08	Mobile0.1-1.0 MW Test Unit	Unknown	--	To build a mobil test unit to provide site specific data on injection fluids and injection well flow.

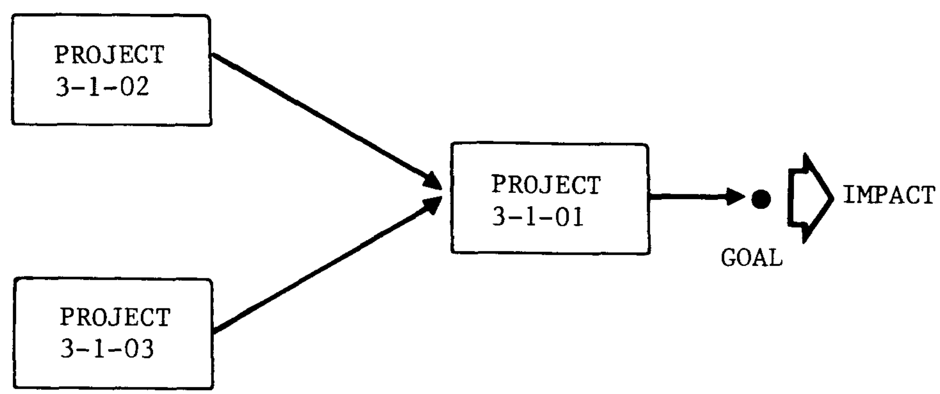


FIGURE 1
INTERDEPENDENCE OF THE PROJECTS CONTAINED IN SUBELEMENT 3-1-A

projects in the Geochemical and Materials Engineering program. Twenty one subelements were formed. They are listed in Figure 2.

If a project can produce identifiable impacts by itself, it alone forms a subelement. In a few cases where a project or a group of projects that form a subelement are rather remote from a quantifiable goal, additional project(s) and costs were postulated. The resulting 21 analyses, one for each subelement, are included in Appendix A.

These analyses followed a common procedure, described in Section 3.0.

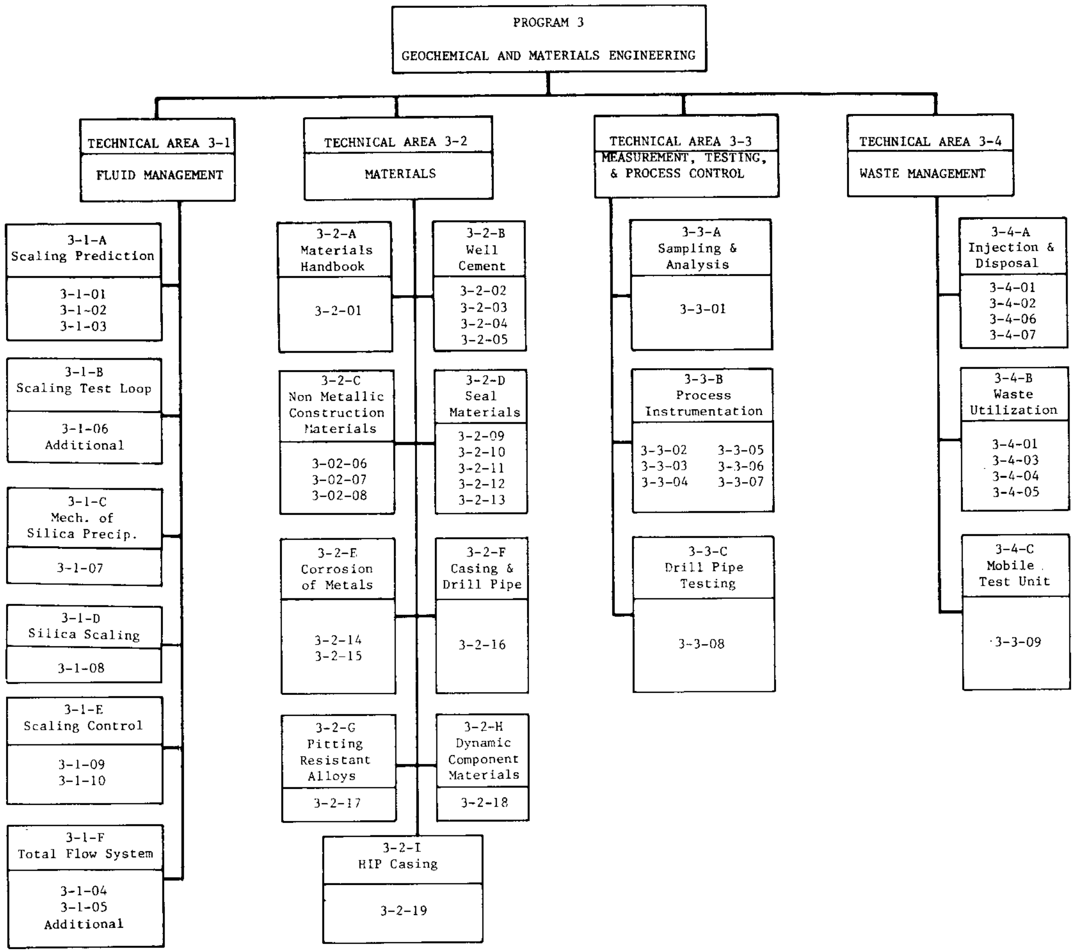


FIGURE 2
ORGANIZATION OF THE PROJECTS OF
THE GEOCHEMICAL & MATERIALS ENGINEERING PROGRAM

3.0 METHOD OF ANALYSIS

The purpose of the analysis was to calculate the figures of merit for each subelement. To do so a number of intermediate tasks were carried out. These tasks are described here in sequential order:

3.1 Identification of Subelement Goal

The goal of the subelement was interpreted from the objectives of the projects contained in the subelement. The developed goal had to:

- Represent and include the R&D results that the projects are intended to achieve.
- Be a method, process, technology, or a piece of hardware which is commercializable and, therefore, would produce an identifiable cost-reducing impact on geothermal electricity production systems.

3.2 Subelement Costs

Subelement costs are the total R&D costs of all the projects contained in the subelement. These costs include sunk and planned costs. The sunk costs (prior to FY78) and planned cost for FY78 were taken from the DGE Management Information System (MIS) sheets [3-5]. Costs planned for Fiscal Years 1979-1983 were provided by DGE officials. Since costs for a Fiscal year were provided in current year dollars, the costs were discounted to 1978 dollars, at a rate of 10% per year by:

$$\text{Present Value (1978)} = \text{Current year cost} \times (1.10)^{1978-\text{Current year}}$$

For example, P.V. (1978) of \$300K planned for subelement 3-1-A in FY82 is:

$$\$300K\ (1.10)^{1978-1982} = \$225K$$

Other costs for Subelement 3-1-A are shown, as an illustration, in Table 5 where the "Prior 77" cost was assumed to be FY 76 cost because its breakdown was not available.

3.3 Identification of Impacted Parameters

Before the benefits of the subelement could be estimated, it was necessary to identify the geothermal energy system parameters which would be impacted by subelement results. These parameters were identified by examining the project objectives, subelement goal, and information about the projects supplied by the contractors. For example, the product of subelement 3-1-A (Figure 2), which is a method to quantify the scaling tendency of geothermal brine, was found to reduce the O&M costs of wells, deep well pumps, piping system, and heat exchangers, and also overdesign and, consequently, the capital cost of heat exchangers. These affected costs are the "impacted parameters" of the subelement.

Impacted parameters were identified from among all the parameters which might have effects on electricity cost. Hence, as initially identified, they might not be necessarily the same as the input variables of the GEOBEN benefits model used to quantify the effects. The capital cost of heat exchangers mentioned above, say, is part of a GEOBEN input variable called "Cost of Process Mechanical (Utility)." When this occurred, the appropriate mathematical relationship between the impacted parameters and input variables of the benefit model had to be worked out.

TABLE 5

COSTS BY FISCAL YEAR FOR SUBELEMENT 3-1-A

PROJECT CODE		COST ($1000) BY FISCAL YEAR									
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78 →	TOTAL
3-1-01	400	149	549	200	200	300	300	300		1300	1849
3-1-02	0	0	0	156	200					356	356
3-1-03	0	0	0	150	1020	0	500			1670	1670
TOTAL	400	149	549	506	1420	300	800	300		3326	3875
($78)	484	164	648	506	1291	273	661	225		2956	3604

3.4 Estimation of the Magnitude of Impacts on System Parameters

"System Parameters" here are the input variables of the benefit model. The impacts on system parameters were estimated by comparing the costs or performance of current technology with those of the new technology to be developed by the R&D subelement. For example, the analysis in Appendix A indicates that the product of Subelement 3-1-A, if brought to practice and used, would reduce the capital cost of heat exchangers by between 15 and 25 percent.

Since the analysis is primarily an estimate of future impacts, establishment of absolute magnitudes was impossible. It was deemed appropriate to postulate a range of changes rather than a single-valued change, e.g., the change from -15% to -25% in the heat exchanger cost above. This was converted to the change in the "Cost of Process Mechanical (Utility Plant)" by multiplying it by a known factor 0.60. The factor 0.6 is the ratio of heat exchanger cost to total process mechanical equipment (utility plant) cost. Thus the impacts on the system parameter "Process Mechanical (Utility) Cost" of Subelement 3-1-A are somewhere between -9% and -15%.

The factor 0.6 used above simplified the calculation markedly. However such factors are not always available. In many cases, extensive analyses were performed before the benefit model inputs could be worked out. Two cases which deserve some attention are subelements 3-2-D and 3-2-H. The expected results of these two subelements are improved elastomeric seals and improved dynamic metallic component materials. Their impacted parameters are the cost and life of drill bits and the drilling rate of penetration. To relate the impacts on these parameters to the impacts on the system parameter "well cost", it was necessary to use a computer model called WELCST [6] that had been developed to analyze impacts of R&D projects on geothermal drilling costs (see Volume II of this report).

As stated above, the estimates of the magnitude of impacts relied heavily on discussions with the R&D contractors and DGE Program Managers, and on published and unpublished conceptual analyses and R&D test results.

3.5 Impact Year

The impact year of the subelement is the year when the results of the subelement can be used and commercialized. It was determined from the reported contractor's schedule.

The GEOBEN benefits model assumes that an engineering/technology improvement must be available for two years prior to the "on-line" date for a geothermal power plant in order to be incorporated into and reduce the cost of the plant. Thus, an improved heat exchanger available at the start of 1985 (impact year) would be incorporated only into plants going into service at the end of 1986 (on-line year) and later.

3.6 Degree of Success

The impacts on system parameters of the subelement were estimated by assuming that:

- The R&D activities will be successfully completed and their objectives are will be achieved.
- Other projects or subelements which impact the same system parameters will not affect the use of the new technology developed in the subelement under consideration.

Thus the benefit estimated for each subelement might be idealistic. It neglects partial success or lack of success during R&D efforts, and assumes that the product of R&D will in fact be used in all plants where it could be used. To account for losses between R&D goals and commercial use of R&D products, a "degree of success" was estimated for each subelement.

The Degree of Success of a subelement is defined as a factor that includes the possibility of partial success and partial use of the subelement results. It was estimated by examining the R&D approach and by estimating the share of market of the resulting technology relative to existing technology and technology currently being developed. The estimate also considered market factors which are not considered in the GEOBEN benefits mode.

A subelement that involves basically compiling measurements and disseminating collected information, such as subelement 3-1-A, would have a degree of success of 1.0 because, although the disseminated information might not be accurate, there is no great reason for the task of making the measurements and reporting them to be partially successful. Another subelement which involves the development of polymer concrete for coating piping and pressure vessel walls to protect against corrosion would share the market with a subelement involving the development of corrosion resistant metals for piping and pressure vessels. The Degree of Success of these two subelements might be different but must add to unity, or to less than unity, if the R&D approaches of either one or both seem unlikely to achieve their goals.

Estimating the Degree of Success was facilitated by dividing the required R&D 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, with modifications to match special characteristics of DGE program policies (1).

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 developed 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 which have geometrical similarity but are smaller in size than 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 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.

The stage or stages into which each subelement fell at the start of F.Y. 1978 was estimated, and indicated in the analysis. The likelihood of technical success was assumed, in general, to increase as a subelement moved through the stages.

By the time a subelement reaches stage v, there has usually been accumulated enough test data to allow fairly good estimates of the technical impact of the subelement on future electric power systems. The likelihood of technical success is then high, and market penetration factors then begin to dominate the estimated Degree of Success.

3.7 Final Calculations

The procedure up to the point generated four quantitative estimates: R&D costs, impacts on system parameters, year of impacts and degree of success. In the subsequent steps of the procedure, the impacts on system parameters and year of impact were used as inputs to the GEOBEN computer model to calculate the estimated benefit. Pessimistic and optimistic estimates were made separately, corresponding to the pessimistic and optimistic estimates of technical impacts on system parameters.

Each estimated benefit was then multiplied by Degree of Success to find the expected benefit, the cost reduction actually anticipated to occur.

The final benefit/cost ratios were calculated by dividing the expected benefit by estimated R&D costs. Two estimates of R&D costs were made for different purposes. For purposes of inputs to decisions about project selection, only current (F.Y.78) plus future R&D costs are placed in the denominator of the benefit/cost ratio. This forward-looking benefit/cost ratio is called the "Figure of

Merit". It does not consider sunk costs, specifically to steer away from any tendency to throw good money after bad.

The second estimate of R&D costs included sunk costs as well as current plus future costs. The benefit/cost ratio based on these total costs is called the "Historical Figure of Merit" to emphasize the relative merit of each subelement through its entire history, from actual beginning to predicted conclusions.

Thus the analysis culminates in four estimates of benefit/cost ratio which indicate the influence of pessimistic and optimistic estimates of impact, and the absence of presence of consideration of sunk costs.

4.0 RESULTS

The results of the benefit/cost analysis of the Geochemical and Materials Engineering program are shown in Tables 6-10.

Table 6 presents a matrix which maps out the impacted system parameters as identified for the 21 R&D subelements of the four technical areas. The listed parameters are the inputs of the benefit model (GEOBEN) and, for clarity, do not include unimpacted parameters. It is noted from the matrix that most parameters are impacted by more than one subelement. In general, the Degree of Success for each subelement has been adjusted to take account of any overlapping economic effects of these multiple impacts on the same parameters.

Tables 7-10 present the numerical results of the analysis. All the cost and benefit figures are expressed in 1978 dollars. Some planned (from FY78 to completion) costs include "additional" costs which are thought to be required, beyond the costs planned by DGE officials, in order to permit the subelement to achieve its goal.

As shown in Tables 7-10, the subelement impacts are estimated for engineering and economic variables first. These impacts are further analyzed to translate them into impacts on hydrothermal electric system parameters, which are then used as inputs for GEOBEN. The outputs of GEOBEN are listed in the column labelled "Calculated Benefit". The as-planned benefit/cost ratios listed in the last column are calculated as follows:

TABLE 6

IDENTIFICATION OF IMPACTED SYSTEM PARAMETER

IMPACTED SYSTEM PARAMETER**	STANDARD TECHNICAL AREA																				
	3-1-						3-2-									3-3-			3-4-		
	SUBELEMENT																				
	A	B	C	D	E	F	A	B	C	D	E	F	G	H	I	A	B	C	A	B	C
				*		*															
PRODUCER																					
Cost per Production Well								X		X		X		X	X			X			
Cost per Injection Well										X		X		X				X			
Cost of Gathering System									X				X								
Cost of Process Mechanical									X				X								
Spent Brine Treatment Cost																				X	
Cost of Distribution System									X				X								
Engineering and Admin. Cost							X				X					X					
General O&M Cost																	X		X	X	
Well O&M Cost (LS)		X	X	X												X		X			
Well O&M Cost (HS, <450°F)		X	X													X		X			
Well O&M Cost (HS, >450°F)		X	X	X														X			
Well Pump O&M Cost (F)		X	X												X			X			
Well Pump O&M Cost (B)		X	X												X			X			
Spent Brine Treatment O&M Cost																	X			X	
Production Well Life (LS)								X				X									
Injection Well Life (LS)																			X	X	X
Production Well Life (HS)								X				X									
Injection Well Life (HS)																			X	X	X
UTILITY																					
Cost of Process Mechanical	X	X			X																
Cost of Piping & Insulation													X								
Cost of Instrumentation																	X				
Engineering and Admin. Cost							X				X					X					
General O&M Cost (F)																	X				
General O&M Cost (B)																	X				
Process Mechanical O&M Cost (B)	X	X			X																

* Not analyzed, see Appendix A.
** LS: Low Salinity, HS: High Salinity, F: Flash, B: Binary

TABLE 7

RESULTS OF THE BENEFIT/COST ANALYSIS FOR THE
STANDARD TECHNICAL AREA 3-1: PRECIPITATION AND GEOCHEMISTRY

MITRE SUBELEMENT CODE	SUBELEMENT TITLE (CONTRACTOR)	COST (10^3 $78)		DATE OF COMM.	ESTIMATED IMPACTS**		CALCULATED BENEFIT (10^6 $78)		DEGREE OF SUCCESS	BENEFIT/COST RATIO (FY78→)	
		SUNK ←FY77	PLANNED FY78→		ON ENGINEERING AND ECONOMIC VARIABLES	ON HYDROTHERMAL ELECTRIC SYSTEM PARAMETERS	PESSIMISTIC	OPTIMISTIC		PESSIMISTIC	OPTIMISTIC
3-1-A	Prediction of Scaling Tendency of Geothermal Brine (LASL, LBL)	648	2956	1983	• 0-30% reduction in labor cost of maintenance activities. • 50% reduction in specified fouling factor.	• 0-9% reduction in O&M costs of well, deep well pump. • 0-0.5% reduction in utility plant O&M cost. • 9-15% reduction in process mechanical cost (utility plant)	72.7	132.3	1.0	24.6	44.7
3-1-B	Study of Scaling in a Test Loop (ORNL)	1006	250 +1239*	1983	As above.	As above	72.7	132.3	0.7	34.2	62.2
3-1-C	Mechanism of Silica Precipitation (LBL)	447	100	1979	• 0-24% reduction in labor cost of maintenance activities of Flash steam plants.	• 0-7.2% reduction in O&M costs of well	0.0	1.9	0.6	0.0	11.5
3-1-D	Study of Silica Precipitation in Supersaturated Water (EIC)	361	0	N/A	Not estimated	Not estimated	N/A	N/A	N/A	N/A	N/A
3-1-E	Scaling Control (DOW, Vetter)	219	75 +174*	1981	• 75% reduction in specified fouling factor • $50K-100K addition for chemical equipment. • 6-12 ppm of controlling agents are required.	• 19.7-26.4% reduction in utility process mechanical cost • 185-370% increase in Binary process mechanical O&M costs.	0.0	28.3	0.3	0.0	34.1
3-1-F	Total Flow System (LLL)	3134 +5965*	0 +1700*	N/A	Not estimated.	Not estimated.	N/A	N/A	0.0	N/A	N/A

* Additional cost to bring the subelement to completion.

** Ranges given include ranges from pessimistic to optimistic estimates, and estimates for different types of conversion plants.

TABLE 8

RESULTS OF THE BENEFIT/COST ANALYSIS FOR THE STANDARD TECHNICAL AREA 3-2: MATERIALS

MITRE SUBELEMENT CODE	SUBELEMENT TITLE (CONTRACTOR)	COST (10^3 $78)		DATE OF COMM.	ESTIMATED IMPACTS**		CALCULATED BENEFIT (10^6 $78)		DEGREE OF SUCCESS	BENEFIT/COST RATIO (FY78→)	
		SUNK ←FY77	PLANNED FY78→		ON ENGINEERING AND ECONOMIC VARIABLES	ON HYDROTHERMAL ELECTRIC SYSTEM PARAMETERS	PESSIMISTIC	OPTIMISTIC		PESSIMISTIC	OPTIMISTIC
3-2-A	Materials Design Handbook (Radian)	62	1249	1981	• $60K-90K reduction in literature search and materials testing costs.	• 1.9-4.5% reduction in pre-construction engineering costs.	17.5	26.6	0.7	9.8	14.9
3-2-B	Well Cement (BNL, NBS, Dowell, Unknown)	540	2350	1982	• Increase well cement life by 1.5-2.0 times. • 10% increase in cement purchased cost. • Eliminating preproduction cement failures. • Eliminating metallic casing for low T, hot water resources.	• 2.7-14.3% increase in well life. • 1.7-3.9% reduction in well cost.	122.2	223.8	0.7	36.4	66.7
3-2-C	Non-Metallic Construction (BNL)	625	3285	1984	• 35-45% reduction in materials costs for pipings. • 2-5% reduction in materials cost for pressure vessels.	• 7.4-31.5% reduction in gathering system cost. • 0.4-1.0% reduction in producer process and mechanical costs. • 24.5-31.5% reduction in distribution piping system. • 1.2-1.6% reduction in in-plant piping and insulation.	86.1	111.5	0.8	21.0	27.2
3-2-D	Seal Materials Development (NASA/JPL, L'Garde, Hughes Aircraft, Sandia, BNL, ASTM)	420	1260	1981	• Increasing application temperature of elastomeric seals to 250°C. • Increasing application temperature of packers for cementing job and cable insulation for logging to 250°C. • Allowing journal bearing bits to be used in portions of wells where they do not survive today.	• 0-3.5% reduction in well cost due to lower drilling cost • 0.6-1.2% reduction in well cost due to less frequent change-out of rotating drill head. • 0-1.2% well cost reduction due to lower cementing cost. • 0.1-0.4% well cost reduction due to lower well stimulation costs. • $13000K-42000K reduction in cable insulation costs of the scenario	44.5	324.7	0.3	10.6	77.3

TABLE 8 (CONTINUED)

RESULTS OF THE BENEFIT/COST ANALYSIS FOR THE STANDARD TECHNICAL AREA 3-2: MATERIALS

MITRE SUBELEMENT CODE	SUBELEMENT TITLE (CONTRACTOR)	COST (10^3 $78)		DATE OF COMM.	ESTIMATED IMPACTS**		CALCULATED BENEFIT (10^6 $78)		DEGREE OF SUCCESS	BENEFIT/COST RATIO (FY78+)	
		SUNK ←FY77	PLANNED FY78→		ON ENGINEERING AND ECONOMIC VARIABLES	ON HYDROTHERMAL ELECTRIC SYSTEM PARAMETERS	PESSIMISTIC	OPTIMISTIC		PESSIMISTIC	OPTIMISTIC
3-2-E	Corrosion of Metal (PNL, ORNL)	1670	275	1979	• $60K-90K reduction in literature search and materials testing cost.	• 1.9-4.5% reduction in pre-construction engineering costs	17.5	26.6	0.3	19.1	29.0
3-2-F	Casing and Drill Pipe Materials (Case Western Reserve U.)	459	547	1979	• 25-30% increase in casing life and drill pipe life. • 4% increase in metal cost.	• 0.1-0.2% increase in well cost. • 1.6-6.1% increase in well life.	26.5	37.6	0.8	38.8	55.0
3-2-G	Pitting and Localized Corrossion Resistant Alloys (BNL)	0	451	1982	• 50% reduction in material requirements for pipings and pressure vessels. • 5% increase in material purchase cost	• 6.3-29.1% reduction in gathering system cost • 8.4-11.6% separator cost • 21.1-29.1% reduction in disposal pipings • 1.1-1.5% reduction in in-plant process piping cost.	86.4	119.3	0.1	19.2	26.5
3-2-H	Dynamic Component Materials (BNL)	0	783	1982	• Allowing air drilling in the lower 30% of well where bit T is up to 400°C • 20% increase in bit cost • 5-10% increase in drilling rate of penetration and bit life. • 50% reduction in downhole motor drilling usage cost • 2-5% reduction in O&M cost of deep well pump.	• $28300K-75200K reduction in well cost up to the year 2000 across the scenario • $11400K-103700K reduction in total O&M cost of deep well pumps used in the scenario	39.7	103.7	0.3	15.2	39.7
3-2-I	Geopressured Hot Isostatic Pressed Clad H.I.P. Materials Development (BNL)	0	2330	1984	• 20-40% increase in geopressured well casing cost • 15-20% reduction in geopressured well O&M cost	• 2-4% increase in geopressured well cost • 15-20% reduction in geopressured well O&M cost	142.0	605.0	0.5	30.5	129.8

** Ranges given include ranges from pessimistic to optimistic estimates, and estimates for different types of conversion plants.

TABLE 9

RESULTS OF THE BENEFIT/COST ANALYSIS FOR THE STANDARD TECHNICAL AREA 3-3:

MITRE SUBELEMENT CODE	SUBELEMENT TITLE (CONTRACTOR)	COST (10^3 \$78)		DATE OF COMM.	ESTIMATED IMPACTS**		CALCULATED BENEFIT (10^6 \$78)		DEGREE OF SUCCESS	BENEFIT/COST RATIO (FY78→)	
		SUNK ←FY77	PLANNED FY78→		ON ENGINEERING AND ECONOMIC VARIABLES	ON HYDROTHERMAL ELECTRIC SYSTEM PARAMETERS	PESSIMISTIC	OPTIMISTIC		PESSIMISTIC	OPTIMISTIC
3-3-A	Sampling and Analysis Manual (PNL)	495	670	1980	• \$10K-15K reduction in literature search cost • \$8K-12K reduction in analysis cost	• 2.9-6.6% reduction in pre-construction engineering costs	27.4	41.5	0.5	20.5	31.0
3-3-B	Process Instrumentation (NAS, PNL)	486	2816	1981	• 0-2% increase in instrumentation costs • 0-30% reduction in labor costs of maintenance activities	• 0-2% increase in instrumentation cost • 0-9% reduction in producer O&M cost • 5-9% reduction in deep well pump O&M cost • 0-3% reduction in utility O&M costs • 2-9% reduction in spent brine treatment O&M cost	3.5	79.9	0.7	0.9	19.9
3-3-C	Non Destructive Evaluation (NDE) Technique (DAI)	40	179 45*	1980	• 50% reduction in mishap frequency in well drilling • 15% of drill pipes rejected	• 0.5-3.3% reduction in well cost	14.0	155.1	0.8	50.0	553.9

* Additional cost to bring the subelement to completion.
** Ranges given include ranges from pessimistic to optimistic estimates, and estimates for different types of conversion plants.

TABLE 10

RESULTS OF THE BENEFIT/COST ANALYSIS FOR THE STANDARD TECHNICAL AREA 3-4:

MITRE SUBELEMENT CODE	SUBELEMENT TITLE (CONTRACTOR)	COST (10^3 $78)		DATE OF COMM.	ESTIMATED IMPACTS**		CALCULATED BENEFIT (10^6 $78)		DEGREE OF SUCCESS	BENEFIT/COST RATIO (FY78→)	
		SUNK ←FY77	PLANNED FY78→		ON ENGINEERING AND ECONOMIC VARIABLES	ON HYDROTHERMAL ELECTRIC SYSTEM PARAMETERS	PESSI-	OPTI-MISTIC		PESSI-MISTIC	OPTI-MISTIC
3-4-A	Spent Fluid Disposal (PNL, Vetter, Oklahoma U)	0	2584	1983	• 5-15% increase in injection well life	• 5-15% increase in injection well life • 1.8-2.6% reduction in producer general O&M costs	30.9	56.9	0.7	8.5	15.6
3-4-B	Waste Utilization (PNL, others unknown)	0	1556	1984	• Eliminate responsibility of injection fluid treatment • 5-15% increase in injection well life	• 80-100% reduction in costs of spent brine treatment • 5-15% increase in injection well life • 1.8-2.6% reduction in producer general O&M costs	261.2	324.4	0.3	50.4	62.5
3-4-C	Mobile Test Unit	0	0 1973*	1982	• Increase knowledge on fluid behavioral interdependence between production and injection wells and the reservoir	• 2-5% increase in injection well life	0.0	9.1	0.5	0.0	2.3

* Additional cost to bring the subelement to completion.
** Ranges given include ranges from pessimistic to optimistic estimates, and estimates for different types of conversion plants.

$$\text{Benefit/Cost Ratio} = \frac{\text{Benefit x Degree of Success}}{\text{Planned Cost}}$$

Some subelements which have been either completed or terminated are not required to be analyzed and therefore their result columns are marked with "not estimated" or "N/A" (not applicable). Some of these subelements still have certain planned costs which were either obligated in FY77 or required to complete on-going activities, and are included for FY78 only.

