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A FIVE YEAR PROGRAM PLAN TO
DEVELOP THE SPARK DRILLING SYSTEM

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ABSTRACT

In this program plan to the Division of Geothermal Energy-ERDA, Sandia Laboratories requests funding approval of a five year program for continuation of ongoing research leading to the development, demonstration and transfer of the necessary technology to make the spark drilling technique a viable and cost effective alternative to rotary drilling methods. Potential benefits to be derived include a reduction in the time and cost of drilling, particularly in the case of deep holes in hard formations. Improved drilling capabilities will allow more economical and timely development and utilization of deep resources in the areas of geothermal and petroleum energy.

A program plan is presented with the significant elements of effort discussed.

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A FIVE YEAR PROGRAM PLAN TO DEVELOP THE SPARK-DRILLING SYSTEM

Introduction

The rationale for pursuing spark drilling as a potentially superior technique for drilling in deep and/or hard formations has been outlined in reference 1. For purposes of clarity, however, a brief summary is given below.

It is generally conceded that most future exploration and development of petroleum, natural gas, and geothermal energy sources will involve drilling to greater depths, through formations which are more difficult to penetrate. In other words, most of the "easy" resources have been found and it is becoming increasingly necessary to engage in extremely difficult, high risk, and very costly drilling operations. The magnitude of this problem is perhaps best illustrated by the recent activity in offshore drilling, where considerable capital outlay has been endured, along with major technical problems, in order to continue drilling in the geological structures where success ratios have been high.

The problems encountered in rotary drilling into deep, hard and hot formations include low penetration rates and a higher incidence of bit and drill string failure resulting in expensive fishing operations. Drilling costs per foot increase almost exponentially with depth, owing to these factors.

Thus, it is clear that an improved drilling technology which allows more rapid and economical penetration of various hard and hot formations would enhance the ability of the U.S. to meet its own energy needs. Current rotary drilling technology has been under continuous development and improvement by a multibillion dollar industry since the turn of the century and should therefore be at or near the optimum for this technology.

Literature searches for innovative techniques holding promise for significant improvement over rotary drilling, revealed reports of Russian experiments of the mid 1950's dealing with rock fracture and drilling by means of high energy electrical discharges in a liquid medium. The Russian reports were not sufficiently clear and detailed to allow definite conclusions to be drawn. There was, however, evidence to indicate that this technique could produce drilling rates substantially higher than those attainable by rotary drilling. Such a drilling system would require a down hole, high energy, high voltage pulse generator in order to be compatible with existing drill rigs. To design such a down hole system requires a knowledge of the electrical (spark) requirements at the bit face. To establish these requirements, it is necessary to determine the relationships between the various spark parameters and the rock fracture mechanisms. Once the optimum spark parameters are defined, effort can be turned toward developing a down hole

system to produce, as nearly as possible, a system with these parameters having adequate life expectancy under the environmental conditions which exist in deep holes.

To this end, Sandia proposed⁽¹⁾ an initial research and feasibility assessment phase to:

- 1) Investigate the relationship between spark (discharge) parameters and the resulting near term response in the adjacent fluid medium (channel energy density and shock wave formation).
- 2) Investigate subsequent shock propagation and cavitation collapse and jetting (bubble dynamics).
- 3) Determine the prevalent rock fracture mechanisms produced by interaction of the shock wave and jetting with various rock formations.
- 4) Begin design and evaluation of a drill bit face to provide reliability, long life, and high efficiency.
- 5) Assess feasibility of the spark drilling concept.

This research included the effects of high hydrostatic pressures and required construction of a laboratory experimental spark drill system. Also, certain instrumentation and transducer development were required in areas where appropriate hardware did not exist. The effort was restricted to that level of investigation necessary to support conclusions concerning the feasibility of the spark drilling concept.

The proposal received funding support and is currently under way. References 2 and 3 give status of the effort as of 7/1/75 and 1/1/76. The feasibility investigation is not yet complete but significant progress has been made as outlined in these reports.

Program Objective

The objective of the program outlined in this proposal is to provide for the completion of necessary research currently in progress, and if feasibility is indicated, to continue development of the spark drilling technique and associated hardware technology to a point where private industry could reasonably be expected to manufacture and utilize such equipment in the accelerated development of our energy resources.

The program would be carried out over a period of five years and would include, in addition to research and required hardware technology and prototype development, extensive test and demonstration drilling operations followed by orientation and transfer of technology to interested sectors of private industry.

For successful completion on this time schedule, this program will require funding by ERDA/DGE for the five year period at moderate levels, with the provision that any reversal or serious decline in projected successful outcome will be cause for program termination. Continuity of funding is considered necessary for orderly completion of the program within the five year period. Even more important than the consideration of continuity for efficient operations, key personnel are often permanently lost by breaks in funding.

Program Plan

The proposed five year research and development program has been subdivided into five major tasks as indicated in Figure 1. The various tasks and associated subtasks are discussed below.

Task I - Research and Feasibility Assessment

This task has been under way for approximately 18 months, but work has recently been halted due to funding limitations in FY-76. Under this proposal, work would be resumed at the beginning of FY-76T, and would culminate in a feasibility assessment and statement to be issued in the third quarter FY-77. This assessment of feasibility will address the concept of spark drilling in terms of the ability to fracture rock and associated power requirements, specific energy, and potential drilling rates in comparison with existing rotary technology. It will not, however, attempt to provide assurance of the success of subsequent hardware development required to achieve a viable down hole system. The Task I effort will extend through FY-77, and will require funding in the amount of \$158K - FY-76A and \$400 K for FY77.

The subtasks to be accomplished during this phase include the following.

Subtask Ia. Shock wave generation by electrical discharge in a liquid.

The objective of this subtask is to determine by experiment and analysis the relationships which exist between system parameters and the phenomena of electrical

breakdown in a liquid. Analytical efforts will involve theoretical treatment of various facets of the problem, and adaptation of existing uni- and multidimensional computer codes to the problem. Experimental efforts will involve the generation of discharges in fluid media in the laboratory and the measurement of the resulting pressure magnitudes and waveshapes along with gap voltage and current during and after breakdown. The system parameters-voltage, energy, electrode spacing, fluid composition and pressure-will be varied and data will be taken so that the relationships between shock wave characteristics and system parameters can be defined well enough to allow system design optimization.

The measurements needed in the experiments will require some transducer development in addition to that which has already been accomplished in the program. Pressure measurements of the bubble collapse and internally in the rock are desired but the instrumentation is not presently available. Transducers for these measurements must be developed along with some improvement of existing instrumentation. Measurement of gap voltage and current during and after breakdown require special techniques to obtain the necessary accuracy and nanosecond resolution. The high voltages, currents and stray fields associated with experiments of this type generally produce spurious responses which require special care in grounding, shielding and impedance matching to obtain meaningful results.

The current status of this subtask is given in Reference 3, the status report as of 1/1/76. The subtask is approximately 40% complete. Significant progress has been made in the investigation of the electrical characteristics of the fluid during breakdown and discharge. The effective impedance across the gap during breakdown and discharge has been measured. The delay in channel formation has been related to applied voltage and an expression