The numerical estimates given in the Estimated Impacts column are, in most cases, expressed as ranges. These ranges cover values of pessimistic and optimistic estimates and their variations from one type of conversion system (e.g., binary plant) to another.

5.0 DISCUSSION AND CONCLUSION

5.1 Projects in the Context of the Program

To summarize the merit of R&D activities in the Geochemical and Materials Engineering program,Table 11 lists the costs and benefits of the projects in the decreasing order of subelement's optimistic figure of merit. If the cummulative cost and benefit are calculated as shown in Table 11 and are plotted out as shown in Figure 3, the benefit can be visualized for any amount of funding regardless of individual projects. Superimposed on Figure 3 are the lines of different benefit/cost ratios which are included for comparison purpose. As expected and as shown in Figure 3, returns of R&D investments are high at low level of R&D investment and leveled off as more R&D money is invested. The overall benefit/cost ratio of the Geochemical and Materials Engineering program as planned, after and including FY78, is between 18.3 and 39.8. If previous costs of on-going projects are included, the "historic" B/C ratio is somewhere between 14.5 and 31.5. These B/C ratios apply to electricity production only. They do not include non-electric applications and geopressured methane production (subelement 3-2-I).

5.2 Benefit/Cost Ratios of Technical Areas

The projects within each of the four technical areas of the Geochemical and Materials Engineering were grouped and an overall Benefit/Cost ratio was estimated for each area, as shown in Table 12.

It is noted that in the Standard Technical Area of

TABLE 11

BENEFIT AND PLANNED COST OF THE PROJECTS IN
THE GEOCHEMICAL AND MATERIALS ENGINEERING PROGRAM

CODE	SUBELEMENT TITLE	NUMBER OF PROJECT[1]	EXPECTED BENEFIT (10^6 \$78)[2]				PLANNED COST (10^6 \$78)		FIGURE OF MERIT[3]		HISTORICAL FIGURE OF MERIT[4]	
			BY SUBELEMENT		CUMMULATIVE							
			PESSIMISTIC	OPTIMISTIC	PESSIMISTIC	OPTIMISTIC	BY SUBELEMENT	CUMMULATIVE	PESSIMISTIC	OPTIMISTIC	PESSIMISTIC	OPTIMISTIC
3-3-C	NDE Technique	1	11.2	124.1	11.2	124.1	0.224	0.224	50.0	553.9	42.4	470.1
3-2-D	Seal Materials	5	13.4	97.4	24.6	221.5	1.260	1.484	10.6	77.3	8.0	58.0
3-2-B	Well Cement	4	85.5	156.7	110.1	378.2	2.350	3.834	36.4	66.7	29.6	54.2
3-4-B	Waste Utilization	3½	78.4	97.3	188.5	475.5	1.556	5.390	50.4	62.5	50.4	62.5
3-2-F	Casing and Drill Pipe Mats.	1	21.2	30.1	209.7	505.6	0.547	5.937	38.8	55.0	21.1	29.9
3-1-A	Scaling Prediction	3	72.7	132.3	282.4	637.9	2.956	8.893	24.6	44.7	20.2	36.7
3-2-H	Dynamic Comp. Materials	1	11.9	31.1	294.3	669.0	0.783	9.676	15.2	39.7	15.2	39.7
3-1-E	Scaling Control	2	0.0	8.5	294.3	677.5	0.249	9.925	0.0	34.1	0.0	18.2
3-3-A	Sampling and Analysis HB	1	13.7	20.9	308.0	698.4	0.670	10.595	20.5	31.0	11.8	17.9
3-2-E	Corrosion of Metals	2	5.3	8.0	313.3	706.4	0.275	10.870	19.1	29.0	2.7	4.1
3-2-C	Non-Metallic Const. Mats.	3	68.9	89.2	382.2	795.6	3.285	14.155	21.0	27.2	17.6	22.8
3-2-G	Pit. & Loc. Cor. Resist. Mats.	1	8.6	11.9	390.8	807.5	0.451	14.606	19.2	26.5	19.2	26.5
3-3-B	Process Instrumentation	6	2.5	55.9	393.3	863.4	2.816	17.422	0.9	19.9	0.8	16.9
3-4-A	Spent Fluid Disposal	3½	21.6	39.8	414.9	903.2	2.584	20.006	8.5	15.6	8.5	15.6
3-2-A	Materials Design HB	1	12.3	18.6	427.2	921.8	1.249	21.255	9.8	14.9	9.4	14.2
3-1-C	Silica Scaling	1	0.0	1.1	427.2	922.9	0.100	21.355	0.0	11.5	0.0	2.0
3-4-C	Mobile Test Unit	1	0.0	4.6	427.2	927.5	1.973	23.328	0.0	2.3	0.0	2.3
3-X-X	ENTIRE PROGRAM	40	----	-----	427.2	927.5	-----	23.328	18.3	39.8	14.5	31.5

[1] Excluding 3 not-estimated projects, 1 duplicating effort (subelement 3-1-B), 1 on geopressured well, ½ project indicates a project has been shared by two subelements.

[2] Degree of success included.

[3] Excluding sunk costs.

[4] Including sunk costs.

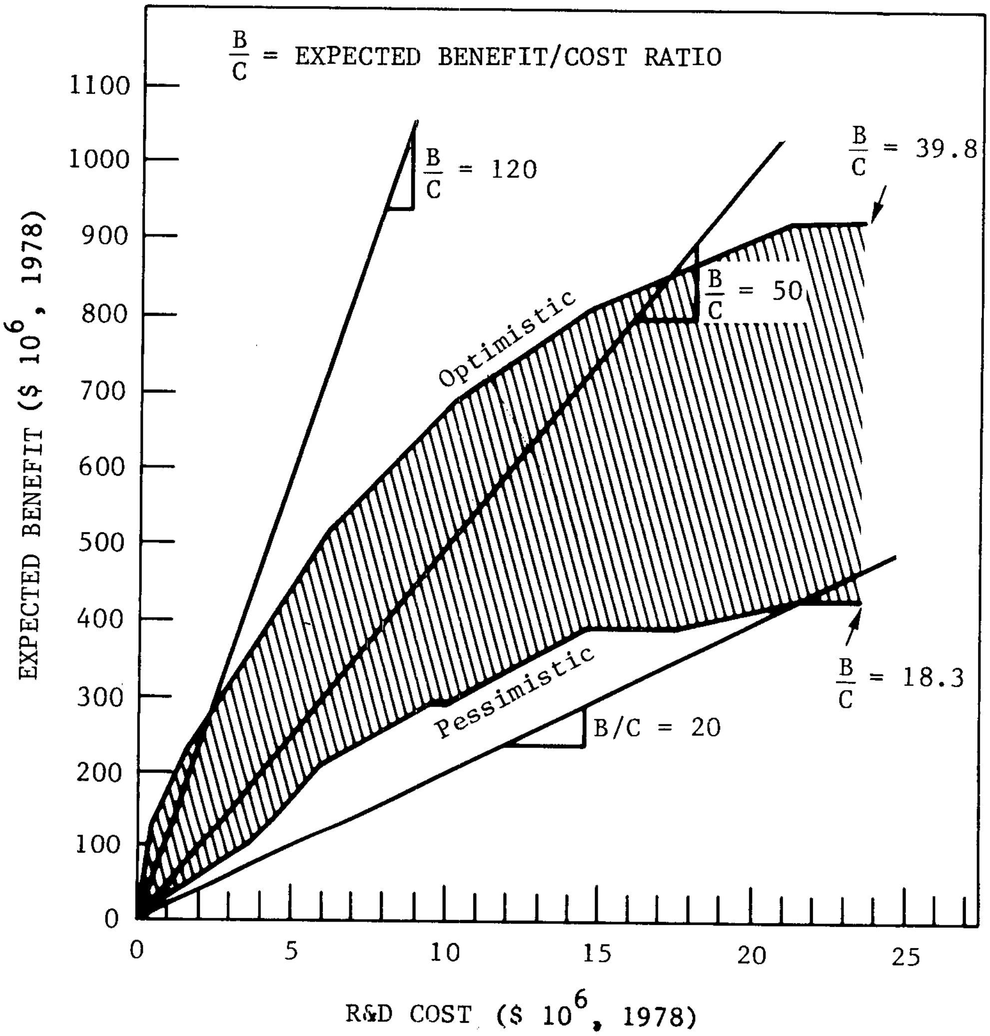


FIGURE 3
EXPECTED BENEFIT VS. PLANNED PLUS ADDITIONAL R&D COST FOR THE GEOCHEMICAL & MATERIALS ENGINEERING PROGRAM

TABLE 12

BENEFIT/COST RATIOS OF STANDARD TECHNICAL AREAS IN GEOCHEMICAL AND MATERIALS ENGINEERING PROGRAM

STANDARD TECHNICAL AREA	COST (10^3 \$78)[1]		EXPECTED BENEFIT[2] (10^6 \$78)		FIGURE OF MERIT[1]		HISTORICAL FIGURE OF MERIT[3]	
	SUNK ←FY77	PLANNED FY78→	PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC	PESSI-MISTIC	OPTI-MISTIC
Precipitation and Geochemistry	1314	3305	72.7	141.9	22.0	42.9	15.7	30.7
Materials	3776	10200	227.1	443.0	22.3	43.4	16.3	31.7
Measurement, Testing, & Process Control Technology	1021	3710	27.4	200.9	7.4	54.1	5.8	42.5
Waste Management	0	6113	100.0	141.7	16.4	23.2	16.4	23.2
ENTIRE PROGRAM	6111	23328	427.1	927.5	18.3	39.8	14.5	31.5

[1] Excluding costs of projects which have been completed or terminated.

[2] Product of calculated benefit and degree of success.

[3] Including sunk costs.

Precipitation and Geochemistry there are four projects which appear to be redundant. These projects were classified into three subelements two of which were marked "not estimated" in Table 7. The two not-estimated subelements involve either basic research too theoretical for identifiable applications or research related to a technology which has been proven uneconomical elsewhere (Total Flow System). The subelement 3-1-B which was analyzed is in direct competition with another subelement, 3-1-A (See Table 7) and therefore its benefits, although estimated, are not included in Tables 11 and 12. The existence of the hard-to-identify-benefit projects in this area and the fact that these projects have been discontinued (although some projects are still receiving "clearing-up" funding) indicate good progress toward better understanding of problems in geothermal utilization.

Table 12 shows for each technical area sunk costs, planned costs (with FY78 costs treated as planned costs), and pessimistic and optimistic estimates of: Expected Benefit, Figure of Merit, and Historical Figure of Merit. "Expected Benefit" is the calculated benefit multiplied by "Degree of Success". "Figure of Merit" is based on planned costs alone; this reflects the forward-looking value of the Technical Area at the start of FY 1978. "Historical Figure of Merit" is based on the sum of sunk and planned costs; it reflects the return on value over all R&D costs for the technical area.

The estimates in Table 12 suggest the following major points of discussion.

(1) R&D in the Materials area produces both the largest expected benefit and the highest mean benefit/cost ratio. This is expected because materials problems are encountered in almost every component of a geothermal system, especially in the components which are in contact with the geothermal liquid. Materials integrity has strong effects on the final cost of electricity production, and, hence, R&D investment in material improvement is expected to yield high returns. It must be noted here that the benefits gained in non-electric applications and geopressured systems were not included.

(2) The lowest mean benefit/cost ratio is found in the Waste Management area. This is not because the area has little room for improvement due to R&D but because successful improvements of such types of projects relating to chemical removal and chemical treatment of the geothermal fluid are rather expensive to achieve. However, it is not that environmental problems arising from the disposal of geothermal spent fluid can be critical depending on the local regulations. These problems sometimes, can put a geothermal power plant in the go or no-go situation in which they must be solved before electricity production can be realized, and therefore benefit R&D investments, although they have low expected cost-saving returns across the board of the geothermal development scenario, are exceptionally high here.

(3) The ratio of optimistic benefit over pessimistic benefit is largest for the area of Measurement, Testing and Process Control Technology. This indicates that the uncertainty in estimating the benefits of the subelements contained in this area is relatively higher than in other areas. Such high uncertainty is mainly due to the difficulties in identifying and then estimating the impacts of the R&D activities involved. It is easy to recognize the importance of having accurate measurements and monitoring capability in a geothermal system. However such importance can only be translated into real benefits if

accurate instruments and monitoring capability are coupled with technologies which can deal economically with undesirable signals appearing on the monitoring screen. In other words, although R&D activities in this area are making an important step toward the control of geothermal system operations, additional activities to transform information from monitoring devices into cost-effective operation strategies are still required.

(4) The benefits estimated for the area of Waste Management, although they are small as discussed in (2), are least uncertain. This is because the objectives of the R&D activities are well defined and are concerned with easily identifiable economic factors in a geothermal system. Wastes discharged from a geothermal power plant include gases, waste heat, waste water, and minerals with or without commercial value. The benefits of utilizing or recovering or disposing of these wastes can be estimated against currently known practic , with minimal uncertainty.

5.3 Potential Impacts of Program on Geothermal Electricity Cost at Liquid-Dominated Prospects.

The total benefit, taking into account all the individual sub-element's Degree of Success, is between about 0.50 and 1.23 billion 1978-dollars. If the project on geopressured well casing is excluded, the benefit is between 0.43 and 0.93 billion 1978-dollars (see Table 11). This benefit is the total saving of electricity production costs for power plants scheduled in the reference scenario for installation between the years 1979 and 2000 inclusively at 27 U.S. liquid-dominated geothermal prospects.

If current technology only (no impacts from R&D) is assumed, the total electricity production cost (capital and O&M costs) for the hydrothermal scenario, as estimated by the GEOBEN model, is $10.93 billion (1978 dollars). Thus the percentage cost reduction expected from the products of the R&D projects in this program range between (0.43/10.93) x 100 = 3.9% and (0.93/10.93) x 100 = 8.5%.

The average electricity cost reduction of 3.9-8.5% may seem to be high but is quite realistic. In individual cases such saving can bring the electricity cost at many prospects down to competitive levels relative to electricity that is generated from other sources of energy.

5.4 Major Conclusions of this Analysis

Following are the major conclusions reached from the benefit/cost analysis of the current R&D activities in the Geochemical and Materials Engineering program:

- As an average across the U.S. scenario for geothermal electricity development, the electricity cost reduction generated is somewhere between 3.9 and 8.5%.
- R&D in materials development area yields highest impacts even when direct heat and geopressured applications are excluded.
- R&D activities in the area of precipitation and geochemistry show evidence of becoming more goal-orientated.
- Although there are high benefit projects, more goal-orientated definitions are needed in the measurement, testing and process control technology area.
- Current projects in the Waste Management area have low benefit/cost ratio, but Waste Management is a critical program element which cannot be neglected.

- Not counting possible overlaps with projects in other R&D programs, the as-planned benefit/cost ratio of the whole program falls somewhere between 18.3 and 39.8.

REFERENCE

1. H.S. Dhillon and D.J. Entingh,"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", MITRE Report MTR-7694, May 1978.

2. J.N. Gupta and J.G. Leigh, "GELCOM, A Geothermal Levelized Busbar Cost Model - Description and User's Guide", MITRE Report M78-17, January 1978.

3. "Geothermal Energy Budget and Planning Detail - Operating Funds" DGE's computer printout # R-1508300-001, December 7, 1977.

4. "Geothermal Energy Current Year Financial Procurement Plan - Operating Funds", DGE's computer printout # R1508315-007, December 5, 1977.

5. "Geothermal Energy Current Year Financial Procurement Plan - Operating Funds", DGE's computer printout # R-1508315-007, April 13, 1978.

6. D.J. Entingh and A. Lopez, "WELCST, Engineering Cost Model of Geothermal Wells - Description and User's Guide", MITRE Report M78-86, December 1978.

APPENDIX A

1.0 INTRODUCTION

This appendix presents the benefit analyses of the subelements of the four technical areas discussed in the main body of this report. The subelements are identified by their code numbers and titles. A subelement code number consists of two digits and a letter and is designated in a manner similar to the project code number. For example, subelement 3-2-B indicates subelement B of the technical area number 2 in program number 3. Program number 3, namely, Geochemical Engineering, has 45 projects that are grouped into 21 subelements shown in Figure A-1.

The analyses are based on the subelement goals. These goals are interpreted from the objectives of the R&D projects contained in the subelements. In a few cases where a project or a group of projects that make up a subelement appear to be somewhat remote from the commercialization of a practical device or process, additional R&D costs required to complete the development are estimated, and the analysis is performed as if the subelement goal will achieve a commercializable improvement in geothermal technology.

In the next 21 sections, one for each subelement, a uniform format is followed. Each section contains a covering summary page followed by the rationale of the analysis. The analysis rationale includes the following subsections:

0. SUBELEMENT Code Number: Title
   The title is written in full rather than in the shortened form shown in Figure A-1.

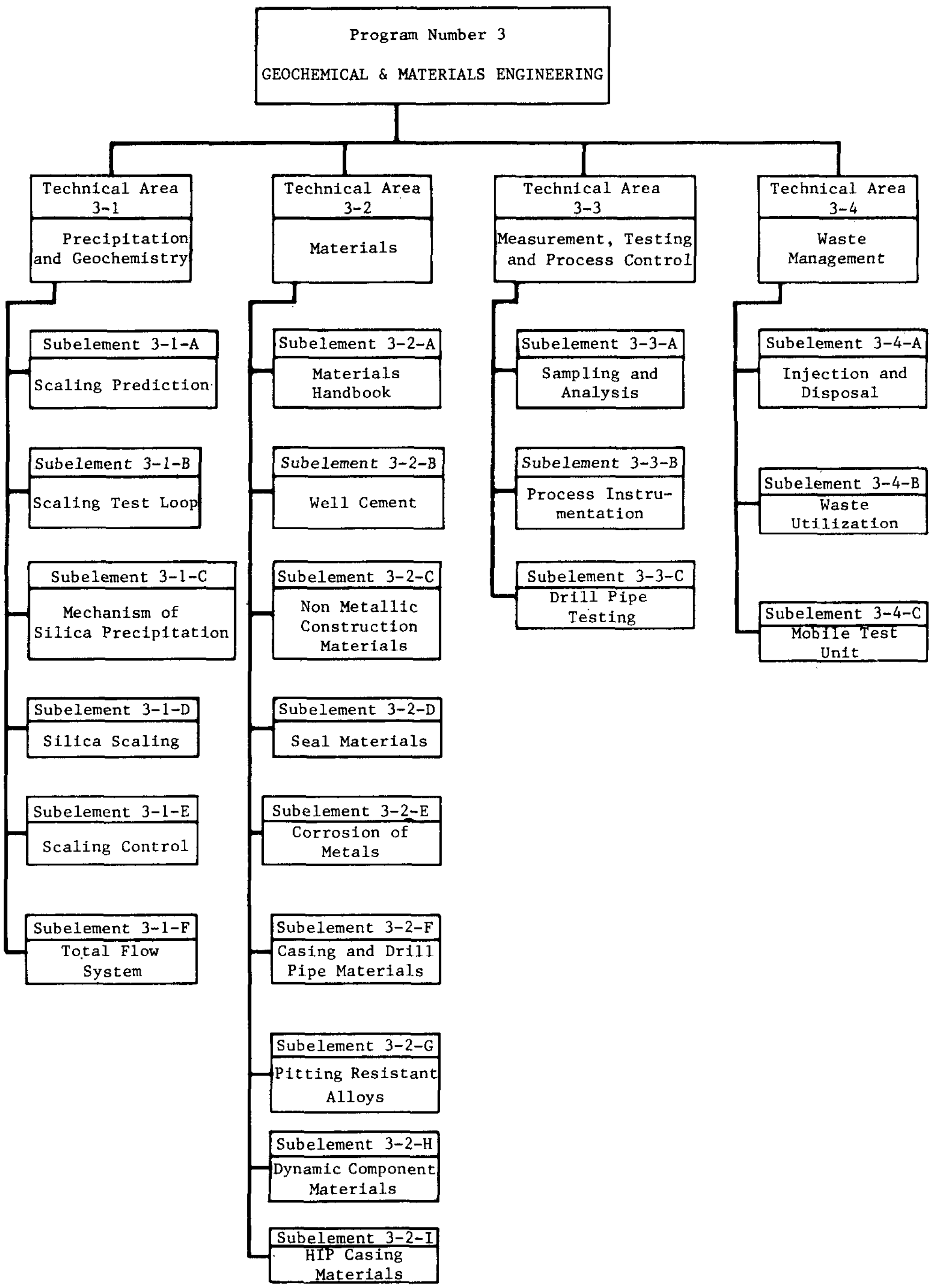


FIGURE A-1
SUBELEMENTS OF THE GEOCHEMICAL AND MATERIALS ENGINEERING PROGRAM

1. PROJECT(S) IN SUBELEMENT:

   This subsection includes a list of the projects contained in the subelement and a block diagram showing the project relationships, to each other and to the subelement goal. The projects can include those additional to the existing ones.

2. GOAL:

   The goal is interpreted from the project objectives.

3. COSTS:

   The subelement costs include the sunk costs, current year (Fiscal Year 1978) costs, and estimated future costs of all the projects, including additional ones, contained in the subelement.

4. IDENTIFICATION OF IMPACTED PARAMETERS:

   These parameters are those which affect electricity generation from hydrothermal resources in terms of costs and component performance characteristics.

5. IMPACTS ON SYSTEM PARAMETERS:

   Primary benefits are derived from consideration of impacted parameters and are expressed in the forms suitable for inputs to the benefits model. The structure and guides for users of the benefits model are described in Volume I of this report.

6. DEGREE OF SUCCESS:

   This is a subjective estimate of the probability of success of the subelement activities relative to the subelement goal.

7. RESULTS:

   The computer calculation using the inputs estimated in subsection 5 yields the subelement benefits. These benefits are expressed in terms of the revenue requirement saving (discounted to 1978 dollars) in electricity production. The electricity production is based on a scenario of power plant installation at 27 hydrothermal prospects in the U.S. between 1979 and 2000. The "figure of merit" of the subelement is then calculated by:

$$\text{Figure of Merit} = \frac{\text{Saving}}{\text{Subelement Cost}} \times \text{Degree of Success}$$

The results of the analysis of primary benefits consist of two sets of figures which are called pessimistic and optimistic benefits. These are used to reflect the uncertainty inherent in such analyses as the ones performed here. The degree of success estimated in subsection 6 reflects the merits of the approaches which are outlined and followed by project contractors in relation to the final R&D goal. Some subelements have sound approaches but their results can be applicable to a fraction of the future sites only. Such fraction, too, will be incorporated in the degrees of success of those subelements.

2.0 SUBELEMENT 3-1-A:

PREDICTION OF SCALING TENDENCY OF GEOTHERMAL BRINE

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-1-A	CONTRACT NUMBER(S) 05ENG36
TITLE Prediction of Scaling Tendency of Geothermal Brine	
CONTRACTOR(S) Los Alamos Scientific Laboratory, Lawrence Berkeley Laboratory	

RELATED PROJECTS
3-1-01 Scale Formation Modeling
3-1-02 Mineral Solubility Data - RFP
3-1-03 Hydrodynamic/Kinetic Reaction Engineering R&D - RFP

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

3-1-02	3-1-03	3-1-01			
Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	549										549
2. DGE Planned:		506	1420	300	800	300					3326
3. Additional:											0
Total:	549	506	1420	300	800	300					3875
Discounted Total of Planned and Additional:											2956

EXPECTED YEAR OF COMMERCIALIZATION 1983

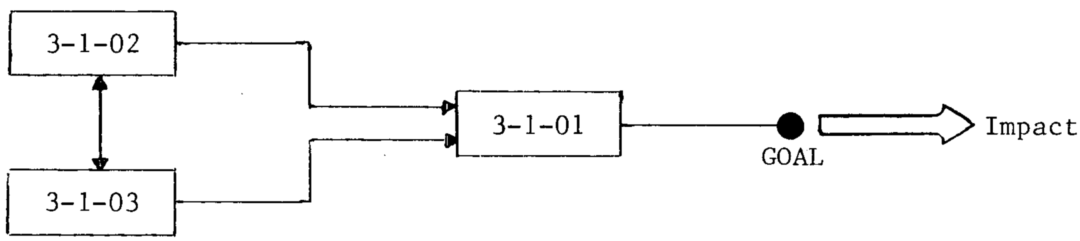
EXPECTED DEGREE OF SUCCESS 1.0

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	132.3
	PESSIMISTIC	72.7
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	44.7
	PESSIMISTIC	24.6
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	36.7
	PESSIMISTIC	20.2

SEE ATTACHED PAGES FOR RATIONALE

2.1 Projects in Subelement

PROJECT CODE	PROJECT TITLE
3-1-01	Scale Formation Modeling
3-1-02	Mineral Solubility Data - RFP
3-1-03	Hydrodynamic/Kinetic Reaction Engineering R&D - RFP



2.2 Goal

Understanding of brine chemistry and capability to predict quantitatively the scaling tendency of geothermal brines.

2.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR											
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	>83	TOTAL 78 →	TOTAL
3-1-01	400	149	549	200	200	300	300	300			1300	1849
3-1-02	0	0	0	156	200						356	356
3-1-03	0	0	0	150	1020	0	500				1670	1670
TOTAL	400	149	549	506	1420	300	800	300			3326	3875
($78)	484	164	648	506	1291	273	661	225			2956	3604

2.4 Identification of Impacted Parameters

Scaling due to deposition of brine constituents can occur in plant components that are in contact with brine. These include well casing, fluid transport systems, and heat exchangers. The benefits of the subelement 3-1-A can be estimated by examining the effects that the R&D projects, assumed successful, could have on these components. The approach is based on the following understandings:

(i) The ability to predict scaling tendency does not solve the scaling problems.

(ii) Since the scaling tendency of dry steam is negligible compared with that of steam-brine mixtures and brine alone, components of dry-steam plants are assumed to be unaffected by scaling.

The benefits of having the ability to predict the scaling tendency of the brine can be identified in two areas: operations management and component design.

Operations Management: Let us assume that a geothermal power plant is in operation and examine the O&M steps taken by the plant manager or a plant engineer to ensure proper functioning of the plant. If the plant manager does not have information on scaling characteristics of the brine, he would determine their effects by continuously examining the performance of those plant components which are in contact with the brine. As an example, he finds that, with constant inlet conditions, the fluid flow rate in the transport system is decreasing. He might assume after checking upstream pressures that the system is being clogged up somewhere along the flow path and might decide at a particular time that the system must be taken apart for either cleaning or replacement. Now, if an accurate method of scaling prediction is available, the manager can estimate when and especially where the system needs cleaning or replacement, and hence, schedule the O&M activities and manage his labor resources more effectively. It is noted, however, that because the O&M requirements are unchanged, the operating power factor can be assumed to be unaffected. The saving which is identifiable here is the reduction in the O&M costs.

Component Design: If the method for predicting scale formation is available, estimates of fouling of components in contact with the brine are possible. Hence, a certain amount of guess work in equipment design can be eliminated, and, consequently, a substantial portion of overdesign can be avoided. The derivative benefit is a reduction in capital costs. Components which are affected by scaling problems are wells (production and injection wells), gathering pipelines, and heat exchangers.

2.5 Impacts on System Parameters

2.5.1 Operation Management

Reduction of O&M costs due to effective management is difficult to quantify without performing an extensive analysis on the overhead structure and operating procedures of geothermal power plants on a site basis. Such extensive analysis is clearly not possible at this stage because the U.S. geothermal industry has not yet been developed to the level which can provide adequate information for doing so.

The estimate presented here thus is approximate and is based on the following assumptions:

(i) The portion of O&M costs which is possibly impacted by effective management is the labor cost. The labor cost is assumed to constitute about 30% of the total O&M costs.

(ii) Scaling problems are expected to be more pronounced at high salinity sites than at low salinity sites.

(iii) Components in contact with brine are assumed to be affected by scaling problems more in flash steam systems than in binary systems.

(iv) The impacts are assumed to depend on the severity of scaling problems. The more pronounced the problems the stronger the impacts.

Because the effectiveness of the O&M management does not solve the scaling problems, only a portion of the labor cost is affected by the results of this subelement. The magnitude of this portion varies depending on the O&M cost items and the accuracy of the prediction method. Thus, the impact of this subelement has a range rather than a single figure. If the prediction method is accurate and the O&M cost item under consideration is sensitive to scaling problems, the effectiveness of the O&M management is assumed to impact no more than 30 percent of the labor cost or, according to assumption (i), 9 percent of the O&M cost. In the other extreme, where the prediction method turns out to be inaccurate and/or the O&M cost item is cost sensitive to scaling problems, the impact can easily be zero.

According to the above argument, the impact of this subelement on any O&M cost item is somewhere between 0 and -9 percent. Taking 0 and -9 percent as the lower and upper limits, impacts on individual O&M cost items were estimated within the framework of assumptions (ii), (iii), and (iv) as follows:

BENEFIT MODEL INPUT PARAMETERS	PESSIMISTIC		OPTIMISTIC	
	FLASH	BINARY	FLASH	BINARY
% Change in Producer General O&M Cost Factor^{+}	0	0	-5.0	-3.0
% Change in Producer* Well O&M Cost Factor (Low Salinity)	0	0	-5.0	-3.0
% Change in Producer Well O&M Cost Factor (High Salinity, T >450^{o}F)	-3.0	-2.0	-9.0	-6.0
% Change in Producer Well O&M Cost Factor (High Salinity, T >450^{o}F)	-5.0	-3.0	-9.0	-6.0
% Change in Producer Deep Well Pump O&M Cost Factor (Flash)	-5.0	0	-9.0	0
% Change in Producer Deep Well Pump O&M Cost Factor (Binary)	0	0	0	-3.0
% Change in Utility General O&M Cost Factor (Binary Systems)	0	0	0	-0.5**

NOTE: (*) Producer owns and operates production and injection wells, separators, and brine and steam pipelines.
(**) Small because only O&M of the heat exchangers is affected.
(+) This factor includes piping systems.

2.5.2 Component Design

Three components are discussed here. They are wells, fluid gathering and transport systems, and heat exchangers. Well design is mainly based on drilling and well completion technologies, and the flow characteristics of the resource. It takes into consideration the scaling tendency of the resource in terms of well economy and well operations but is not dependent on scaling tendency for design purposes. The knowledge of brine scaling tendency would, in some cases, suggest abandoning incompleted wells and would certainly affect the O&M of the wells, but is expected to make minimal impacts on the well capital cost. A similar argument applies to the fluid gathering and transport systems. In designing the pipelines and pressure vessels for the gathering and transport systems, one might tend to overdesign the wall thickness to accomodate the uncertainty in specifying brine corrosion rate, rather than design the system for scaling. Thus it is reasonable to assume that the ability to predict scaling tendency of geothermal brine does not noticeably affect the capital costs of wells and gathering and transport systems. Its benefits can be identified in the heat exchanger costs, however.

The scaling related parameter used in the design of heat exchangers is the waterside fouling factor. The fouling factor is the heat transfer resistance of the scale on the heat exchange surface and is the limit of the scale build-up at which the required performance of the heat exchanger can still be achieved. The higher the value of the fouling factor the more heat exchange surface is required and hence the more costly the heat exchanger. Thus it can be seen that overdesign which results in unnecessary high cost is very likely here if scaling tendency of the brine is not known. Let us now take a closer look at the design method for heat exchangers.

The heat exchange area A is calculated by

$$A = \frac{Q}{U \Delta t_m} \quad (1)$$

where Q and Δt_m are the heat to be transferred and the corrected log mean temperature difference respectively, and are the performance characteristics to be specified prior to designing heat exchanger; U is the overall heat transfer coefficient to be determined. The coefficient U is calculated by:

$$\frac{1}{U} = \frac{1}{h_o} + f_o + \frac{1}{h_i}\frac{A_o}{A_i} + f_i\frac{A_o}{A_i} + r_w \tag{2}$$

where h is the film coefficient, f the fouling factor, and r_w the heat transfer resistance of the tube walls. The subscripts o and i denote outside and inside of the tubes respectively. The cross sectional area ratio A_o/A_i is used to convert the inside quantities to the outside values. Let us consider a design case using 3/4 inch OD tubings with the following quantities:

h_o = 300 Btu/(hr.ft^2 ^{o}F)

f_o = 0.0005 hr. ft^2 ^{o}F/Btu

h_i = 1500 Btu/(hr. ft^2 ^{o}F)

A_o/A_i = 0.75/0.62 = 1.21 (16 BWG tubing)

r_w = negligible

and hence

$$\begin{aligned}\frac{1}{U} &= 0.003333 + 0.0005 + 0.000807 + 1.21\ f_i \\ &= 0.004640 + 1.21\ f_i\end{aligned} \tag{3}$$

The values specified above are typical for exchangers of sensible heat and boiling heat. Let us assume also that because of the lack of knowledge on scaling tendency of the brine, a value 0.004 is taken for f_i. This makes the value of U, according to equation (3), equal to 105.5 Btu/(hour.ft^2°F). If, under the same conditions, the value of f_i is really 0.002 as predicted by the results of subelement 3-1-A, the coefficient U becomes 141.6 Btu/(hour.ft^2°F). Since the heat exchange area is inversely proportional to U, the value of A becomes smaller. If 0.8 power is used for the relationship between capital cost and area for heat exchangers, the new cost becomes:

$$\text{New cost} = \text{old cost} \left(\frac{105.5}{141.6}\right)^{0.8} = \text{old cost} \times 0.79 \qquad (4)$$

Thus a cost reduction of (1 - 0.79) = 21 percent results. If the accuracy of the prediction method developed in subelement 3-1-A is doubtful, some overdesign is required for a safe design. So, instead of 0.002, a value of 0.0025 is used for f_i. The resulting cost saving from calculations using equations (3) and (4) is 16 percent.

The above calculations illustrate the order of magnitude of possible cost saving if overdesign can be avoided. Hence, taking into account the variation in accuracy of the product, it is reasonable to assume that the benefits of the subelement 3-1-A in this aspect is somewhere between 15 and 25 percent saving in heat exchanger capital cost. In terms of the input parameter for the cost mode, heat exchanger cost makes up about 60% of the utility process mechanical capital costs, and the imapct of the benefit becomes:

Benefit Model Input Parameter	PESSIMISTIC (Binary Only)	OPTIMISTIC (Binary Only)
% Change in Capital Cost of Process Mechanical (utility)	-9.0	-15.0

2.6 Degree of Success

The activities involved in the subelement 3-1-A are fairly straightforward. They include two specific tasks:

(i) Observing and reporting brine behaviors, and

(ii) Constructing a computer model to predict scaling tendency of the brine using the data obtained in Task (i).

Therefore, it is expected that the degree of success is high. Indeed since there is no reason to believe otherwise, and since it is expected that the results will be used at all sites, the degree of success is assumed to be 1.0. Note that the accuracy of the prediction method to be developed in this subelement has been accounted for in the estimates of the subelement benefits. The degree of success estimated here is, therefore, no more than the likelihood that the subelement benefits one to be as estimated.

2.7 Results

	BENEFIT ($\$ 10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED & SUNK
OPTIMISTIC	132.3	44.7	36.7
PESSIMISTIC	72.7	24.6	20.2

3.0 SUBELEMENT 3-1-B:

STUDY OF SCALING IN TEST LOOP

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-1-B CONTRACT NUMBER(S) 05ENG26

TITLE Study of Scaling in a Test Loop

CONTRACTOR(S) Oakridge National Laboratory

RELATED PROJECTS 3-1-06: Precipitation and Scaling in Dynamic Geothermal Systems
Additional (i) Extend the same project to cover field conditions and other practical pipe materials and pipe diameters
(ii) Develop prediction method

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
	√				

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	859										859
2. DGE Planned:		250									250
3. Additional:			300	300	500	500					1600
Total:	859	250	300	300	500	500					2709
Discounted Total of Planned and Additional:											1489

EXPECTED YEAR OF COMMERCIALIZATION 1983

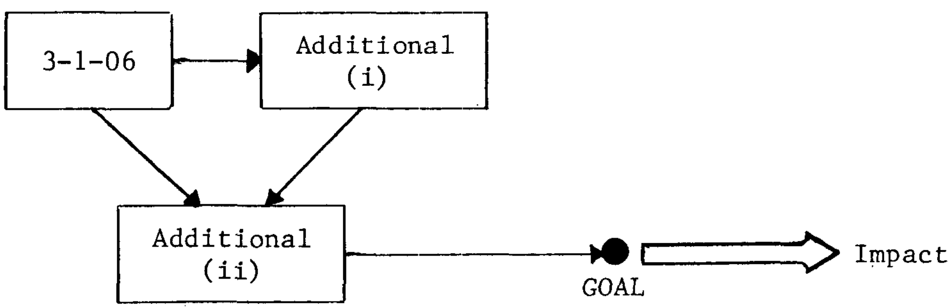
EXPECTED DEGREE OF SUCCESS 0.1

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	132.3
	PESSIMISTIC	72.7
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	88.9
	PESSIMISTIC	53.0
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	48.8
	PESSIMISTIC	29.1

SEE ATTACHED PAGES FOR RATIONALE

3.1 Projects in Subelement

PROJECT CODE		PROJECT TITLE
3-1-06		Precipitation and Scaling in Dynamic Geothermal Systems
Additional	(i)	Project 3-1-06 as it stands now is limited in scope and ranges of applications. To bring it to beneficial goal, it must be extended to cover field conditions and other practical pipe materials and configurations.
	(ii)	After collecting adequate data, a method for predicting the extent of precipitation and scaling using collected data must be developed.



3.2 Goal

Availability of precipitation and scaling data and a method or methods for predicting scaling tendency of geothermal brine.

3.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-1-06	559	300	859	250	0	0	0	0	0	250	1109
Add (i)					300	300	300	300	0	1200	1200
Add (ii)							200	200	0	400	400
TOTAL	559	300	859	250	300	300	500	500	0	1850	2709
($78)	676	330	1006	250	273	248	376	342	0	1489	2495

3.4 Identification of Impacted Parameters

Because the goal of this subelement is the same as that of the previous subelement, 3-1-A, the impacted parameters are the same and are discussed in subsection 1.4. They are:

(i) The labor resource of the O&M management

(ii) The capital cost of the heat exchangers.

3.5 Impacts on System Parameters

The analysis is the same as that of the subelement 3-1-A and is discussed in subsection 1.5. The results are summarized below:

BENEFIT MODEL INPUT PARAMETERS	PESSIMISTIC		OPTIMISTIC	
	FLASH	BINARY	FLASH	BINARY
% Change in Producer Well O&M Cost Factor (Low Salinity)	0	0	-5.0	-3.0
% Change in Producer Well O&M Cost Factor (High Salinity, $T < 450^oF$)	-3.0	-2.0	-9.0	-6.0
% Change in Producer Well O&M Cost Factor (High Salinity, $T > 450^oF$)	-5.0	-3.0	-9.0	-6.0
% Change in Producer Deep Well Pump O&M Cost Factor (Flash, $T < 200^oC$)	-5.0	0	-9.0	0
% Change in Producer Deep Well Pump O&M Cost Factor (Binary, $T < 260^oC$)	0	0	0	-3.0
% Change in Utility General O&M Cost Factor (Binary Systems)	0	0	0	-0.5
% Change in Capital Cost of Process Mechanical (Utility)	0	-9.0	0	-15.0

3.6 Degree of Success

Although the goal of this subelement is the same as that of subelement 3-1-A, the current activity, project 3-1-06, has a somewhat different approach. Project 3-1-06 involves the building of a test loop and carrying out test runs for synthetic brines prepared in the laboratory. It does not consider nonessential chemicals constituents and particularly dissolved gases. Thus, the results might not be applicable to real situations and therefore the degree of success is expected to be smaller than unity. However, if additional projects and fundings are allowed for as suggested, it is reasonable to believe that the degree of success can be the same as that of the subelement 3-1-A, i.e., 1.0.

3.7 Results

	BENEFIT ($ 10^6) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	132.3	88.9	53.0
PESSIMISTIC	72.7	48.8	29.1

It is noted that this subelement duplicates the effort of subelement 3-1-A. Therefore, these results have not been carried forward to the summary table (Table II) in the text of the report.

4.0 SUBELEMENT 3-1-C:

MECHANISM OF SILICA SCALING

BENEFIT / COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-1-C   CONTRACT NUMBER(S) 05ENG48

TITLE Mechanism of Silica Precipitation

CONTRACTOR(S) Lawrence Berkeley Laboratory

RELATED PROJECTS 3-1-07 Empirical Kinetic Reaction Model (LBL)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
		√			

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	379										379
2. DGE Planned:		100									100
3. Additional:											0
Total:	379	100									479

Discounted Total of Planned and Additional:

EXPECTED YEAR OF COMMERCIALIZATION 1979

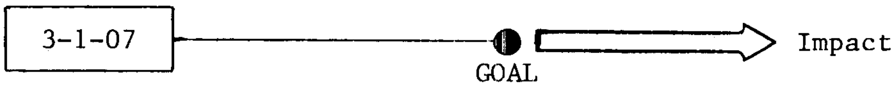
EXPECTED DEGREE OF SUCCESS 0.6

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	1.9
	PESSIMISTIC	0
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	11.5
	PESSIMISTIC	0
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	2.1
	PESSIMISTIC	0

SEE ATTACHED PAGES FOR RATIONALE

4.1 Project in Subelement

Project Code	Project Title
3-1-07	Empirical Kinetic Reaction Model



4.2 Goal

Capability to quantitatively predict the chemical behavior of silica in geothermal brines subjected to the energy conversion process. Silica scaling is a major precipitation problem in systems of brine temperature at 250°C and above.

4.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-1-07	277	102	379	100						100	479
$78	335	112	447	100						100	547

4.4 Identification of Impacted Parameters

The goal of this subelement differs from that of the subelement 3-1-A because it considers only silica precipitation rather than both carbonate and silica precipitation. This difference gives rise to the following points:

(i) Because silica precipitation starts to have its effects in brines at 250°C and above and because system design dictates that flash steam plants are more economical than binary plants at brine temperature greater than 250°C as assumed in the benefits model, binary plants will not be affected by this subelement.

(ii) As the consequence, overdesign of heat exchangers is not considered as an impacted parameter.

Thus the impacted parameter of this subelement is only the O&M cost which has been discussed in subsection 1.4.

4.5 Impacts on System Parameters

The analysis for the effects on O&M costs of this subelement follows the same argument as the one presented for the subelement 3-1-A in subsection 1.5.1. However the impacts are expected to be slightly less because carbonate precipitation also occurs in addition to, although at a lesser extent than, silica precipitation in brines of $T > 250^{\circ}C$. A factor of 0.8 is assumed as the multiplier which translates the benefits identified in subsection 1.5.1 to the benefits for this subelement. Thus the resulted benefits can be summarized as follows:

Benefit Model Input Parameters	PESSIMISTIC (FLASH ONLY)	OPTIMISTIC (FLASH ONLY)
% Change in Producer Well O&M Cost Factor (Low Salinity)	0	-4.0
% Change in Producer Well O&M Cost Factor (High Salinity, $T > 450^{\circ}F$)	-4.0	-7.2

4.6 Degree of Success

The activities in this subelement involve three sequential steps in the following order:

(i) Literature research and collection of published data on silica precipitation

(ii) Building a logical and empirical kinetic computer model for the precipitation of silica using the collected data

(iii) Testing the accuracy of the model using data obtained in laboratory experiments with synthetic brines.

Thus, it can be seen that the degree of success of the model greatly depends on how well the base data and test data represent site specific conditions of U.S. resources. It is understood at the time this report is being wirtten that little work has been done of silica precipitation under field conditions. Therefore, the usefulness of the model might be doubtful, even for resources having brine properties falling within applicable ranges of the model. As a consequence, it is expected that the likelihood that this subelement will have the benefits as estimated is considerably less than 100%. All things considered, it is estimated that the degree of success of this subelement is probably greater than half and far less than unity- and, hence, is assumed to be 0.6.

4.7 Results

	BENEFIT ($ 10^6) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	1.9	11.5	2.1
PESSIMISTIC	0.0	0.0	0.0

5.0 SUBELEMENT 3-1-D:

STUDY OF SILICA PRECIPITATION IN SUPERSATURATED WATER

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-1-D

CONTRACT NUMBER(S) C022607

TITLE Study of Silica Precipitation in Supersaturated Water

CONTRACTOR(S) E.I.C. Corporation

RELATED PROJECTS 3-1-08 Silica Scaling Study

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
	√				

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	299										299
2. DGE Planned:		0									0
3. Additional:											0
Total:	299	0									299

Discounted Total of Planned and Additional: 361

EXPECTED YEAR OF COMMERCIALIZATION N/A

EXPECTED DEGREE OF SUCCESS N/A

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	N/A
	PESSIMISTIC	N/A
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	N/A
	PESSIMISTIC	N/A
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	N/A
	PESSIMISTIC	N/A

SEE ATTACHED PAGES FOR RATIONALE

5.1 Project in Subelement

Project Code | Project Title

3-1-08 | Silica Scaling Study

5.2 Goal

Understanding, through experimental studies, of the condensation of silica from water supersaturated with silicic acid.

5.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-1-07	289	10	299	0						0	299
$78	350	11	361	0						0	361

5.4 Identification of Impacted Parameters

The project involves the laboratory study of silica and solution, which is rather remote from being representative of geothermal brines. It has been completed and therefore terminated in fiscal year 1977. Benefit/cost analysis is therefore not needed.

6.0 SUBELEMENT 3-1-E:

SCALING CONTROL

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-1-E	CONTRACT NUMBER(S) C022833, Unknown

TITLE Scaling Control

CONTRACTOR(S) Dow Chemicals and Vetter Research

RELATED PROJECTS 3-1-09 Scale Formation and Suppression (Dow)

3-1-10 Scale Inhibitors Tests (Vetter)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
		√			

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	192										192
2. DGE Planned:		75									75
3. Additional:			100	100							200
Total:	192	75	100	100							467
Discounted Total of Planned and Additional:											249

EXPECTED YEAR OF COMMERCIALIZATION 1981

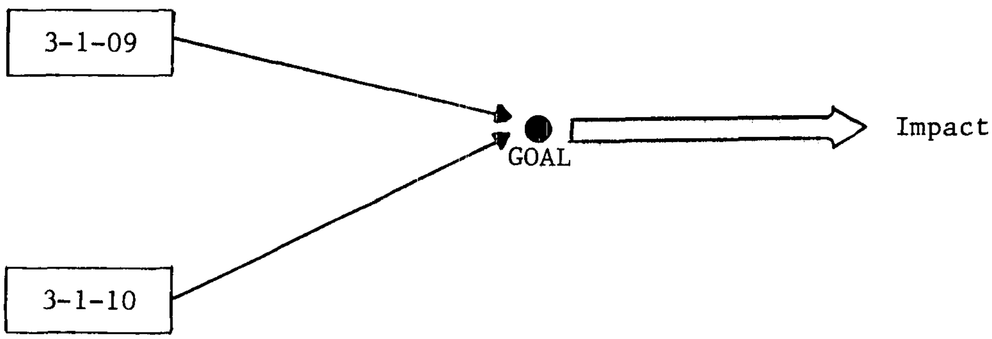
EXPECTED DEGREE OF SUCCESS 0.3

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	28.3
	PESSIMISTIC	0.0
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	34.1
	PESSIMISTIC	0.0
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	18.1
	PESSIMISTIC	0.0

SEE ATTACHED PAGES FOR RATIONALE

6.1 Projects in Subelement

Project Code	Project Title
3-1-09	Scale Formation and Suppression
3-1-10	Scale Inhibition Test



6.2 Goal

A method or methods to control the formation of scale in heat exchangers.

6.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-1-09	65	127	192	52*	0					52	244
3-1-10	0	0	0	23						23	23
TOTAL	65	127	192	75	100+	100+				275	467
($78)	79	140	219	75	91+	83+				249	468

* Obligated in fiscal year 1977.

+ Additional funds are assumed as a requirement to bring the study to a reasonably conclusive state.

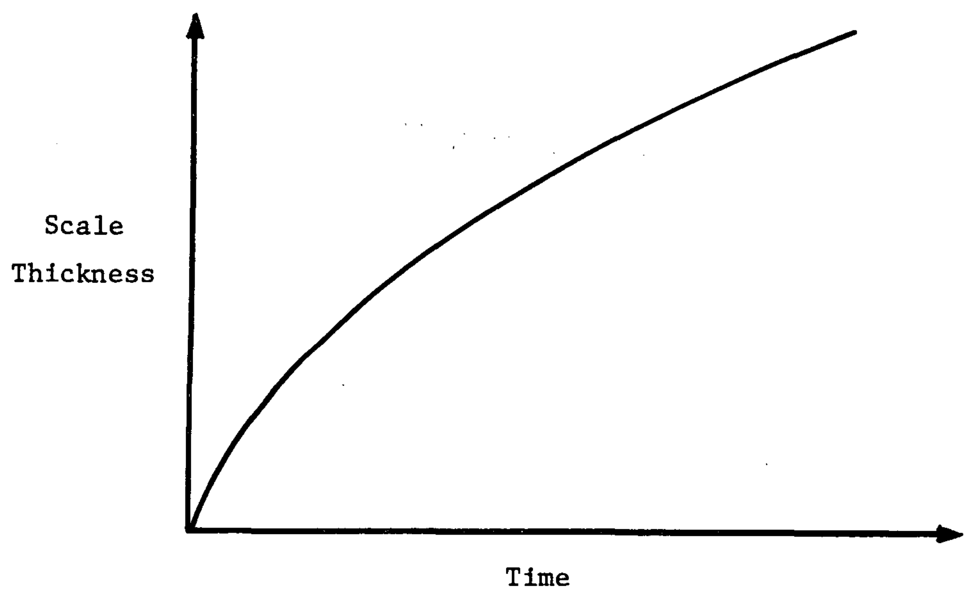


FIGURE 1

SCALE THICKNESS AS A FUNCTION OF TIME

6.4 Identification of Impacted Parameters

According to the subelement goal, only heat exchangers are affected and, therefore, only parameters of binary plants are impacted.

If the scale formation in heat exchangers tubings can be controlled, fouling of the heat exchange surface and hence the heat exchange surface area can be reduced. This means that the capital costs of heat exchangers are reduced. Also, because there is less fouling, the O&M requirements for the heat exchangers are lessened. However the controlling method would require additional equipment for injection of chemicals and additional process control. Thus the impacted parameters can be identified in:

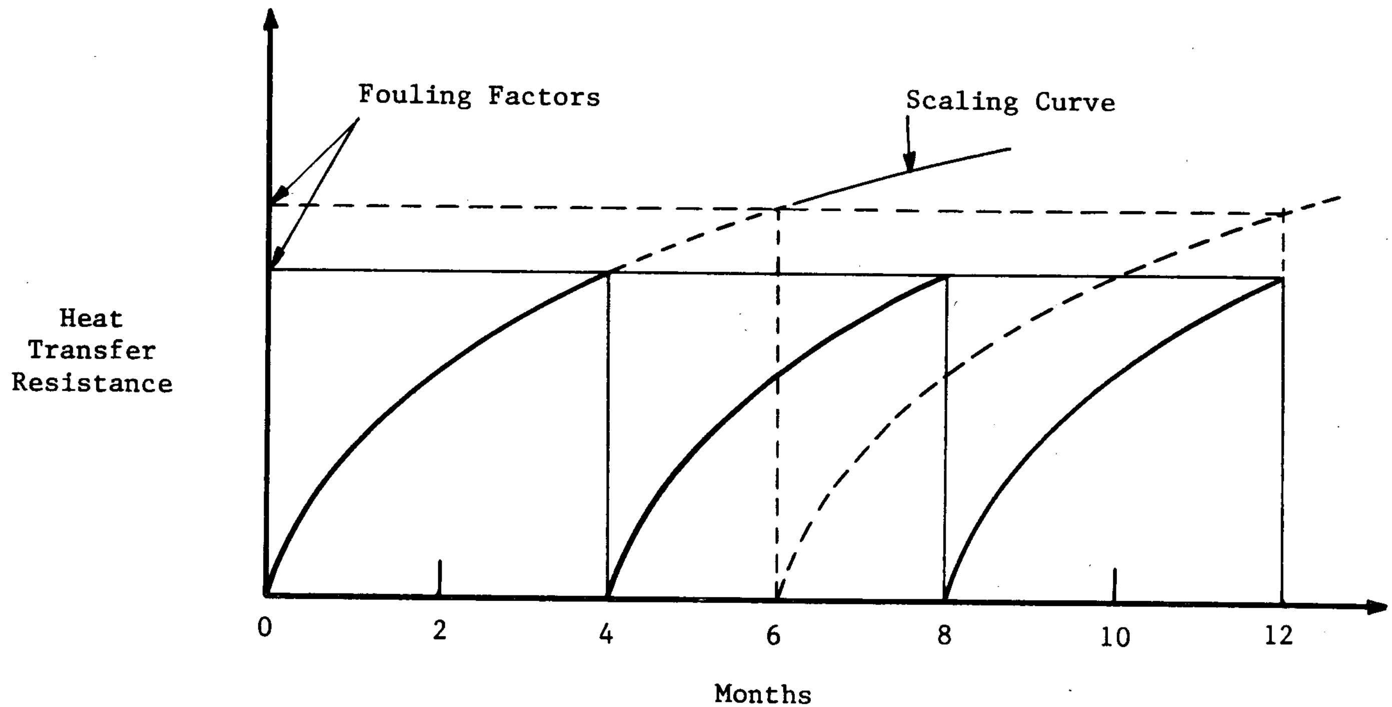
(i) Capital and O&M costs of heat exchangers in binary plants

(ii) Capital and O&M costs of additional equipment for scale control.

6.5 **Impacts on System Parameters**

6.5.1 Heat Exchangers

Fouling or scaling of heat exchange surface is a dynamic process with respect to time. Scaling rate is usually high initially and decreases with time to an approximately constant value. This means that the scale thickness on the surface increases with time as shown in Figure 1. The fouling factor, or sometimes called dirt factor, used in heat exchanger design is defined as the heat transfer resistance of the scale and is calculated from the heat conduction properties and thickness of the scale. However it has a single value which is



Solid Lines: Cleaning 3 times a year, low fouling factor

Dotted Lines: Cleaning 2 times a year, high fouling factor

FIGURE 2

FOULING FACTOR VERSUS FREQUENCY OF CLEANING specified, in the design procedure, at the condition when the scale is so thick that cleaning must be carried out before the thermal performance of the heat exchangers falls below the required level. Therefore it can be seen, as illustrated in Figure 2, that for a particular scaling curve, increasing the fouling factor would reduce maintenance requirements. In other words, there is a trade off between capital cost and O&M cost of a heat exchanger.

It is expected as the results of this subelement that a new scaling curve, marked "controlled" in Figure 3, will be obtained if the R&D projects are successful. As shown in Figure 3, there are three methods to account for the benefits of having the "controlled scaling curve as opposed to the original" uncontrolled scaling curve:

(i) The fouling factor is reduced from f1 to f3 if the maintenance requirement remains unchanged. That means a reduction in heat exchanger capital cost with no change in O&M cost.

(ii) The fouling factor remains unchanged while the maintenance requirement is reduced. The time between cleanings is extended from t_1 to t_3. Hence the capital cost is unchanged but the O&M cost is reduced.

(iii) The fouling factor is reduced to f_2 with $f_1>f_2>f_3$ and the time between cleaning is correspondingly t_2 with $t_1<t_2<t_3$. Both capital and O&M costs are reduced.

Because the reduction in O&M cost is relatively difficult to quantify, method (i) is used. Now, let us consider equation 3 of subsection 2.5.2:

$$\frac{1}{U} = 0.004640 + 1.21\ f_i$$

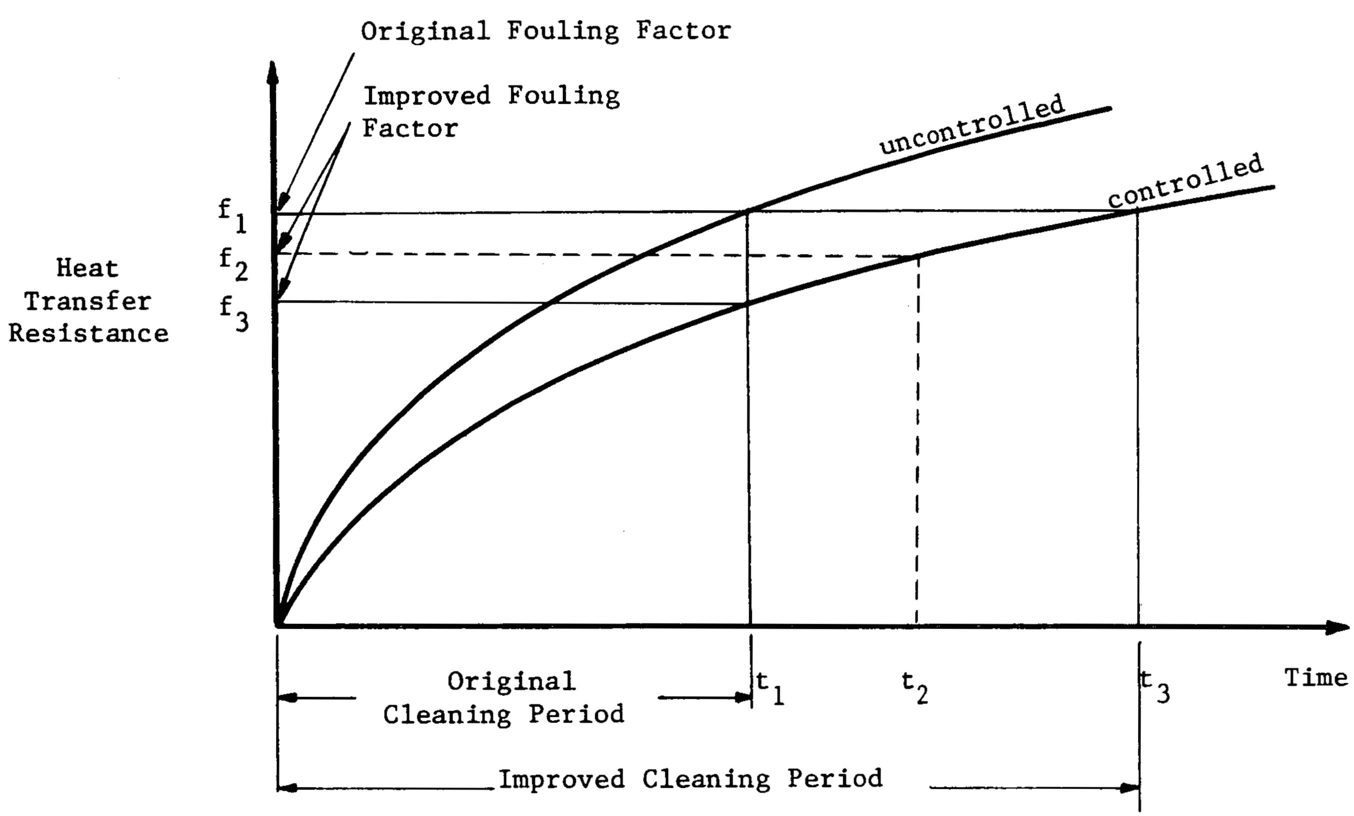


FIGURE 3

UNCONTROLLED SCALING VERSUS CONTROLLED SCALING where f_i denotes the inside fouling factor, i.e., fouling factor of the brine, and U is the overall heat transfer coefficient; following an argument similar to that in 2.5.2. If f_i equals 0.004 under uncontrolled scaling condition, U equals 105.5 Btu/(hr. ft.^{2}°F). If scaling is controlled as desired in the goal of this subelement, a value of 0.001 may be assumed for the fouling factor with unchanged maintenance requirements. The U value becomes 170.9 Btu/(hr. ft.^{2}°F) and the change is

$$\frac{170.9 - 105.5}{105.5} = 0.620 \text{ or } 62.0\%$$

The change in heat exchanger capital cost is thus -62.0% x 0.7 = -43.4%. It is thus possible to assume that the heat exchanger cost saving is somewhere between 35 and 45%.

6.5.2 Additional Equipment

The additional equipment would consist of inhibitor storage, injection devices, and control instruments. From experience, this equipment can be installed at a cost about $50K to $100K. If this cost is charged as part of the heat exchanger system which, according to Nguyen and Dhillon*, costs about $4,800K for a 50 MW binary plant, the system cost is increased by about 50/4800 = 1.0% to 100/4800 = 2.1%.

The chemicals used for inhibiting scale formation are sulfuric acid and/or low molecular weight polymers. Sulfuric acid price is

* V. Thanh Nguyen and Harpal S. Dhillon, "An Analysis of the Geothermal Energy Extraction and Utilization Technology RD&D Program", Report MTR-7886, MITRE Corporation, June 1978.

is currently about \$0.65/lb and the polymer inhibitors used in cooling tower water treatment is from \$0.25 to \$1.25/lb. For the purpose of this subelement, the use of acid would cost far too much because of the large quantity requirement. An analysis of cooling water treatment by Nguyen* indicates a rate of 500 to 1500 ppm of sulfuric acid is required to prevent carbonate and silica precipitations in condenser tubes. Thus the subelement should aim, as it currently does, at polymers. The amount of polymers needed is about 6 to 12 ppm as indicated by Vetter Research.

A 50 MW power plant using brine at 350°F and 140°F rejection temperature with a conversion efficiency of 30% would require a brine rate of:

$$\frac{50 \times 3.142 \times 10^6 \text{ Btu/hr}}{0.30\ (350 - 140)\ \text{Btu/lb}} = 2.49 \times 10^6 \text{ lb/hr}$$

which is equivalent to $2.49 \times 10^6 \times$ (7200 hr/year) = 17.4×10^9 lb/year and requires at least $6 \times 10^{-6} \times 17.4 \times 10^9$ = 104,400 lb/year of polymer inhibitors. If \$1.25/lb is assumed as the cost of inhibitors, the operating cost would be at least \$1.25 x 104,400 = \$130,500/year. The O&M cost for the process mechanical (this includes heat exchangers) in the generating plant is \$70,560/yr (See previous page footnote). This makes a change of 130,500/70560 = 185%. If 12 ppm of polymers is used, the change is 370%.

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* V. Thanh Nguyen, "Cooling Water Treatment for the Raft River Geothermal Loop", Report GEO-012, Garrett Energy Research and Engineering, 1977.

In summary the benefits of this subelement are as follows.

Benefit Model Input Parameters	PESSIMISTIC (Binary Only)	OPTIMISTIC (Binary Only)
% Change in capital cost of Process Mechanical (Utility). (Heat exchanger cost accounts for %*)	(-35 + 2.1) x 0.60 = -19.7	(-45 + 1) x 0.60 = -26.4
T Change in Process Mechanical O&M Cost Factor (Binary System)	370.	185.

* See footnote in previous page.

6.6 Degree of Success

As reported from contractors, controlling methods other than using inhibitors appeared to fail completely, while using inhibitors showed some degree of success. The search for suitable inhibitors usually involves a process of elimination, which might or might not be successful. Also, even if some success has been detected so far, there is no guaranty that such success will be found at all the binary sites in the U.S. All things considered a degree of success of 0.3 would be expected as reasonable for this subelement.

6.7 Results

	BENEFIT ($ 10^6) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	28.3	34.1	18.1
PESSIMISTIC	0.0	0.0	0.0

Note that when the savings at certain sites are negative it is assumed that the new technology would not be used and therefore, the benefits at these sites are zero. This explains the zero benefits for the pessimistic case shown above.

7.0 SUBELEMENT 3-1-F:

TOTAL FLOW SYSTEM

BENEFIT / COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-1-F	CONTRACT NUMBER(S) 05ENG48
TITLE Total Flow System	
CONTRACTOR(S) Lawrence Livermore Laboratory	
RELATED PROJECTS	3-1-04 Brine Chemistry Study 3-1-05 Scale Formation and Control Additional Total Flow Turbine (In other RD&D Program Number 2)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
		✓			

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	2849										2849
2. DGE Planned:		0									0
3. Additional:	5051	1700									6751
Total:	7900	1700									9600
Discounted Total of Planned and Additional:											1700

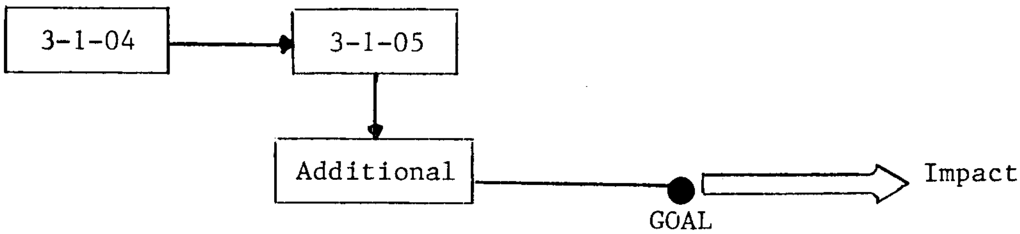
EXPECTED YEAR OF COMMERCIALIZATION	--
EXPECTED DEGREE OF SUCCESS	0

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	N/A
	PESSIMISTIC	N/A
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	N/A
	PESSIMISTIC	N/A
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	N/A
	PESSIMISTIC	N/A

SEE ATTACHED PAGES FOR RATIONALE

7.1 Projects in Subelement

Project Code	Project Title
3-1-04	Brine Chemistry Study
3-1-05	Scale Formation and Control
Additional	Total Flow Turbine (included in RD&D program Number 2)



7.2 Goal

A conversion system driven by mixtures of steam and brine. Specific goal is to eliminate corrosion, scaling and errosion problems in and develop a suitable design for a two-phase, gas-liquid turbine.

7.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-1-04	0	713	713	0						0	713
3-1-05	0	2136	2136	0						0	2136
Addit.*	3719	1332	5051	1700	0					1700	6751
TOTAL	3719	4181	7900	1700	0					1700	9600
($78)	4500	4599	9099	1700						1700	10799

* The additional costs are those from R&D projects on total flow systems in Program 2 - **Extraction and Conversion Technology.**

7.4 Identification of Impacted Parameters

The activities, including the additional projects, have been discontinued. The amount of $1,700K planned for the additional project is for concluding the activities. The analysis for this subelement is therefore not required.

8.0 SUBELEMENT 3-2-A:

MATERIALS DESIGN HANDBOOK

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER	3-2-A	CONTRACT NUMBER(S)	C043904
TITLE	Materials Design Handbook		
CONTRACTOR(S)	Radian Corporation		
RELATED PROJECTS	3-2-01 Materials Design Handbook		

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
✓	✓				

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	56										56
2. DGE Planned:		223	223	250	300	300	300				1596
3. Additional:											0
Total:	56	223	223	250	300	300	300				1652
Discounted Total of Planned and Additional:											1249

EXPECTED YEAR OF COMMERCIALIZATION	1981
EXPECTED DEGREE OF SUCCESS	0.7

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	26.6
	PESSIMISTIC	17.5
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	14.9
	PESSIMISTIC	9.8
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	14.2
	PESSIMISTIC	9.3

SEE ATTACHED PAGES FOR RATIONALE

8.1 Project in Subelement

Project Code	Project Title
3-2-01	Materials Design Handbook

8.2 Goal

An operational guideline handbook for geothermal energy conversion systems. The handbook contains information on case history of materials performance in geothermal systems and provides design engineers with guidelines for selecting materials for geothermal power plants.

8.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-01	0	56	56	223	223	250	300	300	300	1596	1652
$1978	0	62	62	223	203	207	225	205	186	1249	1311

8.4 Identification of Impacted Parameters

The impacted parameters can be identified by examining the purpose of the handbook as described in the following paragraphs*:

> "This manual serves two purposes. First, it is a collection and interpretive summary of existing data on materials performance in geothermal fluids. This data summary will reduce the need for lengthy testing of a

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* Extracted from the introduction section of the handbook in its first edition and draft form.

large number of materials at each new geothermal site. It provides a way to help screen potential construction materials through past experience.

The second purpose of the manual is to provide some guidelines for selecting materials for geothermal power plants. The manual establishes a framework of background information that defines an approach to materials selection. It identifies the processes (power cycles) and equipment used to produce electricity, discusses the importance of fluid chemistry, and defines the forms and mechanisms of corrosive attack that can occur in geothermal process streams."

Thus the manual would save time in design process by providing engineers with needed information, and hence would reduce the preconstruction engineering costs. It does not impact the operation and reliability of the plant, however. If the manual suggests certain materials, for example well cement or pressure vessel steel, which turn out to be reliable, the benefits gained from using those materials should be attributed to those R&D efforts which develop the materials rather than to the reporting efforts of the manual.

8.5 Impacts on System Parameters

To estimate the benefits of this subelement, let us consider the procedures that a design engineer would follow in designing the plant. When a new geothermal site is decided on, a test well is then drilled and completed, sampling and analysis of the brine are performed, and materials for production wells and conversion plant are selected from the knowledge of brine chemistry. If the manual to be produced in this subelement is not available, the following efforts and costs are required:

(i) Literature search: 6 manmonths: cost \$5K x 6 = \$30K
From the literature search, materials are identified and recommended for check tests.

(ii) Check tests: 10 manmonths: cost \$5K x 10 = \$50K
The tests are carried out over a period of perhaps 6 to 18 months.

(iii) Test Materials and Analyses: cost \$10K

Now if the manual is available, the same sequence must still be carried out but to a lesser extent:

(i) Literature search: 1 man week costs \$5K x 0.25 = \$1.25K
This effort is simply reading the manual

(ii) Check tests: 2 manmonths cost \$5K x 2 = \$10K
The time required to perform the tests is assumed to be reduced because guidelines are known beforehand.

(iii) Test Materials and Analyses: cost \$3K

Thus a saving of \$90K - \$14.25K = \$75.75K results. From this figure it is reasonable to assume that a saving can be somewhere between \$60K and \$90K per plant regardless of its size. Since the manual is designed for liquid dominated resources, the above benefits apply to flash steam and binary plants only. Dry steam plants are not affected. The preconstruction engineering costs of flash steam and binary plants are estimated to be about \$1,990 K and \$3,100 K respectively*. Thus the saving in engineering costs becomes 60/1990 = 3.0% and 60/3100 = 1.9% in the pessimistic case. The results are summarized below:

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* V. Thanh Nguyen and Harpal S. Dhillon, "An Analysis of the Geothermal Energy Extraction and Utilization Technology RD&D Program", Report MTR-7886, MITRE Corporation, June 1978.

Benefit Model Input Parameters	PESSIMISTIC Flash	PESSIMISTIC Binary	OPTIMISTIC Flash	OPTIMISTIC Binary
% Change in Capital Cost of Engineering and Administration (Producer)	-3.0	-1.9	-4.5	-2.9
% Change in Capital Cost of Engineering and Administration (Utility)	-3.0	-1.9	-4.5	-2.9

8.6 Degree of Success

Since the subelement is only a compilation of information, there is no reason why it should not be successful and achieve its goal.* Hence the degree of success can be 1.0. However since similar efforts are being attempted in other subelement (Section 12.0, subelement 3-2-E), its degree of success is assumed to be 0.7.

8.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	26.6	14.9	14.2
PESSIMISTIC	17.5	9.8	9.3

9.0 SUBELEMENT 3-2-B:

WELL CEMENT

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER	3-2-B	CONTRACT NUMBER(S)	C020016 A016010 C024190

TITLE Well Cement

CONTRACTOR(S) Brookhaven National Laboratory, National Bureau of Standards, Dowell of Dow Chemicals, unknown

RELATED PROJECTS
3-2-02 High Temperature Polymer Well Cement and Management (BNL)
3-2-03 Geothermal Cement Evaluation (NBS)
3-2-04 Well Completion Evaluation (Dowell)
3-2-05 Cement Downhole Tests (unknown)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
		✓	✓		

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	478										478
2. DGE Planned:		810	761	585	350	150					2656
3. Additional:											0
Total:	478	810	761	585	350	150					3134
Discounted Total of Planned and Additional:											2350

EXPECTED YEAR OF COMMERCIALIZATION 1982

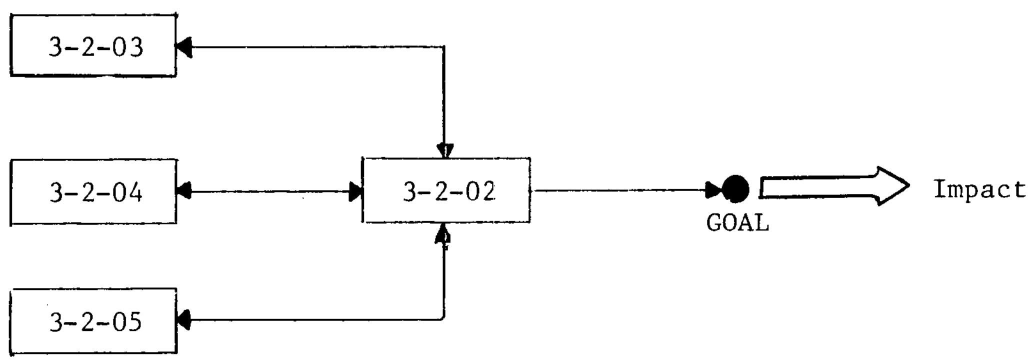
EXPECTED DEGREE OF SUCCESS 0.7

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	223.8
	PESSIMISTIC	122.2
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	66.7
	PESSIMISTIC	36.4
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	54.2
	PESSIMISTIC	29.6

SEE ATTACHED PAGES FOR RATIONALE

9.1 Projects in Subelement

Project Code	Project Title
3-2-02	High Temperature Polymer Well Cement and Management
3-2-03	Geothermal Cement Evaluation
3-2-04	Well Completion Evaluation
3-2-05	Cement Downhole Tests



9.2 Goal

Suitable cements for downhole applications up to 330°C and standardization of cements and cementing procedures.

9.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 83→	TOTAL
3-2-02	123	299	422	500	376	200	200	150	0	1426	1848
3-2-03	0	20	20	60	60	60				180	200
3-2-04	0	36	36	250*						250	286
3-2-05	0	0	0	0	325	325+	150+			800	800
TOTAL	123	355	478	810	761	585	350	150	0	2656	3134
($78)	149	391	540	810	692	483	263	102	0	2350	2890

* Obligated in FY 77.
\+ To be moved to regional offices.

9.4 Identification of Impacted Parameters

As indicated in the subelement goal, new cements would be developed. The new cements are expected to have longer lives than and different costs from currently available cements. It is thus expected that the impacted parameters of the well cement subelement are well life and well cost. They are identified as follows:

Well Life: The life of a geothermal well is limited by either one or a combination of cement failure, casing failure, precipitation in wellbore, and reservoir depletion. Hence an improvement in cement life can only increase to a certain limit the life of those wells which are expected to experience early cement failure. The limit of life increase of such wells is set by the failure mode next in line. Thus it can be seen that, if subelement concerning other failure modes are going to be analyzed, a rationale for the average fraction of well life contributed by different failure modes must be developed. Such rationale will serve as the basis common to subsequent analyses and is discussed in the sub-section 9.5 below.

Well Cost: The results of this subelement have two effects on the well cost. The first effect is directly resulted from the expected change in cost of the newly developed cements. The second effect is derived from a reduction in the pre-production failures of wells as the results of using improved cements (the costs for controlling failed wells are high and are included in the total cost of producing wells).

9.5 Impacts on System Parameters

9.5.1 Rationale for Limiting Factors of Well Life

As mentioned before, the life of a geothermal well is limited primarily by cement failure, casing failure, precipitation in well bore, and reservoir depletion. These four factors affect the well life by reducing the heat flow through the well bore.

Let us consider a typical well of a geothermal field as shown by the sketch in Figure 1. The geothermal fluid is extracted by a pressure differential which exists naturally or is induced by pumping. The fluid first flows through the pores of the reservoir formations and then upward through the well bore which is supported by cement and metal casing. If the physical conditions of the well bore do not change with time, the flow can be diminished by one or a combination of: the lack of reservoir recharge, gradual clogging up of the pores around the well bottom, and cooling off of the resource. The situation is generally called reservoir depletion. The flow can also be further diminished by such physical changes of the well bore as precipitation in the bore or cement cracking, casing being corroded. The precipitation in the well bore physically restricts the flow while cement and casing failures allow water in cooler aquifers to enter the hot stream or vice versa and hence lower the available heat of the produced geothermal fluid. In summary, the following observations pertain:

(i) Heat flow from a well decreases with time.

(ii) Reservoir depletion is expected to be more rapid in high salinity prospects than low salinity prospects keeping other factors constant.

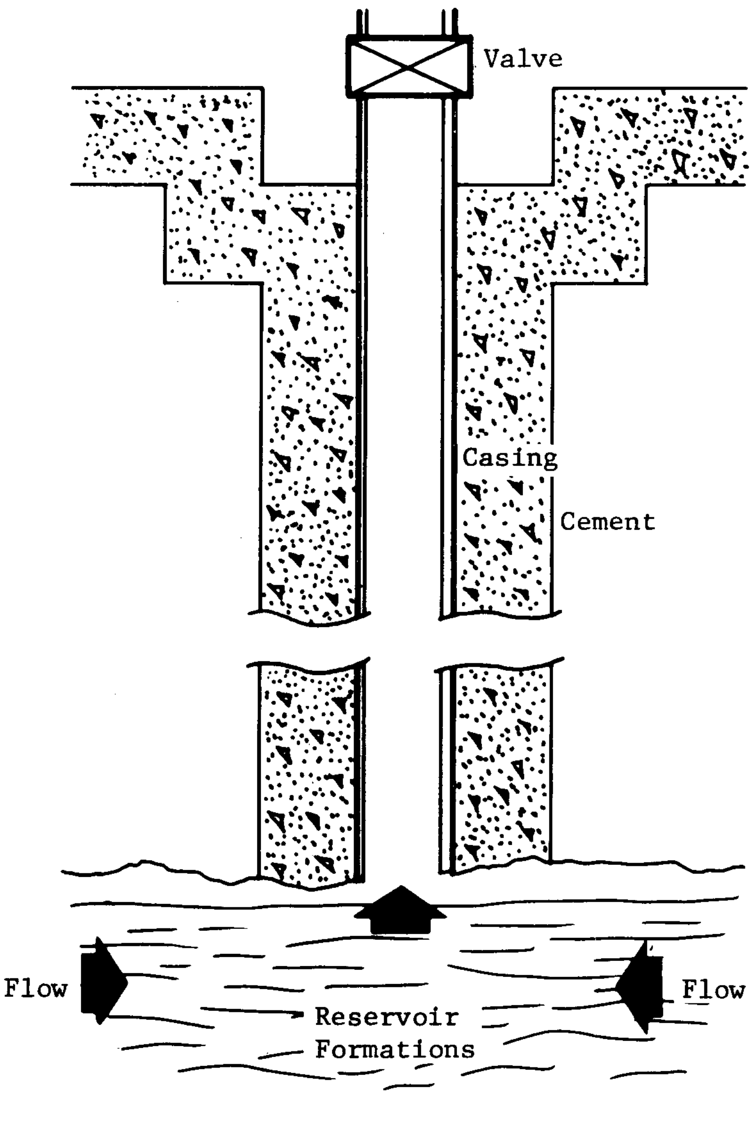


FIGURE 1
SKETCH OF WELL COMPONENTS

(iii) Because cement and casing support each other, the failure of either one must wait for the other to fail before the effects on the brine starts to take place.

To arrive at some quantification of the effects that the four limiting factors mentioned earlier have on the well life, it is necessary to make some assumptions as follows:

Assumption 1: The heat flow rate is assumed to decrease from its original value to zero linearly over a period of time called well life. Thus a system of N wells having a life L years require N/L new wells in the second year to maintain the original total output.

Assumption 2: Well life varies from site to site and is assumed to be 15 years for all types of well flows with the exception that a high salinity brine flashing flow is assumed to limit well life to 7.5 years. These assumed figures, although they are felt to be reasonable for the purposes of this analysis, might be proved to be erroneous as more experiences are gained in operating U.S. resources in the future.

Assumption 3: If problems in the well bore do not exist, it is assumed that the well life is 20 years for high salinity flash flow wells and 30 years for the remaining types of wells.

It follows from the above assumptions that for a low salinity brine flash flow well, say, the flow decreases by 1/30 of its original rate per year due solely to reservoir depletion. The flow is further decreased by problems in well bore by (1/15) - (1/30)= 1/30 of its original value. This additional 1/30 flow reduction is contributed by well

TABLE 1

FLOW REDUCTION FRACTIONS PER YEAR
OF LIMITING FACTORS AND WELL LIFE

WELL LIFE LIMITING FACTORS	SYSTEM				
	DRY STEAM	FLASH STEAM		BINARY	
		LOW SALINITY	HIGH SALINITY	LOW SALINITY	HIGH SALINITY
Reservoir Depletion	1/30	1/30	1/20	1/30	1/30
Bore Precipi-tation	0	1/90	1/16	1/180	1/90
Casing Corrosion	1/60	1/90	1/96	1/72	1/90
Cement Failure	1/60	1/90	1/96	1/72	1/90
TOTAL	1/15	1/15	1/7.5	1/15	1/15
AVERAGE WELL LIFE (YEARS)	15	15	7.5	15	15

bore precipitation, casing corrosion, and cement failure.

Assumption 4: Since casing and cement must both fail before the flow is affected, it is assumed that the fractions of flow reduced by them are equal.

Assumption 5: This assumption is concerned with well bore precipitation. Dry steam wells generally have negligible scaling problems and hence, precipitation effect is assumed to be zero. Because of the flow nature precipitation problems are more pronounced relatively to casing and cement problems for flashing flow than for brine alone flow.

From the five assumptions just stated, a table of flow reduction fractions of the four limiting factors was prepared for use in this subsequent analyses as shown in Table 1.

It is noted that the figures assumed for bore precipitation, casing corrosion, and cement failure of flash steam and binary systems, while consistent with assumptions 4 and 5, are necessarily arbitrary. One could assume somewhat different values for them and still be consistent with the assumptions. Contingencies arrived from a reasonable range of assumed values are included in the results of the benefit analyses. The use of Table 1 is demonstrated by the following example.

An R&D project attempts to develop casing materials which can increase the casing life by 40%. This project, if successful, will have its whole benefits when wells which experience cement failure before casing failure are considered. However it will have no benefit for wells which are expected to have no current problems because good or bad casing material would not make any difference in the flow characteristics of the well (neglecting of course the safety problems which might arise from an unstable anchorage of well head equipment). Thus, the benefits of this project should be estimated on a site-by-site basis. Such approach is clearly not possible here because we are considering a future scenario of geothermal energy development which does not generate site-specific operating experience required. An on-the-average approach must be used here. The increase by a factor of 1.40 on the casing life, as the results of this project will reduce the effects that casing failure have on the well flow. This reduction is assumed to be proportional to the flow reduction fractions listed in Table 1 and the casing life factor 1.40. Thus for the low salinity brine flashing flow, say, the new well life is calculated by:

$$\frac{1}{L} = \frac{1}{30} + \frac{1}{90} + \frac{1}{90 \times 1.4} + \frac{1}{90} = \frac{5 + (1/1.4)}{90}$$

and $L = 15.75$ years

which when compared with the current average well life yields a change in well life of:

$$\frac{15.75 - 15.0}{15.0} = 0.05 \text{ or } 5\%$$

9.5.2 Impacts on Well Life of Subelement 3-2-B

Discussions with the cement program leader, Mr. L.E. Kukacka of the Brookhaven National Laboratory, indicated that the cements being developed under his program are expected to last twice as long as the currently available cements. This is assumed here as an optimistic estimate. The pessimistic estimate is assumed to be about 50% increase in cement life. Thus the cement life factor is increased from 1.0 to somewhere between 1.5 and 2.0 and the calculation using these factors and Table 1 yields the following changes of well life:

	PESSIMISTIC		OPTIMISTIC	
	Life (yrs)	%	Life (yrs)	%
Dry steam well	16.36	9.1	17.14	14.3
Flash Steam well (Low Salinity)	15.88	5.9	16.36	9.1
Flash Steam well (High Salinity)	7.70	2.7	7.80	4.1
Binary (Low Salinity)	16.12	7.5	16.74	11.6
Binary (High Salinity)	15.38	5.9	16.36	9.1

which when expressed in terms of the benefit model input parameters become:

BENEFIT MODEL INPUT PARAMETERS	PESSIMISTIC			OPTIMISTIC		
	Steam	Flash	Binary	Steam	Flash	Binary
% Change in Life Span of Production Wells (Low Salinity)	9.1	5.9	7.5	14.3	9.1	11.6
% Change in Life Span of Production Wells (High Salinity)	9.1	2.7	5.9	14.3	4.1	9.1

9.5.3 Impacts on Well Cost of Subelement 3-2-B

Cement Cost: The purchased cost of the new cements is expected, as indicated by Mr. Kukacka, to increase by about 10%. This figure is assumed here as optimistic, the pessimistic value is assumed to be 15%. Cement cost usually accounts for about 2%* of the total well cost. Hence the well cost change is somewhere between 0.2 to 0.3%. Note that cementing cost is unchanged.

Controlling cost for pre-production failed wells: The avoidance of well failures due to using unsuitable cements can eliminate the cost of controlling abandoned wells which would otherwise be necessary because of environmental reasons. It has been found, also according to Mr. Kukacka, that about 1-2% of wells were failed due to cement problems and that the costs of controlling these wells are about twice as much as the cost of a production well. These costs are generally charged to the cost of producing wells.

Let the true cost of a production well be C and consider 100 wells which are to be drilled. The total drilling and completion cost is 100C. One or two of the 100 wells fail and the cost for controlling them is also C. Thus the resulted cost is 101C or 102C and the final cost per producing well is 101C/99 or 102C/98. Now if no well fails, the cost of producing wells is still C per well. The change is therefore:

$$\frac{(101C/99) - C}{C} = \frac{101}{99} - 1 = 0.02 \text{ or } 2.0\%$$

or

$$\frac{(102C/98) - C}{C} = \frac{102}{98} - 1 = 0.041 \text{ or } 4.1\%$$

* Joseph M. Kenedy and Roy M. Wolke, "From Here to There by Demonstration Drilling", Proc. of the 2nd U.N. Conference on the Development and Use of Geoth. Res., San Francisco, May 1975, p. 1503.

These figures represent the possible savings if suitable cements are used and, hence, are considered as the benefits of the cement R&D program. The net savings after taking into account the increases in cement cost are 2.0% - 0.3% = 1.7% (pessimistic), and 4.1% - 0.2% = 3.9% (optimistic). The results are summarized below:

BENEFIT MODEL INPUT PARAMETERS	PESSIMISTIC (All)	OPTIMISTIC (All)
% Change in Cost per production well	-1.7	-3.9

Note: The minus sign indicates saving.

It is noted that so far injection wells are not mentioned. This is because wells for injection are not subject to high temperature and therefore are unlikely to have cement problems.

It is also noted that better cements can eliminate the use of metallic casing for wells in low temperature, hot water resources. However since these resources will not be used for electricity generation, this type of benefit is not considered in this analysis.

9.6 Degree of Success

The subelement purpose is to develop cements which are suitable for wells of temperature up to 330°C. This temperature range covers most of the U.S. hydrothermal resources. The exceptions are Puna field (356°C) and Salton Sea field (340°C). Hence, if the subelement goal is achieved, the market coverage fraction of the new cements, although it is not a hundred percents, is high. However, the approach in the process of cement development is still a trial-and-error approach despite of the support of cement know how in oil and gas industry. It is therefore felt that the degree of success can be reasonably assumed to be 0.7.

9.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	223.8	66.7	54.2
PESSIMISTIC	122.2	36.4	29.6

10.0 SUMELEMENT 3-2-C:

NON-METALLIC CONSTRUCTION MATERIALS

BENEFIT / COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-2-C

CONTRACT NUMBER(S) C020016

TITLE Non-Metallic Construction Materials

CONTRACTOR(S) Brookhaven National Laboratory

RELATED PROJECTS
3-2-06 Alternate Materials of Construction and Management (BNL)
3-2-07 Alternate Materials for Non-Electric Applications (BNL)
3-2-08 D.A.I. Intensity Polymer Concrete Erosion (BNL/DAI)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
		√			

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	531										531
2. DGE Planned:		242	350	800	550	1100	1450	0			4492
3. Additional:											0
Total:	531	242	350	800	550	1100	1450	0			5023
Discounted Total of Planned and Additional:											3285

EXPECTED YEAR OF COMMERCIALIZATION 1984

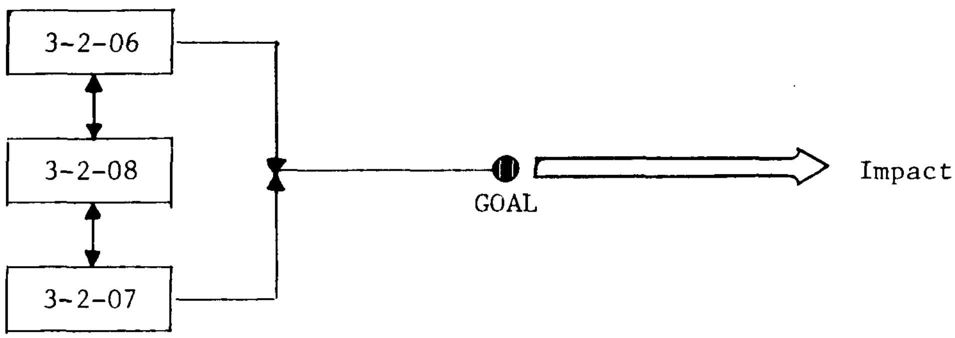
EXPECTED DEGREE OF SUCCESS 0.8

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	111.5
	PESSIMISTIC	86.1
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	27.2
	PESSIMISTIC	21.0
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	22.8
	PESSIMISTIC	17.6

SEE ATTACHED PAGES FOR RATIONALE

10.1 Projects in Subelement

Project Code	Project Title
3-2-06	Alternate Materials of Construction and Management
3-2-07	Alternate Materials for Non-Electric Application
3-2-08	D.A.I. Intensity Polymer Concrete Erosion



10.2 Goal

Non-metallic coatings including plastics, concrete polymers, and refractory cements to replace the portions of metal which are designed to allow for corrosion and erosion in pipings and pressure vessels.

10.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-06	370	161	531	180	200	800	550	1100	1450	4280	4811
3-2-07	0	0	0	50	150					200	200
3-2-08	0	0	0	12	0					12	12
TOTAL	370	161	531	242	350	800	550	1100	1450	4492	5023
($78)	448	177	625	242	318	661	413	751	900	3285	3910

10.4 Identification of Impacted Parameters

The corrosion rate of carbon steel by hot saline water is about 0.25 mm/year even following efficient deaeration of the water. This indicates that components of a geothermal power plant which are in contact in the brines must be overdesigned to allow for corrosion during the life span of the power plant. The wall thickness of the components must be increased from the thickness required to withstand operating pressures by an amount equal to the corroded thickness during the plant life time. Hence if coatings which do not corrode away can be developed and apply such additional thickness can be eliminated and consequently, the capital costs can be reduced. The impacted parameters identified here are the capital costs of those components which are in contact with the brine. It is noted that the subelement goals do not include improvements in well casing.

10.5 Impacts on System Parameters

Components of the power plant affected by the results of this subelement are pipelines and pressure vessels. The analysis presented here make use of cost data reported by Mr. Kukacka, projects leader, of the Brookhaven National Laboratory:

Vessel shells and internal structures	\$952/ton
Large diameter (>20 inch) pipe	\$3870/ton
Small diameter pipe	\$3124/ton
Polymer concrete	\$318/ton
Applying cement liners	\$5/ft^2

Note: The cost figures are in 1978 dollars.

10.5.1 Pipelines

Consider a one foot section of pipe subjected to a typical operating pressure of 250 psig. The pipe has a diameter D and wall thickness t and is made of steel which typically has a design stress of 8,000 psi. The minimum required thickness is

$$t = \frac{250D}{8000 \times 2} = 0.0156D$$

Let us also assume an average diameter of 20 inches and base the calculation on pipe material cost of $3800/ton. The above thickness becomes 0.0156 x 20 = 0.31 inches which yields a cost of:

$$\frac{0.31}{12} \times \frac{\pi\,20}{12} \times 1 \times (62.34 \times 7.8\ \frac{lb}{ft^3}) \times (\frac{3800}{2000}\ \frac{\$}{lb}) = \$125/ft$$

Now, a thirty-year life plant would require an additional thickness of 0.25 mm/yr x 30 = 7.5 mm or 7.5/25.4 = 0.30 in. The cost which is proportioned to the wall thickness becomes:

$$\frac{0.31 + 0.30}{0.31} \times 125 = \$246/ft$$

This means that the material cost for pipelines with current technology is about $246/ft which includes an overdesign cost of 246 - 125 = $121/ft. If coatings are used with a thickness of 1/4 inch and density of 2 x 62.34 lb/ft^3 (approximate concrete density), the coating material cost is:

$$\frac{0.25}{12} \times \frac{\pi\ 20}{12} \times 1 \times (62.34 \times 2)\ (\frac{318}{2000}) = \$2/ft$$

and the applying cost is

$$\frac{\pi\ 20}{12} \times 1 \times (5\ \frac{\$}{ft^2}) = \$26/ft.$$

TABLE 1

MATERIAL COSTS FOR PIPELINES AND PRESSURE VESSELS IN 1978 DOLLARS

	CURRENT	WITH COATING
Pipelines		
Cost for strength requirement ($/ft)	125	125
Cost for Corrosion allowance ($/ft)	121	0
Cost of coating ($/ft)	0	28
TOTAL ($/ft)	246	153
Change ($/ft)	0	-93
(%)	0	-37.8
Pressure Vessel		
Cost for strength requirement ($)		
shell	639	639
inner pipe	100*	100*
Cost for corrosion allowance ($)		
shell	511	0
inner pipe	240	0
Cost of coating (mats + application)($)	0	691
TOTAL ($)	1490	1430
Change ($)	0	-60
(%)	0	-4.0

* Assumed.

The materials cost saving is thus 37.8% as shown in the summary in Table 1. This estimate is noted to fall within the range of 35 - 45% estimated by Mr. Kukacka.

10.5.2 Pressure Vessels

Since pressure vessels, e.g., well head separator, are subject to the same conditions as the pipelines, the method of calculation is similar to the above. If the New Zealand design shown in Figure 1 is assumed, the wall thickness requirement for strength is

$$t = \frac{250 \times 4D^2}{8000 \times 10D} = 0.0125D$$

If D in the above equation is assumed to be 30 inches, t is equal to 0.0125 x 30 = 0.375 inches, and the steel cost becomes:

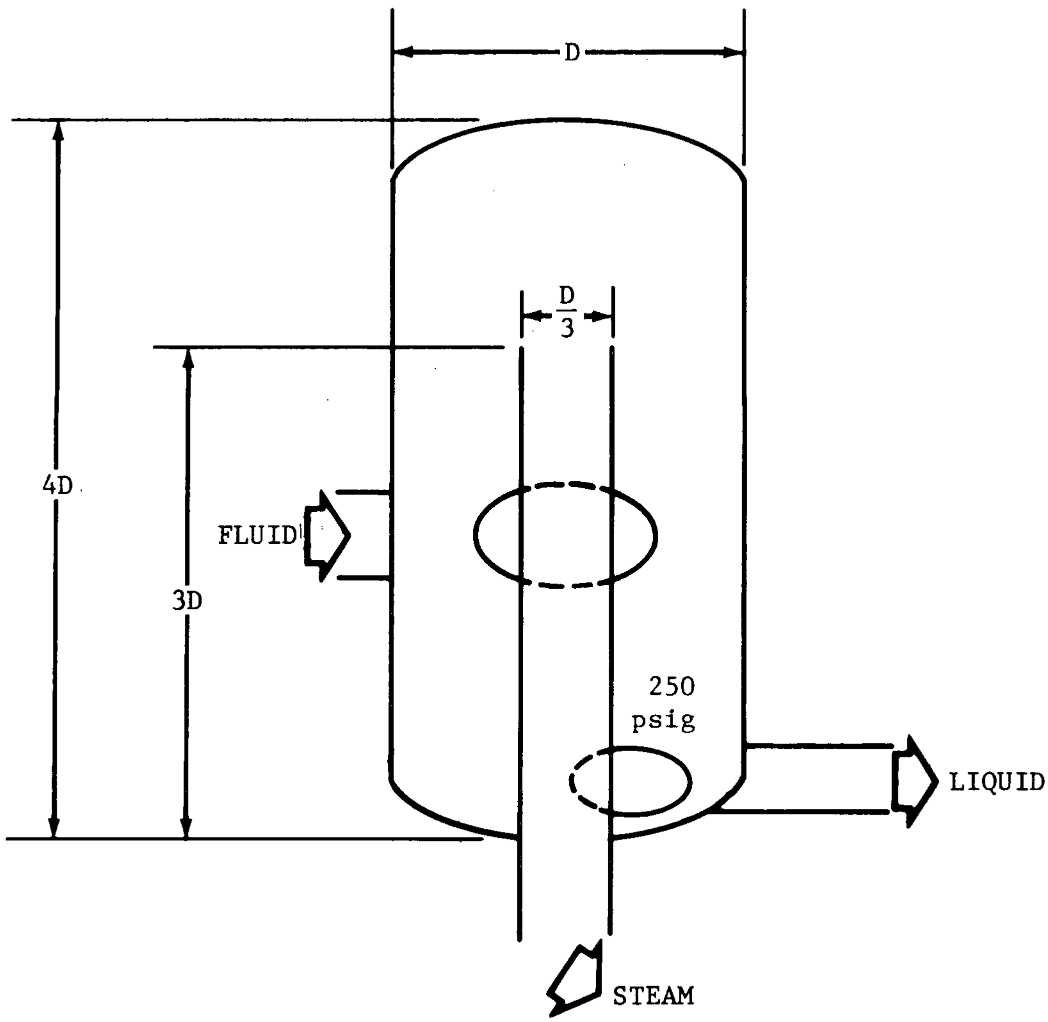
$$\frac{0.375}{12}\left[\frac{\pi\ 30}{12} \times \left(\frac{4 \times 30}{12}\right) + 2\ \frac{\pi\ 30^2}{144 \times 4}\right](62.34 \times 7.8)\left(\frac{952}{2000}\right) = \$639$$

Cost of corrosion allowance (thickness=0.30 in.) is proportional to the above figure as follows:

$$\frac{0.30}{0.375} \times 639 = \$511$$

The inner pipe theoretically does not require strength, however let us assume its cost is \$100 and its thickness is 0.25 in. The corrosion allowance must be incorporated on both sides of this pipe making the total thickness for corrosion at least 0.60 in. Hence cost for corrosion allowance is:

$$\frac{0.60}{0.25} \times 100 = \$240$$



(P. Bangma, "The Development and Performance of a Steam-Water Separator for Use on Geothermal Bores", Proc. of the Conf. on New Sources of Energy, Vol. 3, p. 60, Rome, 21-31 August 1961)

FIGURE 1
A DESIGN OF WELL HEAD SEPARATOR

Cost of coating materials of 1/4" thick for shell and inner pipe is:

$$\left(\frac{0.25}{0.375}\ \frac{318}{952} \times 639 + \frac{0.25}{0.30}\ \frac{318}{952} \times 240\right)\ \frac{2}{7.8} = \$53$$

Coating application costs:

$$(\$5/ft^2)\left[\pi D \times 4D + 2\frac{\pi D^2}{4} + 2\ (\pi\ \frac{1}{3}D \times 3D)\right] = 102.1\ D^2 = \$638$$

The change is, as shown in Table 1, about - 4.0%.

10.5.3 Impacts on Benefit Model Input Parameters

From the figures above, it is reasonable to assume that the cost savings on materials costs are 35 - 45% for pipelines and 2 - 5% for pressure vessels. If the material costs are assumed to make up 70% of the installed cost of pipelines and 50% of the installed cost of pressure vessels, the savings become 24.5 - 31.5% for pipelines and 1 - 2.5% for pressure vessels. These figures are related to the benefit model input parameters as shown in Table 2, which is self-explanatory.

10.6 Degree of Success

The results of this subelement, if the contained projects are successful, can be used on appropriate components in all sites, and hence their market share can be assumed as 100%. However like other materials projects, the search for suitable coatings is a trial-and-error process. Therefore the degree of success can be reasonably assumed to be 0.8.

10.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY 78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	111.5	27.2	22.8
PESSIMISTIC	86.1	21.0	17.6

TABLE 2

IMPACTS ON THE COST MODEL INPUT PARAMETERS

COST MODEL INPUT PARAMETER	COMPONENTS* INCLUDED IN INPUT PARAMETER	COST FRACTION** OF IMPACTED COMPONENTS	IMPACTS ON INPUT PARAMETERS	
			PESSIMISTIC	OPTIMISTIC
Capital cost of gathering system	piping for steam, brine or both to plant	100% for binary	-24.5%	-31.5%
		30% for flash	-7.4%	-9.5%
Capital cost of process Mechanical (producer)	deep well pumps, process pumps, valves, separators	0% for binary	0	0
		40% for flash	9.8%	12.6%
Capital cost of Distribution System	piping for disposal brine from plant to wells	100% for binary	-24.5%	-31.5%
		100% for flash	-24.5%	-31.5%
Capital cost of piping and insulation	in-plant process piping and insulation	5% for binary	-1.2%	-1.6%
		0% for flash	0	0

* Underlined is the component affected by this subelement's results.

** Estimated.

11.0 SUBELEMENT 3-2-D:

SEAL MATERIALS DEVELOPMENT

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-2-D	CONTRACT NUMBER(S) A361011, C031308, C031325, C040789, 951074
TITLE Seal Materials Development	
CONTRACTOR(S) NASA/JPL, L'Garde, Hughes Aircraft, Sandia Lab., BNL, ASTM	
RELATED PROJECTS 3-2-09 High Temperature Elastomers R&D (NASA/JPL) 3-2-10 Alternate High Temperature Seal Materials (BNL) 3-2-11 High Temperature Elastomers (L'Garde) 3-2-12 Development of Well Logging Materials (Hughes)	3-2-13 Geo. Seal Symposium (ASTM)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
		√			

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	378										378
2. DGE Planned:		434	205	550	0	300					1469
3. Additional:											0
Total:											1847
Discounted Total of Planned and Additional:											1260

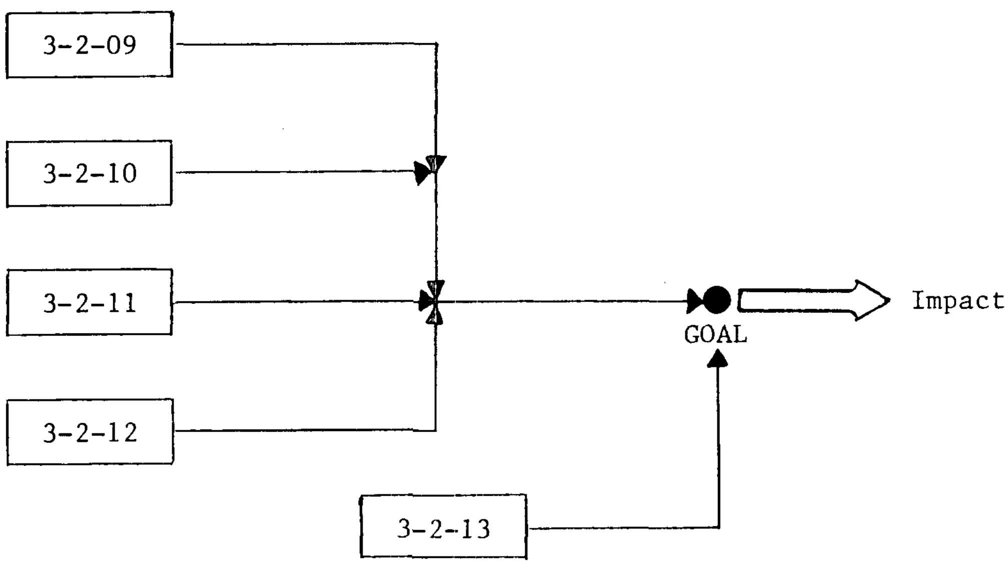
EXPECTED YEAR OF COMMERCIALIZATION	1981
EXPECTED DEGREE OF SUCCESS	0.3

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	324.7
	PESSIMISTIC	44.5
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	77.3
	PESSIMISTIC	10.6
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	58.0
	PESSIMISTIC	7.9

SEE ATTACHED PAGES FOR RATIONALE

11.1 Projects in Subelement

Project Code	Project Title
3-2-09	High Temperature Elastomers R&D
3-2-10	Alternate High Temperature Seal Materials RFP
3-2-11	High Temperature Elastomers
3-2-12	Development of Elastomers for Well Logging Equipment
3-2-13	Geothermal Seal Symposium - Boston



11.2 Goal

Elastomeric seal materials which are suitable for use in geothermal environments at temperatures up to 250°C.

11.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-09	40	64	104	104	0					104	208
3-2-10	0	0	0	0	125	550	0	300		975	975
3-2-11	0	182	182	220	80					300	482
3-2-12	0	92	92	87*	0					87	179
3-2-13	0	0	0	3	0					3	3
TOTAL	40	338	378	414	205	550	0	300		1469	1847
($78)	48	372	420	414	186	455	0	205		1260	1680

* Obligated in Fiscal Year 1977.

11.4 Identification of Impacted Parameters

Elastomeric materials are used as seals in many well-drilling and completion tools, including drill bits, packers, and logging sondes and cables. Currently available elastomeric materials tend to fail at temperatures above 200°C in static sealing applications, and about 100°C in dynamic rotary sealing applications.

Improved seals in drill bits could extend the temperature at which sealed journal bearing drill bits can be used, thus increasing bit life under high temperature drilling conditions. Improved seals in packers would reduce the difficulty and cost of cementing jobs and stimulation jobs. In fact, a common opinion in the geothermal drilling industry is that many desirable geothermal stimulation jobs will not be practicable until a new high temperature packer is developed.

Logging equipment uses elastomers as static seals in logging sondes and as insulation in logging cable. These two types of materials are analyzed together because they are similar in that if one type is developed, it can be used for the other application.

11.5 Impacts on System Parameters

The impacted parameters identified above are related to the system parameter "well cost". Such relationship has been analyzed and incorporated in a computer code developed by MITRE called WELCST. The user's guide and description for this code is reported elsewhere*. The WELCST model is used here together with the benefit model and the impacts of the subelement will be listed in terms of dollars rather than the changes in the benefit model inputs.

11.5.1 Drill Bits

Most geothermal drilling is done with sealed journal bearing tricone tungsten-carbide insert bits. The seals in these bits fail when the bottom hole circulating temperature of the drilling fluid exceeds about 100°C**. Once the seals fail the journal bearings then fail extremely rapidly because they lose lubrication and are eroded by grit from the drilling fluid.

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* D.J. Entingh and A. Lopez, "WELCST, Engineering Cost Model of Geothermal Wells: Description and User's Guide", MITRE/Metrek Report M-78-86, December 1978.

** Personal communication, R.R. Hendrickson, Terra Tek, Inc.

Above 100^{o}C roller bearing bits are used. (These are usually unsealed, because seals offer only very short term protection against penetration by drilling fluid). The roller bearings withstand grit better than do journal bearings, but the life of an unsealed roller bearing bit is only about one-third to one-fifth that of a sealed journal bearing bit. Thus seals that could survive more than 100^{o}C would allow the stronger journal bearing bit to be used in portions of geothermal wells where they do not survive today.

Two conditions were examined using MITRE's WELCST model of geothermal well costs: drilling in mud and drilling in air.

(a) Drilling in mud. Improved seals will reduce drilling costs only when bottom hole mud temperatures exceed 100^{o}C. The WELCST model contains equations for bottom hole cooling and reheating due to circulation and interrupted circulation of mud. WELCST assumes that almost all drilling at the 27 U.S. geothermal prospects considered in the model will be drilled with mud. Runs of the model under varying parameters suggest that at only 2 of the 27 prospects will circulating bottom hole mud temperatures tend to exceed 100^{o}C while the bit is rotating. The average cost savings across all wells indicated by WELCST due to seals improved to tolerate 150^{o}C is only about 0.03% per well. Higher temperature limits on seals do not add any more benefits from mud drilling. Thus the 0.03% reduction in well cost is accepted as both the optimistic and the pessimistic estimate of the benefit due to this factor.

(b) Drilling in air. When air is the drilling fluid in the hotter portions of geothermal wells, roller bearing bits (lifetime about 18-30 hrs.) must be used rather than sealed journal bearing bits (lifetime about 90 hr.) because the bits are not cooled much by the air circulation. Nonetheless, air drilling is often advantageous because penetration rates in air can be two to three times those in mud. High-temperature seals might have a large economic benefit if they allowed journal bearing bits to be used in air drilling. This would take combined advantage of the higher rates of penetration in air and the longer life of journal bearings.

The WELCST model was used to evaluate this possibility, by varying the bit seal temperature limit while drilling a typical geothermal well in which air is used for part of the drilling. The "typical" well was defined by: depth = 6500 ft., bottom hole formation temperature = 250°C, rock drillability = medium hard, upper 70% of well drilled in mud, lower 30% drilled in air. It was assumed that the temperature to which the bit seals are exposed is approximately that of the rock being drilled (this assumption implies that air carries heat away from the bit fast enough to compensate heating due to friction, but does not provide significant borehole cooling).

Runs of the model indicate no economic benefit in this use until the seal temperature limit reaches about 200°C. If the limit is raised to 250°C, the cost of the well is reduced by 3.5%. Therefore the pessimistic estimate of the impact from this factor is set at at zero, and the optimistic estimate estimate is set at a 3.5% reduction in production well costs.

11.5.2 Rotating Drill Head

The seals at the rotating drilling head need frequent change-out because of embrittlement caused by the high temperature of the return drilling fluids. The change-out of these seals is relatively easy and requires one day at the most. If the change-out takes place while tripping a bit, much of its down-time cost is absorbed into the tripping cost. Thus if suitable seals are developed and used to eliminate change-out, the cost savings per well will range from $5K to $10K, or 0.6% to about 1.2%.

11.5.3 Cementing Cost

The current status of geothermal well cementing was described as follows*: When cementing intermediate casing at the Geysers the well must be cooled prior to going in with the packer and special precautions must be taken. One squeeze costs $60K-$75K which is about five times as much as the cost at a comparable oil well. Another source (Union Oil, 5/78), estimates that greater than 50% of the time more than one try is required to pack off in the 205-260°C (400-500°F) range.

The 50% of the time mentioned above can be translated to about one day of operation or about $10K in cost.** Thus the impact of

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* Personal communication from Mr. Allan R. Hirasuna, GEM Program Manager, L'Garde, Inc.

** Personal communication from Mr. Louis Capuano, Drilling Manager of Thermogenic Company.

this factor will range from zero to about 1.2% reduction in cost per well.

11.5.4 Well Stimulation Costs

High temperature packers are an essential requirement for efficient and successful stimulation of geothermal wells. Recent estimates indicate that from 5 to 10% of geothermal wells will be stimulated*. High temperature packers could save between $10K and $30K per fracturing job. Assuming a typical well cost of $800K, this factor could save between 0.1% and 0.35% of the cost per well when averaged across all production and injection wells.

11.5.5 Logging Equipment Costs

A recent analysis of the economic benefits from geothermal logging tool development** estimates a total benefit ranging from $60 million to $180 million for the development of improved sondes and from $30 million to $98 million for the development of improved logging cables. Elastomers are credited here with 5% of the expected benefit from the sondes, where they will be used mainly as static seals, and 30% of the benefit from the cables, where their role as insulation is very important. Consequently, the pessimistic benefit is estimated as $3 + $10 = $13 million, and the optimistic benefit estimated as $9 M + $33 M = $42 million across all wells in the benefits model developmental scenario.

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* See Volume III of this report.
** See Volume II of this report.

11.5.6 Summary of Impacts

The current average well cost is about $800/well, and the discounted benefit of a 1.0% reduction in well cost occurring by an impact year of 1981 is about $45 million. The benefit from the five impacts described above are:

IMPACTED COST ITEM	BENEFIT ($ MILLIONS, 1978) PESSIMISTIC	OPTIMISTIC
Drilling in Mud	1.4	1.4
Drilling in Air	0.	157.5
Rotating Drill Head	27.	54.0
Cementing Cost	0.	54.0
Well Stimulation	4.5	15.8
Logging Equipment	13.0	42.0
TOTAL	45.9	324.7

11.6 Degree of Success

The current elastomeric materials are practical over the temperature range 100°C to 200°C, depending on the application. Thus the anticipated market for elastomers in geothermal tools will be shared by existing and novel materials. Moreover, the projects comprising this subelement are of the trial-and-error materials testing type, and to date are not showing signs of delivering large increases in seal temperature limits. Considering these factors, the anticipated degree of success of the subelement as a whole is set as a fairly low value: 0.3.

11.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	$324.7	77.3	58.0
PESSIMISTIC	$ 45.9	10.9	8.2

12.0 SUBELEMENT 3-2-E:

CORROSION OF METALS

BENEFIT / COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-2-E

CONTRACT NUMBER(S) 4511830, 05ENG26

TITLE Corrosion of Metals

CONTRACTOR(S) Pacific Northwest Laboratory, Oak Ridge National Laboratory

RELATED PROJECTS
- 3-2-14 Iron-Base Alloys versus Alternate Materials (PNL)
- 3-2-15 Corrosivity of Brine (ORNL)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
				✓	

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	1432										1432
2. DGE Planned:		275									275
3. Additional:											0
Total:											1707
Discounted Total of Planned and Additional:											275

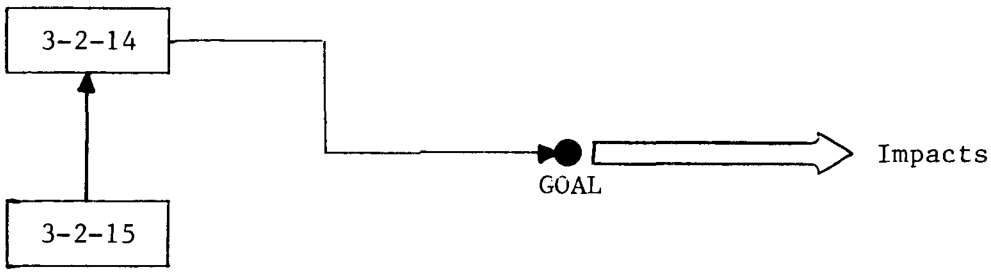
EXPECTED YEAR OF COMMERCIALIZATION	1979
EXPECTED DEGREE OF SUCCESS	0.3

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	26.6
	PESSIMISTIC	17.5
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	29.0
	PESSIMISTIC	19.1
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	4.8
	PESSIMISTIC	3.1

SEE ATTACHED PAGES FOR RATIONALE

12.1 Projects in Subelement

Project Code	Project Title
3-2-14	Iron-base alloys versus Alternate Materials
3-2-15	Corrosivity of Brine



12.2 Goal

To study corrosion of metals in geothermal brine and to establish the applicability of existing iron-base alloys in geothermal systems under various brine conditions.

12.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-14	493	349	842	275	0					275	1117
3-2-15	370	220	590	0						0	590
TOTAL	863	569	1432	275						275	1707
($78)	1044	626	1670	275						275	1945

12.4 Identification of Impacted Parameters

Insufficient knowledge and information regarding corrosion of materials in geothermal brines has frequently led to corrosion failures and shutdowns of the plants or parts of the plants. Thus site-specific corrosion tests must, as is current practice, be run after a test well has been drilled and completed. The extent of these tests depend on how much is known about brine corrosivity specific to the site under development. Since this R&D subelement essentially provides design engineers with information for selecting proper materials, and is not attempting to develop new materials, it only reduces his effort in materials selection process and does not affect the operation and equipment costs of the plant. Hence the only impacted parameter is the pre-construction engineering cost.

12.5 Impacts on System Parameter

The impacts of the results of this subelement on the engineering costs can be quantified in terms of the reduction in corrosion test effort as follows:

(i) If this subelement does not exist, the following efforts are required:

- Literature search: 6 manmonths, cost: $5K x 6 = $30K. Materials are recommended for tests.
- Corrosion tests: 10 manmonths, cost: $5K x 10 = $50K. The tests are carried out over a period of perhaps 6 to 18 months.
- Test Materials and Analyses: cost $10K

TOTAL = $90K

(ii) As the results of this subelement, the above efforts are reduced as follows:

- Literature search: 1 manweek, cost: $5K x 0.25 = $1.25K
- Corrosion tests: 2 manmonths, cost: $5K x 2 = $10K
- Materials and Analyses:
  cost: $3K

TOTAL $14.25K

Thus a saving of $90K - $14.25K = $75.25K results. From this figure it is reasonable to assume that the saving is somewhere between $60K and $90K per plant regardless of its size. Since the corrosion of metals is concerned, the types of plant that are noticeably affected by the results of this subelement are those which contain components in contact with brine (liquid). These plants are flash steam and binary plants, and involve pre-construction engineering costs of $1,990K for flash steam plant and $3,100K for binary plant*. The saving in engineering costs becomes 60/1990 = 3.0% and 60/3100 = 1.9% in the pessimistic case. The results are summarized for the benefit model input parameter changes as follows:

	PESSIMISTIC		OPTIMISTIC	
BENEFIT MODEL INPUT PARAMETER	Flash	Binary	Flash	Binary
% Change in Capital Cost of Engineering and Administration (Producer)	-3.0	-1.9	-4.5	-2.9
% Change in Capital Cost of Engineering and Administration (Utility)	-3.0	-1.9	-4.5	-2.9

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* V. Thanh Nguyen and Harpal S. Dhillon, "An Analysis of the Geothermal Energy Extraction and Utilization Technology RD&D Program", Report MTR-7886, MITRE Corporation, June 1978.

12.6 Degree of Success

Since subelement involves corrosion tests and is a compilation of the results of these tests, there is no reason why it should not be successful and achieve its goal. The degree of success would be 1.0. However since the objectives of the projects contained in this subelement are included in the Materials Design Handbook subelement, the market of commercialization of this subelement is shared by that of the Handbook. Thus, its degree of success can be assumed as the difference between unity and the Handbook's degree of success, i.e. 0.3.

12.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	26.6	29.0	4.8
PESSIMISTIC	17.5	19.1	3.1

13.0 SUBELEMENT 3-2-F:

CASING AND DRILL PIPE MATERIALS

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-2-F	CONTRACT NUMBER(S) S022602

TITLE Casing and Drill Pipe Materials

CONTRACTOR(S) Case Western Reserve University

RELATED PROJECTS

3-2-16 Casing and Drill Pipe Materials (CWRU)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
		✓			

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	383										383
2. DGE Planned:		234	180	180							594
3. Additional:											0
Total:											977
Discounted Total of Planned and Additional:											547

EXPECTED YEAR OF COMMERCIALIZATION 1979

EXPECTED DEGREE OF SUCCESS 0.8

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	37.6
	PESSIMISTIC	26.5
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	55.0
	PESSIMISTIC	38.8
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	29.9
	PESSIMISTIC	21.1

SEE ATTACHED PAGES FOR RATIONALE

13.1 Project in Subelement

Project Code	Project Title
3-2-16	Casing and Drill Pipe Materials

13.2 Goal

To increase the reliability in service against sulphide stress cracking and/or chloride cracking of casing, tubing, drill pipe, and other downhole components.

13.3 Cost

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-16	337	46	383	234	180	180	0			594	977
$78	408	51	459	234	164	149	0			547	1006

13.4 Identification of Impacted Parameters

The components which are to be improved as the results of this subelement are used in drilling and completion of wells. Materials currently used for casing, for example, are low strength, plain carbon steels. These low yield strength levels range from 40 or 55 ksi to 80 ksi. These steels have metallurgical structures with low toughness and high sensitivity to typical aggressive geothermal environments, particularly in terms of H_2S, Chloride and pH. The improved materials to be developed would give longer use of casing and drill pipes and therefore impact the well life and well cost as discussed in the next subsection.

13.5 Impacts on System Parameters

According to the R&D project manager*, the new steels can be manufactured at a 4% increase in cost and can have a 25-30% increase in strength. Since increase in strength would increase drill pipes and casing lives, well life would be increased and drilling cost would be reduced. To calculate these impacts, it is necessary to relate the strength increase to life increase for steel. That is a full analysis of piping design for loads, stresses and concentrations, thermal gradients and transients is required. Such analysis is clearly a monumental task and well beyond the scope of this report. To simplify the problem, the steel life is assumed to be increased by the same factor as its strength, i.e., 25-30%.

13.5.1 Well Life

Since well life is dependent on other factors such as precipitation, cement life and reservoir properties than casing life, a rationale for the impacts of casing life on well life is required here. Such rationale has been discussed and presented in subsection 9.5.1 and therefore will not be repeated here. Well life increase

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* A.R. Troiano and R.F. Heheman, "Estimating Technical Performance Impacts of Geothermal R&D projects", enclosure of letter to Mr. John Walker of DGE dated June 7, 1978.

due to 25-30% casing life increase can be estimated by using Table 1 of 9.5.1. The results are shown below.

	PESSIMISTIC		OPTIMISTIC	
New Life Factor of Casing	1.25		1.30	
	Life (yrs)	%	Life (yrs)	%
Dry steam well	15.79	5.3	15.92	6.1
Flash steam well (low salinity)	15.52	3.4	15.60	4.0
(high salinity)	7.62	1.6	7.64	1.8
Binary well (low salinity)	15.65	4.3	15.76	5.1
(high salinity)	15.52	3.4	15.60	4.0

13.5.2 Well Cost

In this case, well cost is affected by two factors: drill pipe cost and casing cost.

The life of drill pipes has been assumed to be increased by 25-30%. If drill pipes are used until failure, the number of pipes used for drilling would be reduced by a factor of 1/1.25 = 0.80 to 1/1.30 = 0.769. Since drill pipe cost is proportional to the number of pipes used, the above factors also represent cost reduction. Now because the new steel costs 4% more, the actual drill pipe cost becomes 0.80 x 1.04 = 0.832 to 0.769 x 1.04 = 0.800 of the original cost. A cost reduction from 1 - 0.832 = 16.8% to 1 - 0.800 = 20.0% results.

The cost of drill pipe constitute about 1.2%, and casing cost about 8.8% of the total well cost*. Hence the impacts on the well cost of the new materials are:

Due to drill pipe cost change:	-0.20%	to	-0.24%
Due to casing cost change (0.04 x 8.8%)	0.35%	to	0.35%
Net Change	0.15%	to	0.11%

13.5.3 Summary

The above changes are expressed in terms of the benefit model input parameters as follows:

	PESSIMISTIC			OPTIMISTIC		
	Steam	Flash	Binary	Steam	Flash	Binary
% Change in Cost per production well	0.2	0.2	0.2	0.1	0.1	0.1
% Change in Cost per injection well	0.2	0.2	0.2	0.1	0.1	0.1
% Change in Life Span of production well (low salinity)	5.3	3.4	4.3	6.1	4.0	5.1
% Change in Life Span of production well (high salinity)	5.3	16.	3.4	6.1	1.8	4.0

Note: Effects on life span of injection wells are assumed to be negligible.

13.6 Degree of Success

From conversation with the project manager, it is understood that the new steels can be developed with reasonable confidence and

* D.J. Entingh and A. Lopez, "WELCST, Engineering Cost Model of Geothermal Wells: Description and Users Guide", MITRE/Metrek Report M-78-86, December 1978.

the market for them is large. Hence the degree of success is taken to be 0.8.

13.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	37.6	55.0	29.1
PESSIMISTIC	26.5	38.8	21.1

14.0 SUBELEMENT 3-2-G:

PITTING AND LOCALIZED CORROSION RESISTANT ALLOYS

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-2-G CONTRACT NUMBER(S) C020016

TITLE Pitting and Localized Corrosion Resistant Alloys

CONTRACTOR(S) Brookhaven National Laboratory

RELATED PROJECTS

3-2-17 Pitting Resistant Alloys Development and Management

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
	√	√			

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	0										0
2. DGE Planned:		0	150								150
3. Additional:				200	200						400
Total:	0	0	150	200	200						550
Discounted Total of Planned and Additional:											451

EXPECTED YEAR OF COMMERCIALIZATION 1982

EXPECTED DEGREE OF SUCCESS 0.1

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	119.3
	PESSIMISTIC	86.4
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	26.5
	PESSIMISTIC	19.2
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	26.5
	PESSIMISTIC	19.2

SEE ATTACHED PAGES FOR RATIONALE

14.1 Project in Subelement

Project Code	Project Title
3-2-17	Pitting Resistant Alloys Development and Management

14.2 Objective

To develop pitting and localized corrosion resistant materials for pipes and pressure vessels.

14.3 Cost

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-17	0	0	0	0	150	200*	200*			550	550
$78	0	0	0	0	136	165	150			451	451

* Additional funds assumed.

14.4 Identification of Impacted Parameters

Because of pitting and localized corrosion the materials requirements for pipes and pressure vessels have been overdesigned. This makes the costs of these components higher than necessary to satisfy the strength requirements. If pitting and localized corrosion resistant materials can be developed, such overdesign can be substantially reduced and consequently capital costs of pipes and pressure vessels can be reduced.

14.5 Impacts on System Parameters

To calculate the impacts on the capital costs of pipes and pressure vessels, it is necessary to examine the wall thickness of the components that is required to satisfy the strength requirement and then to compare it with the thickness required for strength and for corrosion at certain rates. Thus the analysis is similar to the one performed for the non-metallic construction materials subelement and presented in subsection 10.5. Let us use the results listed in Table 1 of subsection 10.5 to calculate the impacts of this subelement here. The calculations are summarized as follows:

		For Strength Requirement	For Strength + Corrosion
Cost of pipe (Diameter = 20 inches) materials ($/ft)		125	246
Cost of pressure vessel ($):	shell	639	1150
	inner pipe	100	340
	TOTAL	739	1490
Saving if corrosion allowances are not needed ($)	pipe	0	121
	pressure vessel	0	751

The savings are therefore 121/246 = 49.2% for pipelines and 751/1490 = 50.4% for pressure vessels. These savings are applicable when no corrosion allowance is given and the material cost is unchanged. They are adjusted as follows: Let us assume that 10 to 15% of the strength requirement thickness is allowed for corrosion for newly developed corrosion resistant materials which have the same O&M requirements as the currently used materials. Let us also assume that the corrosion resistant materials will cost 5% more than existing materials. The materials costs for 10% corrosion allowance become:

$$125 \times 1.10 \times 1.05 = \$144/\text{ft for pipelines}$$

$$739 \times 1.10 \times 1.05 = \$854 \text{ for pressure vessels}$$

The change in materials costs is:

$$\frac{144-246}{246} = -41.5\% \text{ for pipelines}$$

and

$$\frac{854-1490}{1490} = -\ 42.7\% \text{ for pressure vessels}$$

Material cost is only a fraction of the installed cost. This fraction is assumed to be 70% for pipelines and 50% for pressure vessels. Thus the above figures become -41.5 x 0.70 = -29.1% and -42.7 x 0.5 = -21.3%. These results and those for the 15% corrosion allowance case are translated into the impacts on the benefit model input parameters as shown in Table 1.

14.6 Degree of Success

As indicated in Subsection 14.3, the project of this subelement will not start until Fiscal Year 1979. Little information about the project is available. Therefore it is difficult to determine the degree of success of this subelement. However since the project, as described by its objective, is relatively straight forward and requires levels of effort and uncertainty similar to other projects in the materials development area, the degree of success can be reasonably assumed to be the same as that of the subelement 3-2-C. There is

TABLE 1

IMPACTS ON THE BENEFIT MODEL INPUT PARAMETER

BENEFIT MODEL INPUT PARAMETER	COMPONENTS* INCLUDED IN INPUT PARAMETER	COST FRACTION OF IMPACTED COMPONENTS	IMPACTS ON INPUT PARAMETER	
			PESSI-MISTIC (%)	OPTI-MISTIC (%)
Capital Cost of Gathering System	Piping for steam, brine or both to plant	100% for Binary 30% for Flash	-21.1 -6.3	-29.1 -8.7
Capital Cost of Process Mechanical (Producer)	Deep well pumps, process pumps, valves, separators	0% for Binary 40% for Flash	0 -8.4	0 -11.6
Capital Cost of Distribution System	Piping for disposal brine from plant to well	100% for Binary 100% for Flash	-21.1 -21.1	-29.1 -29.1
Capital Cost of Piping and Insulation	In-plant process piping and insulation	5% for Binary 0% for Flash	-1.1 0	-1.5 0

an overlap between the market for the non-metallic construction materials and the materials developed in this subelement. Only one type or the other can be applied. Thus the degree of success of this subelement can be taken as 0.1.

14.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	119.3	26.5	26.5
PESSIMISTIC	86.4	19.2	19.2

15.0 SUBELEMENT 3-2-H:

DYNAMIC COMPONENT MATERIALS

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-2-H	CONTRACT NUMBER(S) C020016
TITLE Dynamic Component Materials	
CONTRACTOR(S) Brookhaven National Laboratory	
RELATED PROJECTS 3-2-18 Materials Testing and Development Subcontracts - RFP	

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
				√	

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	0										0
2. DGE Planned:		0	200	500	250	0					950
3. Additional:											0
Total:		0	200	500	250	0					950
Discounted Total of Planned and Additional:											783

EXPECTED YEAR OF COMMERCIALIZATION	1982
EXPECTED DEGREE OF SUCCESS	0.3

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	103.7
	PESSIMISTIC	39.7
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	39.7
	PESSIMISTIC	15.2
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	39.7
	PESSIMISTIC	15.2

SEE ATTACHED PAGES FOR RATIONALE

15.1 Projects in Subelement

Project Code	Project Title
3-2-18	Materials Testing and Development Subcontracts - RFP

15.2 Objective

To develop high temperature (350-400°C), fracture toughness, and fatigue resistant materials for dynamic parts in pumps and borehole technology.

15.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-18	0	0	0	0	200	500	250	0		950	950
$78	0	0	0	0	182	413	188	0		783	783

15.4 Identification of Impacted Parameters

The components concerned here are bearings and metal seals which are small and cost little compared with equipment costs. Thus the impacts on equipment or plant component costs can be assumed to be negligible. It is expected, however, that the revenue losses due to bearing and metal seal failures in drilling operations are substantial. Part of these losses can be saved if fracture toughness and fatigue resistant materials can be developed. Thus the major impacted parameter is the drilling cost. The project results can also save some O&M cost for pumps especially downhole pump and allow new equipment such as downhole motor for drilling to be used.

15.5 Impacts on System Parameters

15.5.1 Metallic Composite Seals for Drill Bits

Following arguments and analyses identical to those used for elastomeric seals in Section 11 of this Appendix, the effects of high temperature composite seals will be to extend the temperature range of drilling fluid in which sealed journal bearing bits can be used. It is likely however, that composite seals will have to be physically larger than existing seals, and thus bits will have to be redesigned to incorporate them. Bit redesign and the cost of the seal is expected to raise the price of the bits by 30% above prices for similar types.

Given this cost premium, heterogeneous seal bits deliver no benefit if all the wells in the development scenario are drilled with mud. If the lower 30% of the wells are drilled in air with the new seal temperature limits (400°C), the heterogeneous seal will deliver according to the WELCST model a benefit ranging from 1% to 3.3% of the average well cost, or about $\$8.4 \times 10^6$ (pessimistic) or $\$27.9 \times 10^6$ (optimistic) as resulted from the benefit model.

15.5.2 Improved Bearing Materials for Bits

The improved hardness and fracture toughness of bit bearing materials can be translated into higher weight supporting ability and longer life for the bearings. Consequently the drilling rate of penetration and bit life are increased. Let us assume that the use of the newly developed bearing materials increase bit cost by 20%, rate of penetration by 5-10%, and bit life by 5-10%. These increases yield through the use of the WELCST and benefit models a benefit from $\$18.3 \times 10^6$ (pessimistic) to $\$28.9 \times 10^6$ (optimistic).

15.5.3 Downhole Drilling Motors

Downhole motors are now used for some directional drilling, and could be used for straight hole drilling. Downhole motor costs for directional drilling now run between $5K to $15K per well. The motors have to be serviced frequently on site because of bearing failures. Bearing and motor redesign could cut the total cost in half, saving, for an $800K well, between 0.3% and 0.9% of the well cost. If one third of this savings is attributed to improved selection of materials, the net benefit is approximately $\$6.8 \times 10^6$ (pessimistic) and $\$20.3 \times 10^6$ (optimistic).

Estimates of benefits from use of downhole motors for straight-hole drilling is more problematic, because current motors are quite uneconomic for this use in U.S. geothermal wells, and may continue to be so for some time. The main advantages for downhole motors in this use would be in the elimination of doglegs and in increased rate of penetration due to higher bit rotational speeds. At the reported frequency of doglegs, their elimination would save on the order of \$1500 per well. This translates to a net benefit of less than half a million dollars across the developmental scenario, and so is not considered further here. If downhole motor costs are \$2000/day, compared to \$5000/day for rig rent, rates of penetration given the motor would have to be 40% above current rates for the driller to break even using the motor. Such increased penetration rates seem unlikely in the near or intermediate term. Therefore, no benefit is postulated from this use.

15.5.4 O&M Cost of Downhole Pumps

Surface process pumps are assumed to be unaffected by this subelement because process pumps which are in contact with geothermal brine and operating in the range 350 - 400^{o}C are unlikely in the plant. The O&M cost of downhole pumps mainly includes service costs caused by corrosion, erosion, and scaling problems. The service costs of parts such as bearings or metal seals are expected to be small. It is assumed that this cost is about 2 to 5% of the total pump O&M cost. When evaluated using the benefit model, the net benefit from this factor is \$11.4 x 10^6 (pessimistic) and \$28.5 x 10^6 (optimistic).

15.5.4 Summary of Impacts

The combined impacts identified above are:

Impacts of Dynamic Component Materials On:	Benefit ($ Millions, 1978) Pessimistic	Optimistic
1. Drill bit seals	8.5	27.9
2. Drill bit bearings	6.8	20.3
3. Downhole Drilling Motors	13.0	27.0
4. Downhole Pump O&M	11.4	28.5
(TOTAL)	39.7	103.7

15.6 Degree of Success

This subelement will not start until Fiscal year 1979 and, like other subelements in materials development, has some uncertainty in the expected degree of success. In addition, since the temperature range of 350-400°C does not exist in all the sites, the market share of the subelement results is not 100%. It is expected, therefore, that the degree of success of this subelement is the same as that of the elastomeric seal subelement, which is 0.3.

15.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	103.7	39.7	39.7
PESSIMISTIC	39.7	15.2	15.2

It should be noted that the economic benefits expected from this R&D subelement overlap entirely with benefits postulated from certain subelements of the Geothermal Drilling Technology Program (Volume II of this report). No explicit connection has been made for these overlaps.

16.0 SUBELEMENT 3-2-I:

GEOPRESSURED HOT ISOSTATIC PRESSED CLAD (HIP) MATERIALS DEVELOPMENT

BENEFIT / COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-2-I CONTRACT NUMBER(S) C020016

TITLE Geopressured HIP Materials

CONTRACTOR(S) Brookhaven National Laboratory

RELATED PROJECTS

3-2-19 Geopressured HIP Materials Development, Commercialization and Subcontracts.

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
			✓		

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	0										0
2. DGE Planned:		0	0	300	250	500	2500				3550
3. Additional:											0
Total:		0	0	300	250	500	2500				3550
Discounted Total of Planned and Additional:											2330

EXPECTED YEAR OF COMMERCIALIZATION 1984

EXPECTED DEGREE OF SUCCESS 0.5

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	605.0
	PESSIMISTIC	142.0
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	129.8
	PESSIMISTIC	30.5
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	129.8
	PESSIMISTIC	30.5

SEE ATTACHED PAGES FOR RATIONALE

16.1 Project in Subelement

Project Code	Project Title
3-2-19	Geopressured Hot Isostatic Pressed (HIP) Materials Development, Commercialization and Subcontracts

16.2 Objective

To develop low cost, clad (hot isostatic pressed), corrosion and erosion resistant casing materials for, primarily, geopressured applications.

16.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-2-19	0	0	0	0	0	300	250	500	2500	3550	3550
$78	0	0	0	0	0	248	188	342	1552	2330	2330

16.4 Identification of Impacted Parameters

The subelement objective is to develop materials suitable for well casing to withstand the errosion and corrosion natures of geopressured fluid as it flows up a geopressured well. Hence, the impacted parameters are well capital cost and well O&M cost.

16.5 Impacts on System Parameters

The impacts of this subelement are in line with the development of geopressured resources. Therefore analysis for them can only be performed through a geopressured resources development scenario which, unfortunately, does not exist at this stage. However, in a recent publication,* Robert A. Hefner, III of G.H.K. Cos. in Oklahoma City suggested that total U.S. geopressured methane production could reach 8×10^{12} standard cubic feet by the year 2000. If this figure is used here, the total number of wells drilled by the year 2000 can be calculated using the following data:

Total production: 8×10^{12} scf

Concentration of CH_4: 40 to 50 sfc/bbl water**, use 45 scf/bbl

Production rate per well: 20,000 - 40,000 bbl/day**, use 30,000 bbl/day

To meet the year 2000 target, the production must be:

$$\frac{8 \times 10^{12}}{30000 \times 365 \times 45} = 16235 \text{ Well-years}$$

The date of starting production can be any year after 1985, and the number of wells drilled is usually increased with time after 1985. As a rough estimate, let us assume that the total number of production wells can be calculated based on the middle year between 1985 and 2000, i.e. 1993 which has a production period of 2000-1993 = 7 years. Hence the total well number is:

$$\frac{16235}{7} = 2319 \text{ wells}$$

The present cost per well is \$3.5M - 15M* and is assumed here to be

(*) : "The New Gas Bonanza", Newsweek, October 30, 1978.

(**): D.G. Debout et al., "Geopressured Geothermal Fairway Evaluation and Test-Well Site Location Frio Formation, Texas Gulf Coast", Report ORO/4891-4, Department of Energy, January 1978.

\$4M. The total O&M cost is calculated based on some assumed figures as follows:

Selling price: \$2.10/1000 scf*

Rate of return on investment: 20%

Additional equipment cost for gas processing - \$0.5M/well.

Total revenue return = $\$2.1 \times 8 \times 10^9 = \$16.80 \times 10^9$

Total well cost = $\$(4 + 0.5) \times 10^6 \times 2319 = \$10.435 \times 10^9$

Return = $\$10.435 \times 10^9 \times 0.20 = \$2.087 \times 10^9$

Total O&M cost = $16.80 - 10.435 - 2.087 = \$4.278 \times 10^9$

The benefit of using the HIP casing which is the result of this subelement can be calculated by assuming that:

Well casing cost increase: 20 - 40%

Casing cost/well cost: 0.10

Hence, well cost increase = 2 - 4%

Total well cost (10^9)=\$10.435x(1.02 to 1.04)	=\$10.644	to	10.852
Return at 20%	= 2.129	to	2.170
Reduction in O&M cost: 15 - 20%			
Total O&M cost(10^9)=\$4.278x(0.80 to 0.85)	= 3.422		3.636
TOTAL(10^9)	=\$16.195		16.658

Thus the resulted saving is somewhere between $\$(16.80 - 16.658) \times 10^9 = \$142 \times 10^6$ and $\$(16.80 - 16.195) \times 10^9 = \$605 \times 10^6$. Since all the cost figures are expressed in 1978 dollars, these

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*"The New Gas Bonanza", Newsweek, October 30, 1978.

benefits do not require discounting.

The well casing cost increase assumed here is mainly due to the additional material fabrication cost. The clading of high toughness materials on to steel has been done for short sections of pipe with some cost increase. Since there has been no information available on the clading process of long sections of pipe, it is rather difficult to justify for the assumed values of 20 - 40% used in the above calculation. Therefore the results of the calculation might be speculative.

The reduction of 15 - 20% in the O&M cost might be low because errosion problems in geopressured wells are expected to be severe and therefore the impacts that are erosion resistant casing have on the operating and maintenance of the wells are expected to be high. However, again, it is difficult to justify the assumed figures at this stage.

16.6 <u>Degree of Success</u>

The hot isostatic press technology is currently available for clading small sections of pipe. The success of transferring this technology to clading long sections of pipe has some degree of uncertainty, however. Thence the degree of success of this subelement, considering the fact that the project will not start until 1980, can only be assumed to be 0.5 at this stage.

16.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	605	129.8	129.8
PESSIMISTIC	142	30.5	30.5

17.0 SUBELEMENT 3-3-A:

SAMPLING AND ANALYSIS MANUAL

BENEFIT / COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-3-A	CONTRACT NUMBER(S) 4511830
TITLE Sampling and Analysis Manual	
CONTRACTOR(S) Pacific Northwest Laboratory	
RELATED PROJECTS 3-3-01 Sampling and Analysis Techniques	

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
	✓				

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	440										440
2. DGE Planned:		235	175	175	175	0					760
3. Additional:											0
Total:											1200

Discounted Total of Planned and Additional: 670

EXPECTED YEAR OF COMMERCIALIZATION	1980
EXPECTED DEGREE OF SUCCESS	0.5

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	41.5
	PESSIMISTIC	27.4
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	31.0
	PESSIMISTIC	20.5
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	17.8
	PESSIMISTIC	11.8

SEE ATTACHED PAGES FOR RATIONALE

17.1 Project In Subelement

Project Code	Project Title
3-3-01	Sampling and Analysis Techniques

17.2 Goal

A manual on sampling and analysis techniques that are used for chemical analysis of geothermal fluids with accuracy, reliability and intercomparability of reported results.

17.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-3-01	100	340	440	235	175	175	175	0		760	1200
$78	121	374	495	235	159	145	131	0		670	1165

17.4 Identification of Impacted Parameters

To identify parameters which will be impacted by this subelement let us consider a laboratory who gets the assignment to sample and analyze geothermal fluids. This laboratory would probably begin with a literature search to determine which methods are presently used for sampling and analysis. Some sampling methods presently used are mentioned and discussed in various articles contained in the literature and would be accessible. However, methods that are unique to a given situation and sometimes divulged only by contacting the appropriate geothermal developer would not be easily accessed. Analysis methods used are usually adopted from published methods for water, waste water, sea water, or oil field analyses. However modifications of these methods for particular geothermal fluid samples are generally not easily available unless contact is made with an laboratory experienced in analyzing geothermal fluid samples.

After the laboratory has made the necessary literature search, the next step would probably be to evaluate the available methods for suitability. If some of these methods are selected for use, it is necessary to evaluate the reported results and determine if the methods were done, as reported, correctly with no gross errors. This is important in determining if the results when the methods are used in a certain site would lead to power plant design or plant life errors. For example, a saving of $2M for vacuum pumps by Republic Geothermal for a 36 MW_e plant is dependent on obtaining reliable results from CO_2 sampling and analysis data*. If the above sequence of events were to occur it could easily take the inexperienced laboratory several manmonths of effort to properly take and analyze a single geothermal fluid sample.

Thus, it can be seen that the manual of sampling and analysis methods for geothermal fluids (including gases) produced from this subelement will allow inexperienced and experienced laboratories to

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* The figures are reported in a letter written to Mr. John Walker of DGE by Mr. E.M. Woodruff of Battelle Pacific Northwest Laboratories dated June 20, 1978.

quickly reference the current technology of sampling and analysis methods. In addition, available procedures will be referenced to actual field tests and will include comments and ranges of applicability. The impacted parameters is therefore the pre-construction engineering cost.

17.5 Impacts on System Parameters

The impacts on the pre-construction engineering cost can be quantified by comparing the costs of sampling and analysis between current practice without the manual and the practice with the manual.

17.5.1 Current Practice Without the Manual

The cost of sampling and analysis is estimated by the contractor as follows:

(i) Literature search: 3 manmonths, cost: \$5K x 3 = \$15K
The R&D contractor's efforts to search and analyze the literature of sampling and analysis methods consumed one man year costing \$50K, so \$15K is a conservatively low estimate of these costs.

(ii) Sampling and analysis time: 2 manmonths, cost: \$10K
Round robin testing of geothermal brine and dissolved gas samples during FY1977 indicated that this amount of time was necessary to analyze for 40 parameters. To characterize geothermal samples, by consensus of approximately 20 experienced laboratories, required 2 manmonths.

(iii) Recheck for sampling and/or analysis errors : 1 manmonth, cost: \$5K
This is probably a conservatively low estimate depending on the complexity of the sampling and analyses.

Thus a total of \$30K is required to provide adequate design information from the first well. For subsequent wells in the same site the same cost, excluding the cost for literature search, incurs.

17.5.2 Practice with the Manual

The use of the sampling and analysis manual would cost, as estimated by the contractor, as follows:

(i) Literature Search: 1 man week, cost: \$1.25K

(ii) Sampling and Analysis: 1 manmonth, cost: \$5K

(iii) Recheck for Errors: none, since right procedures would be known from the manual.

The total cost becomes \$6.25K for the first well.

17.5.3 Impacts on Engineering Cost

The saving in costs are 15 - 1.25 = \$13.75K for literature search and 15 - 5 = \$10K for analysis. Let us assume ranges for these savings which are \$10K to \$15K for literature search and \$8K to \$12K for analysis. Let us also assume some number of wells required for a 50 MW_e plant. A dry steam 50 MW_e plant would require, according to experiences with the Geysers, about 7 wells*. A flash steam plant of the same capacity would require 11 wells* (Japan), and a binary plant would require about 10 wells*. The cost savings due to the use of the manual for the pessimistic case become:

For dry steam plant = 10 + 8 x 7 = \$66K
For flash steam plant = 10 + 8 x 11 = \$98K
For binary plant = 10 + 8 x 10 = \$90K

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* V. Thanh Nguyen and Harpal S. Dhillon, "An Analysis of the Geothermal Energy Extraction and Utilization Technology RD&D Program", MITRE/Metrek Report MTR-7886, The MITRE Corporation, June 1978.

The total pre-construction engineering cost has been estimated* to be $1,500K for dry steam, $1,990K for flash steam, and $3,100K for binary plants. Hence the impacts on the benefit model input parameters are as follows.

BENEFIT MODEL INPUT PARAMETER	PESSIMISTIC			OPTIMISTIC		
	Steam	Flash	Binary	Steam	Flash	Binary
% Change in Capital Cost of Engineering and Administration (Producer)	-4.4	-4.9	-2.9	-6.6	-7.4	-4.4
% Change in Capital Cost of Engineering and Administration (Utility)	-4.4	-4.9	-2.9	-6.6	-7.4	-4.4

17.6 Degree of Success

This subelement is mainly a compilation of information for sampling and analysis methods. The potential level of accuracy of the information has been considered in the pessimistic estimate of impact. However, because the benefits of this subelement are not expected to be gained fully for the second and subsequent plants at one site, the applicability of the products is only partial. For this reason, the degree of success of this subelement is assumed to be 0.5.

17.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	41.5	31.0	17.8
PESSIMISTIC	27.4	20.5	11.8

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* V. Thanh Nguyen and Harpal S. Dhillon, "An Analysis of the Geothermal Energy Extraction and Utilization Technology RD&D Program", MTR-7886, The MITRE Corporation, June 1978.

18.0 SUBELEMENT 3-3-B:

PROCESS INSTRUMENTATION

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-3-B CONTRACT NUMBER(S) C012551, 4511830

TITLE Process Instrumentation

CONTRACTOR(S) National Academy of Science, Pacific Northwest Laboratory

RELATED PROJECTS 3-3-02 Assessment of Geothermal Brine (NAS)
3-3-03 Geochemical Controls and Instruments Application (PNL)
3-3-04 Reservoir In-Line Monitor R&D Subcontracts - RFP (PNL)
3-3-05 Monitor Instrument Field Experiment (PNL)
3-3-06 Cable Test (unknown)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
✓					

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	429										429
2. DGE Planned:		729	1140	1000	300						3169
3. Additional:											0
Total:	429	729	1140	1000	300						3598

Discounted Total of Planned and Additional: 2816

EXPECTED YEAR OF COMMERCIALIZATION 1981

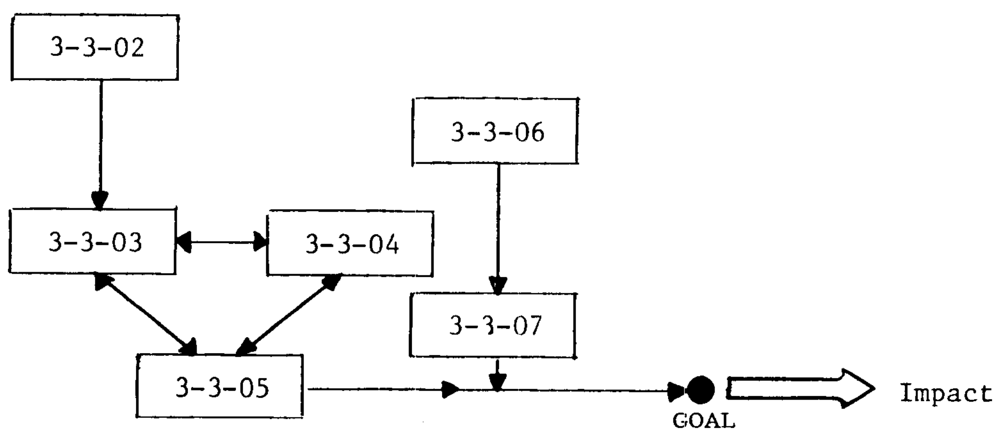
EXPECTED DEGREE OF SUCCESS 0.7

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	79.9
	PESSIMISTIC	3.5
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	19.9
	PESSIMISTIC	0.9
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	16.9
	PESSIMISTIC	0.7

SEE ATTACHED PAGES FOR RATIONALE

18.1 Projects in Subelement

Project Code	Project Title
3-3-02	Assessment of Geothermal Brine
3-3-03	Geochemical Controls and Instruments Application
3-3-04	Reservoir In-Line Monitor R&D Subcontracts RFP
3-3-05	Monitor Instrument Field Experiment
3-3-06	Cable Tests Subcontracts
3-3-07	High Temperature Cable Materials R&D Subcontracts



18.2 Goal

Instruments and sensors suitable for use in monitoring chemical variables of geothermal processes.

18.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-3-02	0	69	69	0						0	69
3-3-03	130	230	360	195	200	200				595	955
3-3-04	0	0	0	334	200	100				634	634
3-3-05	0	0	0	0	550	400				950	950
3-3-06	0	0	0	200	0					200	200
3-3-07	0	0	0	0	190	300	300			790	790
TOTAL	130	299	429	729	1140	1000	300			3169	3598
$78	157	329	486	729	1036	826	225			2816	3302

18.4 Identification of Impacted Parameters

The major objective of this subelement is to characterize instrumentation requirements and to develop electrical and electrochemical probes and cable materials that can be used to measure the chemical environment of geothermal brine and steam under the high pressure, high temperature conditions of a geothermal well and associated piping. Probes will be developed to measure CO_2, pH, oxidation-reduction potential, conductivity, corrosivity, sulfide ion concentration, heat transport, and scale thickness. A reference electrode will also be developed because some of the above measurements require a stable reference potential. The data from these devices will provide information for control of corrosion, scale deposition, and pollution in both newly explored and established geothermal fields as well as in the associated power generating equipment. Thus the results of this subelement will allow effective management in operating and maintenance activities for those components that are in contact with the brine and for pollution abatement.

It is noted that the subelement will not provide methods for controlling corrosion and scale deposition. Therefore it will not affect the design and performance of the plant.

18.5 Impacts on System Parameters

As indicated above, only O&M costs are affected. The impacts on the O&M costs that result from having ability to know ahead of time when corrosion and scaling problems become serious are similar to those impacts resulted from proper knowledge of brine chemistry. In this respect, the estimates presented in subsection 2.5.1 can be used here. Impacts on the O&M cost of pollution abatement operations must be on the same order of magnitude as those estimated for corrosion and scaling. In addition to impacts on O&M costs, it is assumed that instrumentation capital costs are increased from 0 to 2% for dry steam and flash steam systems and 0 to 4% for binary system. The results are summarized as follows:

BENEFIT MODEL INPUT PARAMETER	PESSIMISTIC Steam	Flash	Binary	OPTIMISTIC Steam	Flash	Binary
% Change in capital cost of Instrumentation	2.0	2.0	1.0	0	0	0
% Change in Producer General O&M Cost Factor	0	0	0	0	-5.0	-3.0

BENEFIT MODEL INPUT PARAMETER	PESSIMISTIC Steam	Flash	Binary	OPTIMISTIC Steam	Flash	Binary
% Change in Producer O&M Cost Factor (Low Salinity)*	0	0	0	-2.0	-5.0	-3.0
% Change in Producer O&M Cost Factor (High Salinity, T <450°F)*	0	-3.0	-2.0	-2.0	-9.0	-6.0
% Change in Producer O&M Cost Factor (High Salinity, T >450°F)*	0	-5.0	-3.0	-2.0	-9.0	-6.0
% Change in Producer Deep Well Pump O&M Cost Factor (Flash, T <200°C)	N/A	-5.0	N/A	N/A	-9.0	N/A
% Change in Producer Deep Well Pump O&M Cost Factor (Binary, T <200°C)	N/A	N/A	0	N/A	N/A	-3.0
% Change in Utility General O&M Cost Factor (Flash System)	N/A	0	N/A	N/A	-3.0	N/A
% Change in Utility General O&M Cost Factor (Binary System)	N/A	N/A	0	N/A	N/A	-2.0
% Change in Producer Spent Brine Treatment O&M Cost Factor	0	-2.0	-3.0	N/A	-5.0	-9.0

Note: * Includes piping system.

18.6 Degree of Success

The subelement results would have wide application. However there is some uncertainty in their success relative to the subelement goal. The activities involve development and testing of equipment, therefore it is possible that the equipment would not turn out to be as good as expected, and consequently the degree of success at this stage is less than unity. It is felt that a degree of success of 0.7 is reasonable for this subelement.

18.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	79.9	19.9	16.9
PESSIMISTIC	3.5	0.9	0.7

19.0 SUBELEMENT 3-3-C:

NON-DESTRUCTIVE EVALUATION TECHNIQUE

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-3-C	CONTRACT NUMBER(S) C014045
TITLE Non-Destructive Evaluation Technique	
CONTRACTOR(S) Daedalean Associates, Inc.	
RELATED PROJECTS 3-3-08 Non-Destructive Evaluation for Drill Pipe	

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
				√	

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	36										36
2. DGE Planned:		179									179
3. Additional:			50								50
Total:	36	179	50								265

Discounted Total of Planned and Additional: 224

EXPECTED YEAR OF COMMERCIALIZATION	1980
EXPECTED DEGREE OF SUCCESS	0.8

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	155.1
	PESSIMISTIC	14.0
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	553.9
	PESSIMISTIC	50.0
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	470.0
	PESSIMISTIC	42.4

SEE ATTACHED PAGES FOR RATIONALE

19.1 Project In Subelement

Project Code	Project Title
3-3-08	Non-Destructive Evaluation for Drill Pipe

19.2 Goal

Method and instrumentation for detecting incipient cracks of drill pipes in field applications.

19.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-3-08	0	36	36	179	50*					229	265
$78	0	40	40	179	45					224	264

* Additional

19.4 Identification of Impacted Parameters

One of the major cost factors involved in the operation of a geothermal drill rig is the removal of pipe strings that have catastrophically failed at deep levels in the well. Material cost and rig rental time of such recovery efforts, in many cases, are so great that the developers are forced to abandon the well. The removal costs or the costs sunk in abandoned wells are then charged to successful wells and passed along to consumers in the form of higher well cost.

The successful completion of this subelement would provide technology that would prevent some of these catastrophic losses and thus reduce the well cost.

19.5 Impacts on System Parameters

To analyze for the impacts that the results of this subelement has on the well cost, it is necessary to know a number of variables. These variables include frequency of drill pipe failures during drilling, frequency and cost of successful removing broken drill pipe from unfinished wells, frequency of unsuccessful removals, and cost of controlling abandoned wells. To yield data for these variables, a survey of geothermal well drilling data in the U.S. was conducted*. For the purpose of this analysis, assumptions must be made. It is assumed that:

Average fraction * of mishaps (broken drill pipe)	= 0.30
Average fraction* of successful removal	= 0.25
Average fraction* of unsuccessful removal	= 0.05
Average drilling time without mishap per well	= 10 days
Average removal time	= 3 days
Average drilling before mishap	= 5 days
Average additional (to rig rental) cost of removal	= $10K/well
Average additional (to rig rental and removal) cost of abandoned wells	= $50K/well

The calculations are based on a well cost without mishap of $800K/well and a cost breakdown as below*:

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* D.J. Entingh and A. Lopez, "WELCST, Engineering Cost Model of Geothermal Wells: Description and Users' Guide", MITRE/Metrek Report M-78-86, December 1978.

	PERCENTS OF TOTAL WELL COST
Drill pipe	0.6
Rig up x down	12.6
Drill string inspection	0.8
Rig rental	37.9
Others	48.1
TOTAL	100.0

Now, if the application of the Non-Destructive Evaluation (NDE) technique is successful the following results are assumed:

	Pessimistic	Optimistic
Mishap Fraction	0.15	0.15
Successful removal fraction	0.10	0.11
Unsuccessful removal fraction	0.05	0.04
Number of drill pipe rejected	15%	15%

It is noted that the mishap fraction assumed above is mainly due to stuck drill pipes and/or drill bit which cause twist-off even if there is no incipient crack in the drill pipes. Also, twist-off due to stuck drill pipes and/or drill bit is difficult to remove hence the unsuccessful removal fraction is only marginally reduced. The calculation for the optimistic case is shown below:

COST ITEM	COST WITHOUT MISHAP[1] ($1000)	COST OF CURRENT STATE ($1000)	COST WITH NDE ($1000)
Others	384.80	379.99[2]	380.95[3]
Drill pipes	4.80	4.68[4]	5.53[5]
Rig up and down	100.80	100.80[6]	100.80[6]
Drill string inspection	6.40	6.24[7]	0.17[8]
Rig rental	303.20	322.91[9]	310.78[10]
Removal		3.00[11]	1.50[12]
Controlling abandoned		2.50[13]	2.00[14]
TOTAL	800.00	820.12	801.73
Number of Completed Wells	1	0.95	0.96
Cost per Well	800.00	863.28	835.14

(1) Percent of total well cost x $800K.

(2) Three quarters of "others" cost are charged to 0.05 abandoned well: $384.80K x (1-0.05 + 3/4 0.05) = $379.99K.

(3) Similar to (2): $384.80K x (1-0.04 + 3/4 0.04) = $380.95K.

(4) Since 5 days are passed before mishap occurs, 0.5 of drill pipe cost is charged to abandoned well:
$4.80K x (1-0.05 + 0.5 x 0.05) = $4.68K.

(5) Since 15% of drill pipes are rejected, the cost increases by 1/0.85:
$4.80K x (1-0.04 + 0.5 x 0.04)/ 0.85 = $5.53K.

(6) Rig move and rig up and down are required regardless of whether or not mishap occurs.

(7) Inspection cost is similar to drill pipe charge:
$6.40K x (1-0.05 + 0.5 x 0.05) = $6.24K.

(8) According to the contractor, current test is performed on 7/8 of a pipe length and costs 50 times more, on the unit length basis, than the NDE technique:

$$\$6.40K \times (1-0.04 + 0.5 \times 0.04) \times \frac{8}{7} \times \frac{1}{50} / 0.85 = \$0.17K$$

(9) Including 5 days before mishap occurs and 3 days of removal time:

$$\$303.20K \times (1-0.30 + \frac{10+3}{10} \times 0.25 + \frac{5+3}{10} \times 0.05) = \$322.91K$$

(10) Similar to (9):

$$\$303.20K \times (1-0.15 + 1.3 \times 0.11 + 0.8 \times 0.04) = \$310.78K$$

(11) $10K x 0.30 = $3.00K

(12) $10K x 0.15 = $1.50K

(13) $50K x 0.05 = $2.50K

(14) $50K x 0.04 = $2.00K

Thus the optimistic impact of this subelement is about (863.28 - 835.14)/863.28 = 3.26% reduction in well cost. For the pessimistic case the well cost reduction becomes 0.46%. The impacts of this subelement are expressed in terms of the benefit model input parameters as follows:

Benefit Model Input Parameter	PESSIMISTIC (All types)	OPTIMISTIC (All types)
% Change in cost per production well	-0.5	-3.3
% Change in cost per injection well	-0.5	-3.3

19.6 Degree of Success

Although the NDE technique is reasonably straight forward, there is still some uncertainty in whether or not the technique can be carried out in field conditions and at the test rate suggested by the contractor. It is felt that 0.8 is a reasonable figure for the degree of success.

19.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	155.1	693.0	566.4
PESSIMISTIC	14.0	62.6	51.2

20.0 SUBELEMENT 3-4-A:

SPENT FLUID DISPOSAL

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER	3-4-A	CONTRACT NUMBER(S)	4511830 Others unknown

TITLE Spent Fluid Disposal

CONTRACTOR(S) Pacific Northwest Laboratory, Vetter/Oklahoma U., others unknown

RELATED PROJECTS
- 3-4-01 Injection Fluid Characteristics (PNL)
- 3-4-02 Injection and Stimulation Chemicals (Vetter)
- 3-4-06 Spent Fluid Disposal (Unknown)
- 3-4-07 Waste Disposal Inter-Regional Coordination (Unknown)

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

		✓	✓		
Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	0										0
2. DGE Planned:		436	1025	850	250	250	250				3051
3. Additional:											0
Total:											3051
Discounted Total of Planned and Additional:											2584

EXPECTED YEAR OF COMMERCIALIZATION 1983

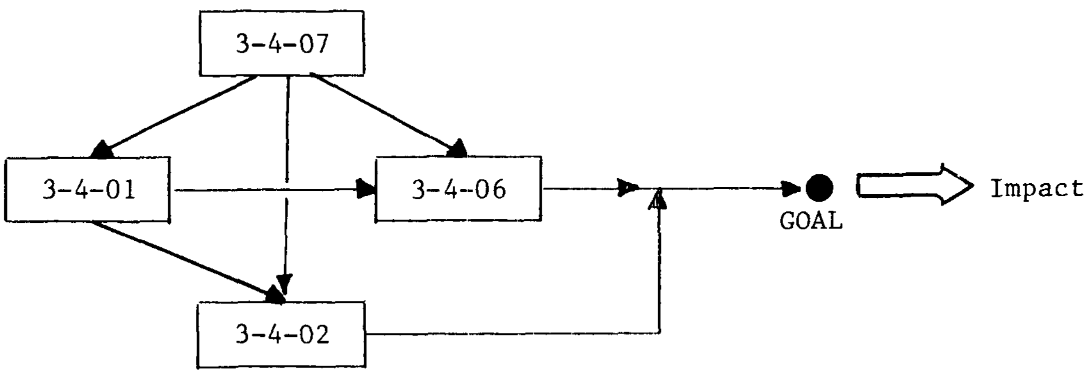
EXPECTED DEGREE OF SUCCESS 0.7

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	56.9
	PESSIMISTIC	30.9
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	15.6
	PESSIMISTIC	8.5
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	15.6
	PESSIMISTIC	8.5

SEE ATTACHED PAGES FOR RATIONALE

20.1 Projects in Subelement

Project Code	Project Title
3-4-01	Injection Fluid Characteristics
3-4-02	Injection and Stimulation Chemicals
3-4-06	Spent Fluid Disposal
3-4-07	Waste Disposal Inter-Regional Coordination



20.2 Goal

Technology to enhance injection well flow.

20.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-4-01*	0	0	0	70	275					345	345
3-4-02	0	0	0	58	500	600				1158	1158
3-4-06	0	0	0	308	0					308	308
3-4-07	0	0	0	0	250	250	250	250	250	1250	1250
TOTAL	0	0	0	436	1025	850	250	250	250	3051	3051
($78)	0	0	0	436	932	702	188	171	155	2584	2584

* Only half of the costs are charged here, the other half is charged to subelement 3-4-B.

20.4 Identification of Impacted Parameters

The performance of an injection well is determined by the injected brine flow rate which in turn is determined by the permeability of the rock formation. The brine usually carries suspended solids and chemicals which interact with the formation and gradually reduce the permeability. Consequently, the injection rate decreases with time. It is therefore necessary to stimulate an inject well from time to time to either dislodge or dissolve off the solids or precipitates which accumulate in the formation as the brine flows through the formation. Such stimulation cannot rid off all the accumulation however. The rock permeability still deteriorates and eventually reaches a level where the injection well becomes uneconomical to operate. The well is then abandoned with a certain cost for plugging it.

If a site requires N injection wells which have an average life of L years, and if it can be assumed that brine flow rate decreases linearly with time during the L years, the number of new wells which must be drilled in the second year would be N/L. The life of an injection well used for a particular brine depends primarily on the capability of the stimulation technology to restore the brine flow rate to its original value. If one stimulation technology can restore the brine flow rate closer to its original value than another, it would maintain a longer well life and result in less new wells having to be drilled. The purpose of the activities in this subelement is to develop a stimulation technology which could work better than the one currently used and, as the results, increase the well life and reduce the maintenance requirements such as stimulation frequency, and costs of plugging abandoned wells.

However, there is a question here as to whether the stimulation frequency should be reduced with the new and better stimulation technology to reduce O&M cost or it should be unchanged to gain the benefits from the resulted increase in well life. Such trade-off will be discussed in the next subsection.

20.5 Impacts on System Parameters

Let us consider an injection well through which the brine flow rate is decreased, in the absence of stimulation, by 20% of the original value per year, and which can be used until the flow level reaches 20% (See Figure 1). This well would have a life of 4 years as shown in Figure 1. Let us also consider the effects of current and new stimulation schemes on the well life and make some assumptions about them as follows:

1. The rate at which the flow rate declines is assumed unchanged after stimulation.
2. Current practice is assumed to require stimulation once a year, and the recovery immediately after stimulation is assumed to be 10%.
3. The recovery immediately after stimulation resulted from using new stimulation technology is assumed to be 15% (a 50% improvement).

The well life with current stimulation practice is 7.5 years as illustrated by curve 1 of Figure 1. If the new technology is used,

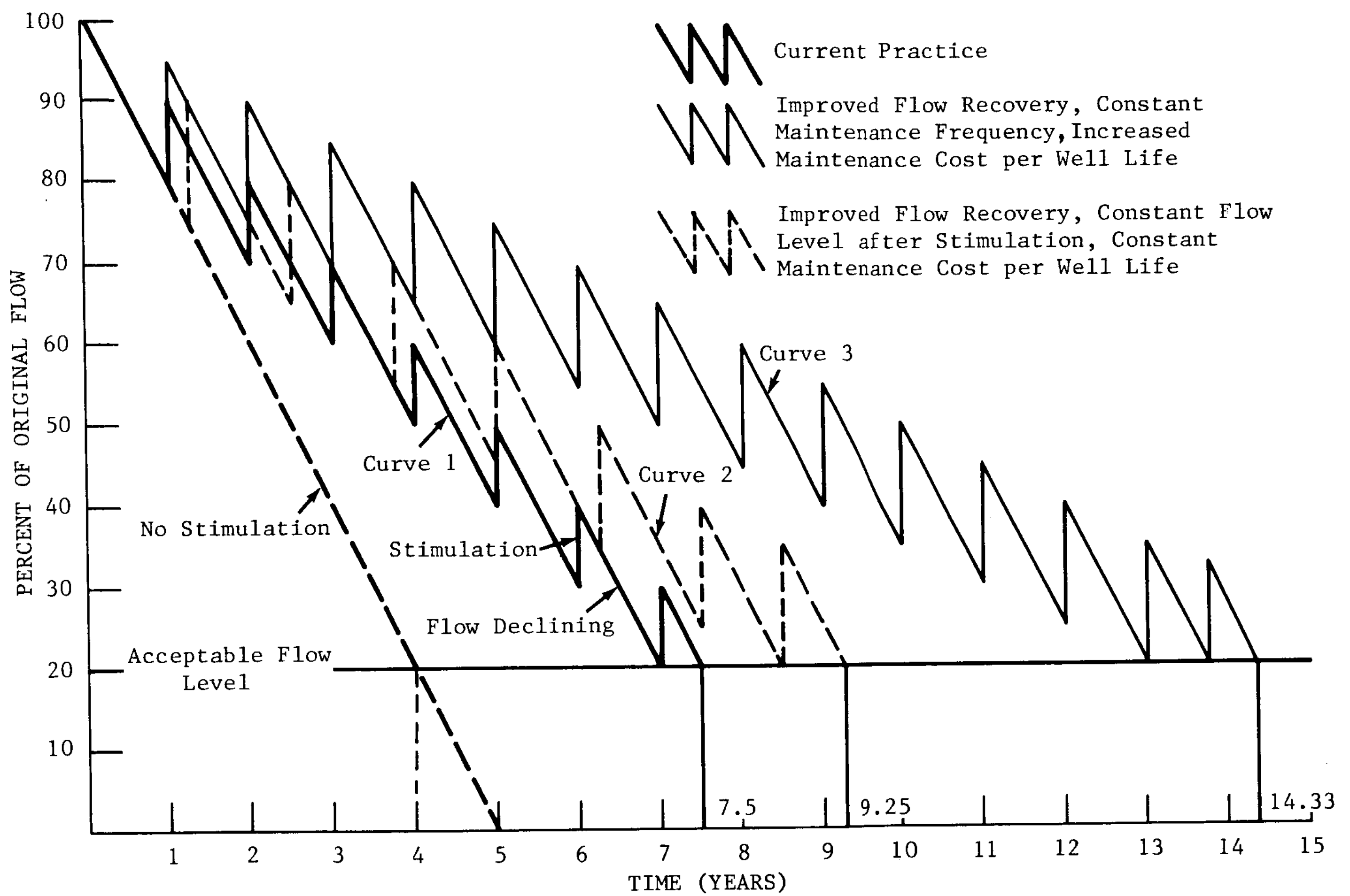


FIGURE 1
IMPACTS ON MAINTENANCE COST AND WELL LIFE OF IMPROVED STIMULATION TECHNOLOGY FOR INJECTION OF SPENT BRINE

there are two end possible practices. One practice is to let the flow rate decline for a relatively long period and then stimulate the well and formation to bring the flow rate to the same level as in the current practice. The result is the curve 2 of Figure 1 which indicates a well life of 9.25 years. The other practice is to stimulate the system once per year as the current practice with the results of curve 3 and well life of 14.33 years. Now let us compute the costs of these practices based on the assumption that 5 injection wells are required and the costs of each stimulation and plugging up abandoned wells are unchanged:

	COST ($1000) OF CURRENT PRACTICE	COST ($1000) OF NEW TECHNOLOGY	
	CURVE 1	CURVE 2	CURVE 3
Starting ($500K/well)	2500	2500	2500
Stimulation ($65Keach time*)+,	28600.0	19921.6	19615.7
Average per year	953.3	664.1	653.9
New well/yr ($500K x N/L)	333.3	270.3	174.5
Plugging up ($50K/well*)/yr	33.3	27.0	17.4
Total O&M per year	1319.9	961.4	845.8

* Tod Larson, "The Cost of Geothermal Energy Development", Geothermal World Directory, p. 314, 1977-78.

+ Based on 30 year plant life and including stimulation of new wells as they are placed in service:

For curve 1: $\$65K \times [5 \times 30 + \frac{5}{7.5}(1+2+3+...+29)]$

For curve 2: $\$65K \times [5 \times 24 + \frac{5}{9.25} \times 1.25\,(1+2+3+...+23)]$

For curve 3: $\$65K \times [5 \times 30 + \frac{5}{14.33}(1+2+3+...+29)]$

The above computation indicates that the scheme represented by Curve 3 shows the highest benefit. Thus it can be assumed that the impacts of the results of this subelement can be maximized by leaving the stimulation frequency unchanged.

The assumption of 50% improvement on stimulation capability (assumption 3) increases the well life from 7.5 years to 14.33 years. Such improvement may not be realistic because of the fact that reservoir engineering problems are usually complex and difficult to solve, and hence a nearly 100 percent increase in well life is difficult to believe.

Impacts on System Parameters

To be realistic and consistent with the R&D contractors' prediction, let us assume that the well life will be increased by 10 to 15%. Such improvement is translated into the impacts on the benefit model input parameters as follows:

Stimulation cost per year based on 30 year plant life (pessimistic case)

$$\$65K \times [5 \times 30 + \frac{5}{7.5 \times 1.1}(1+2+3+...+29)]/30 = \$896.2K$$

Plugging up cost per year (pessimistic case):

$$\$50K \times 5/(7.5 \times 1.1) = \$30.3K$$

Total O&M cost (excluding new well cost) = $926.5K

This, when compared with the current practice O&M cost of 953.3 + 33.3 = $986.6K yields a reduction of (986.6 = 926.5)/986.6 = 6.1% excluding new well cost. The new well cost reduction has been incorporated in the well life increase in the benefit model inputs.

Similarly, the reduction in O&M cost for optimistic case is calculated as follows:

$$\$65K \times [150 + \frac{5}{7.5\times1.15}(1+2+3+...+29)]/30 = \$871.4K$$

$50K x 5/(7.5x1.15) =	29.0
Result =	$900.4K
Compared with	$986.6K
Reduction	8.7%

The results are summarized as follows:

BENEFIT MODEL INPUT PARAMETERS	PESSIMISTIC (ALL PLANTS)	OPTIMISTIC (ALL PLANTS)
% Change in Producer General O&M Cost Factor*	-1.8	-2.6
% Change in Life Span of Injection Wells (High Salinity)	10.0	15.0
% Change in Life Span of Injection Wells (Low Salinity)**	5.0	10.0

* This factor covers O&M costs for production wells, injection wells, and piping system. O&M cost of injection wells is assumed to account for 30% of this factor.

** The impacts on injection well life for low salinity brines are expected to be less than those on injection well life for high salinity brines.

20.6 Degree of Success

The flow of brine through the rock formation can be described as a filtering process in which suspended solids or precipitates are being filtered from the brine by the porous formation. Depending on the particle size of the solids relative to the pore size of the formation, the solids can either accumulate at the formation front end, i.e., the well bore, or enter and be retained in the formation. If the solid particles are small enough, the filtering process might never take place and hence no deterioration of the flow occurs unless the filtering process is complicated by unfavorable chemical reactions between the brine and rock. Thus it can be seen that the applicability of the new stimulaiton technology depends on local conditions. In some cases, current practice is satisfactory and new technology will not yield any improvement; and in some other cases new technology would yield 100 percent impacts. Therefore a degree of success of 0.7 is assumed for this subelement.

20.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	56.9	15.6	15.6
PESSIMISTIC	30.9	8.5	8.5

21.0 SUBELEMENT 3-4-B:

WASTE UTILIZATION

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-4-B

CONTRACT NUMBER(S) 4511830, others unknown

TITLE Waste Utilization

CONTRACTOR(S) Pacific Northwest Laboratory, others known

RELATED PROJECTS
3-4-01 Injection Fluid Characteristics (DOE/SAM./PNL)
3-4-03 Geochemical Engineering and Process Handbook
3-4-04 Gas and Waste Utilization
3-4-05 Waste Utilization Process Subcontracts

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
				✓	

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	0										0
2. DGE Planned:		330	525	0	600	300	150				1905
3. Additional:											0
Total:											1905
Discounted Total of Planned and Additional:											1556

EXPECTED YEAR OF COMMERCIALIZATION 1984

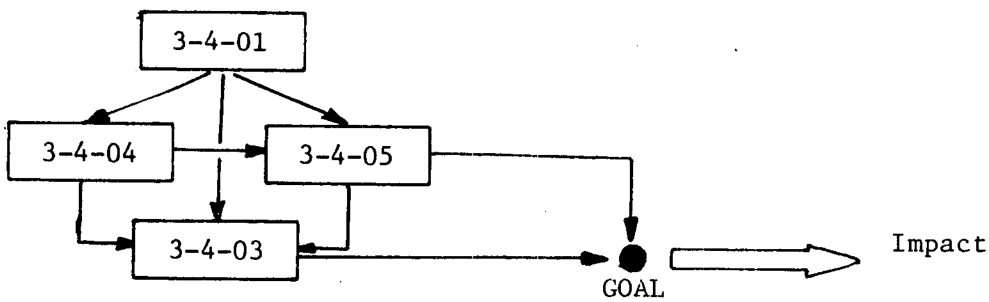
EXPECTED DEGREE OF SUCCESS 0.3

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	324.4
	PESSIMISTIC	261.2
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	62.5
	PESSIMISTIC	50.4
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	62.5
	PESSIMISTIC	50.4

SEE ATTACHED PAGES FOR RATIONALE

21.1 Projects in Subelement

PROJECT CODE	PROJECT TITLE
3-4-01	Injection Fluid Characteristics
3-4-03	Geochemical Engineering and Process Handbook
3-4-04	Gas and Waste Utilization
3-4-05	Waste Utilization Process Subcontracts



21.2 Goal

Efficient and economical processes to recover minerals and utilize waste heat and water in spent fluid.

21.3 Costs

PROJECT CODE	COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78 →	TOTAL
3-4-01*	0	0	0	70	275					345	345
3-4-03	0	0	0	210	250					460	460
3-4-05	0	0	0	50						50	50
TOTAL	0	0	0	330	525	0	600	300	150	1050	1050
($78)	0	0	0	330	477	0	451	205	93	1556	1556

* Only halves of the costs are charged here; the remainder are charged to Subelement 3-4-A.

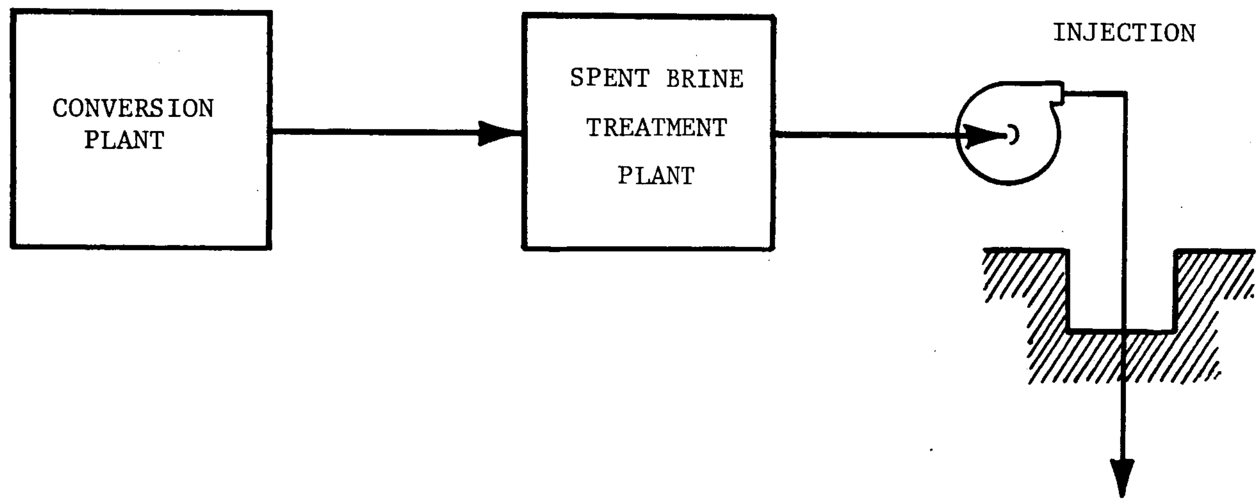


FIGURE 1

DISCHARGE END OF A GEOTHERMAL POWER PLANT (SCHEME)

21.4 Identification of Impacted Parameters

The activities in this subelement are to develop and document in a handbook, chemical and energy processes for utilization of wastes from geothermal power plants. Wastes from a geothermal power plant are mainly water, minerals, and gases. The availability of technologies for recovery and utilization of these wastes would generate revenue for geothermal industry and at the same time eliminate many disposal problems. With the current practice, spent brine must, in many cases, be treated before subsurface injection. Such spent brine treatment can be incorporated into the waste utilization process and therefore the O&M and capital costs of the spent brine treatment facilities will be impacted by the results of this subelement. Other impacted parameters can be identified in the O&M cost and life span of injection wells.

21.5 Impacts on System Parameters

The spent fluid discharged from a power plant is usually warm and contains, at some sites, minerals which have commercial values. This fluid often must be treated before being disposed of via subsurface injection. So, in general, the flow of the spent fluid can be represented by Figure 1 where the fluid leaving the power plant is treated in the treatment plant and then pumped into injection wells.

Now if a mineral recovery and waste utilization process is developed and used, there will be a number of schemes by which the process is applied to a geothermal power plant. Before discussing these schemes, let us assume that the newly developed recovery and utilization process will be installed and operated by a private industry. Thus some kind of agreement is to be reached between the producer, who is responsible for the treatment and disposal of the spent brine, and such private industry. Of course, the agreement must benefit both parties and must be dependent on the resolution of such issues as the cost of spent brine, treatment responsibility, and injection responsibility.

The producer would want to sell the spent brine at a price and pass the responsibility of brine treatment and injections over to the private industry. However, the private industry would want to make the highest profits by trying to get the brine free of charge and without having to worry about treatment and injection. Various process application schemes can result from these two ends of bargaining. However, a compromise would be reached if both parties agree that:

(i) Chemical treatment expertise is usually possessed by the private industry.

(ii) Injection operations require the experience of the producer.

(iii) Recovery and treatment processes involve precipitation reactions which in turn involve temperature variation. Thence the private industry would prefer to take the brine at the power plant discharge point to the treatment plant discharge point.

(iv) Profit margin for a mineral recovery and waste utilization process is low because of low mineral concentrations (to the private industry's point of view) in the brine.

If the above points are agreed, the likely scheme would be as shown in Figure 2. In this scheme, the private industry would have the treatment plant incorporated into its recovery and utilization process, and the brine returned to the producer is likely to be cleaner than in the original setup in Figure 1.

Let us assume the scheme 2 (Figure 2) to be the resulting impact of this subelement on those sites where the mineral recovery and waste utilization process is economical and applicable. To be conservative, let us also assume that the private industry has the brine free of charge. Indeed, the producer would probably be more than happy already if he could have improved quality injection brine without having to treat it. From these assumptions, the O&M and capital costs of the spent brine treatment plant of the applicable site can be eliminated or, in other words, can be reduced by, say, 80 to 100 percent. In addition the improved quality of injection brine impacts the O&M costs and life span of injection wells. How much this impact is is rather difficult to estimate at this stage. However it might not be very far off if the rationale employed in the previous section, Subsection 20.5, is adopted and the same results are used.

In summary, the impacts of this subelement are likely to be as follows:

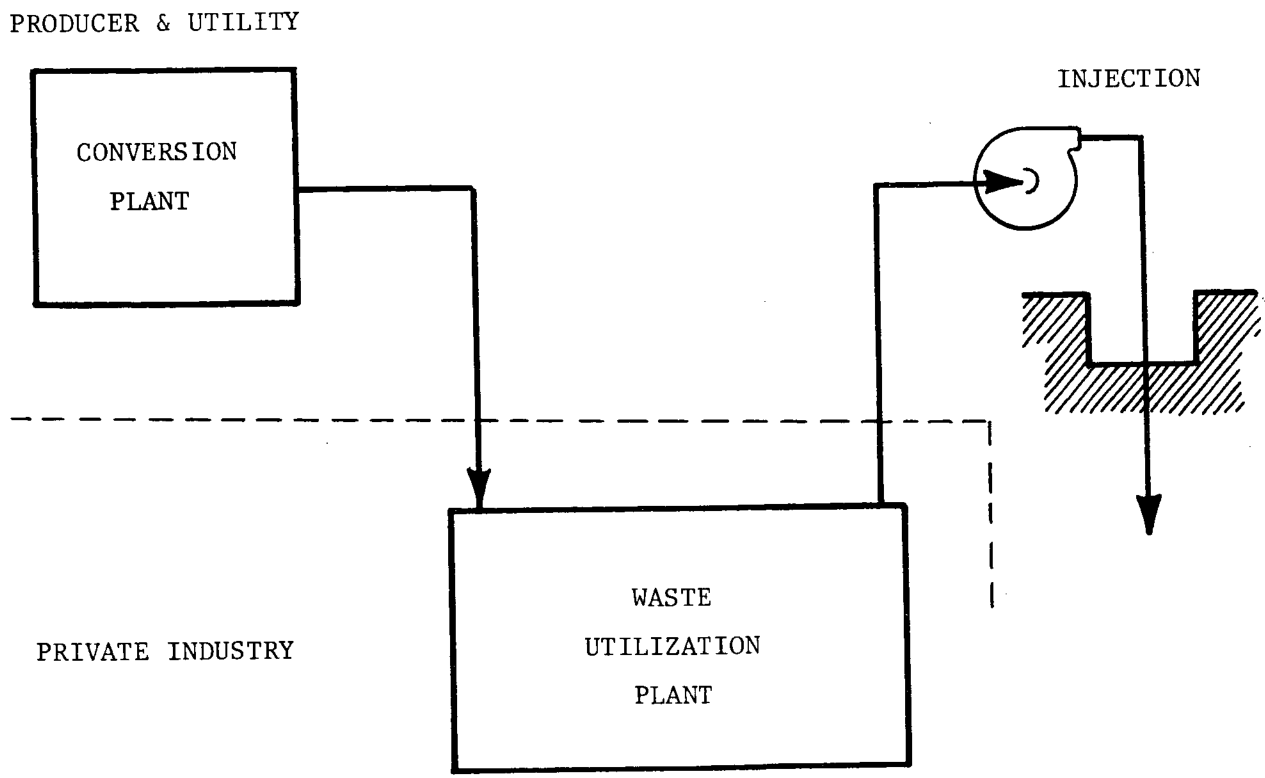


FIGURE 2

A POSSIBLE ARRANGEMENT BETWEEN PRODUCER AND CHEMICAL INDUSTRIES FOR INSTALLMENT OF WASTE UTILIZATION PLANT (SCHEME 2)

BENEFIT MODEL INPUT PARAMETER	PESSIMISTIC (All Plants)	OPTIMISTIC (All Plants)
% Change Capital Cost of Spent Brine Treatment (Producer)	-80.0	-100.0
% Change in Producer Spent Brine Treatment O&M Cost Factor	-80.0	-100.0
% Change in Producer General O&M Cost Factor*	-1.8	-2.6
% Change in Life Span of Injection Wells (Low Salinity)*	5.0	10.0
% Change in Life Span of Injection Wells (High Salinity)*	10.0	15.0

* Adopted from subsection 20.5.

21.6 Degree of Success

There exists a market share between the results of this subelement and that of the "Spent Fluid Disposal" subelement, number 3-4-A. This is quite true, because wherever a waste utilization process is used, new spent fluid disposal technology is not required and vice versa. Since the degree of success of the Spent Fluid Disposal subelement is 0.7, the degree of success of this subelement must be 0.3.

21.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	324.9	62.5	62.5
PESSIMISTIC	237.5	50.3	50.3

22.0 SUBELEMENT 3-4-C:

MOBILE TEST UNIT

BENEFIT/COST RATIONALE AND RESULTS

SUBELEMENT NUMBER 3-4-C	CONTRACT NUMBER(S) Unknown
TITLE Mobile Test Unit	
CONTRACTOR(S) Unknown	
RELATED PROJECTS 3-3-09 Mobile 0.1 - 1.0 MW Test Unit	

CURRENT STATE OF R&D: (CHECK APPROPRIATE STAGES)

Preliminary Study	Basic Research	Exploratory Development	Advanced Development	Engineering Development	Demonstration & Commercialization
				✓	

($1000s, CURRENT YEAR)

F.Y.	To 78	78	79	80	81	82	83	84	85	>85	TOTAL
1. Sunk:	0										0
2. DGE Planned:		0									0
3. Additional:			500	1200	700						2400
Total:											2400
Discounted Total of Planned and Additional:											1973

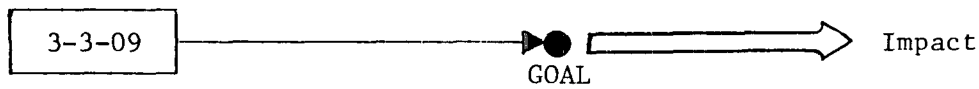
EXPECTED YEAR OF COMMERCIALIZATION	1982
EXPECTED DEGREE OF SUCCESS	0.5

CALCULATED BENEFIT (DISCOUNTED TO $ MILLIONS, 1978)	OPTIMISTIC	9.1
	PESSIMISTIC	0.0
FIGURE OF MERIT (W/O SUNK COSTS)	OPTIMISTIC	2.3
	PESSIMISTIC	0.0
HISTORICAL FIGURE OF MERIT (W/SUNK COSTS)	OPTIMISTIC	2.3
	PESSIMISTIC	0.0

SEE ATTACHED PAGES FOR RATIONALE

22.1 Project in Subelement

Project Code	Project Title
3-3-09	Mobile 0.1 - 1.0 MW Test Unit



22.2 Goal

A mobile test unit of 0.1 - 1.0 MW capacity for use in field testing to provide data for injection well flow enhancement.

22.3 Costs

The costs for this subelement has not been planned. Hence if the project is approved the costs must be estimated. The capital cost of the unit can be calculated assuming a 0.7 scaling power as follows:

Capital cost of a 50 MW binary plant is about $37,000K*

Capital cost of a 1 MW, say, binary plant is:

$$\left(\frac{1}{50}\right)^{0.7} \times 37,000K = \$2,393K$$

The above cost might be in the high side. However since the test unit has mobility, extensive instrumentation, high engineering design cost, and high level of flexibility, the amount of $2400K would probably be required to develop it. From this figure, let us assume that $2400K are required to contract for a 0.1 - 1.0 MW unit

* V. Thanh Nguyen and Harpal S. Dhillon, "An Analysis of the Geothermal Energy Extraction and Utilization Technology RD&D Program", MITRE Report MTR-7886, June 1978.

regardless whether it is a binary or flash steam system. Let us also assume that the project will start in FY1979 and requires 3 years before the unit can be used for field testing. The project cost breakdown is as follows:

PROJECT CODE	ADDITIONAL COST ($1000) BY FISCAL YEAR										
	PRIOR 77	77	TOTAL	78	79	80	81	82	83	TOTAL 78→	TOTAL
3-3-09	0	0	0	0	500	1200	700			2400	2400
($78)	0	0	0	0	455	992	526			1973	1973

22.4 Identification of Impacted Parameters

The test unit is to provide site specific data for injection well flow enhancement. It involves the operation of a mobile scale and injection unit at a number of sites for prolonged periods. The operation includes flow through, flash and binary cycles depending on the characteristics of the site. The reservoir, production wells and injection wells will be monitored to develop a link between the scaling phenomena and characteristics of the injected fluid. As the results, a manual of procedures of reinjection of geothermal fluids will be produced. Therefore this subelement will make the reinjection operation more effective and consequently increase the injection well life.

22.5 Impacts on System Parameters

The increase in the injection well life resulted by effective operation alone is expected to be small and is difficult to estimate. Indeed, the understanding of scaling phenomena and characteristics of the injected fluid produced from this subelement does not really solve the scaling and well plugging problems without the development of some technology to do so. Hence for the pessimistic case, the impact is negligible and is assumed to be zero. If the impact is to be positive, it depends on how effective the operation is relative to the current practice. To make this comparison, it is necessary to identify what improvement in the operating procedure will be considered in the manual produced by the test unit. Such identification is not possible at this stage because there is no information, even very preliminary information, available. Thus for the optimistic case, it is assumed without base that the increase in injection well life is about 2-5%. In summary the impacts of this subelement are as follows:

BENEFIT MODEL INPUT PARAMETER	PESSIMISTIC (All plants)	OPTIMISTIC (All plants)
% Change in Life Span of Injection Wells (Low Salinity)	0	2.0
% Change in Life Span of Injection Wells (High Salinity)	0	5.0

22.6 Degree of Success

The construction and operation of the test unit are not difficult and only require state-of-the-art technology. However the use of such unit might not be found at all of the geothermal sites. Hence the degree of success of this subelement may be assumed to be 0.5.

22.7 Results

	BENEFIT ($\$10^6$) 1978 DOLLARS	FIGURE OF MERIT	
		FY78 TO COMPLETION	HISTORICAL PLANNED + SUNK
OPTIMISTIC	9.1	2.3	2.3
PESSIMISTIC	0	0	0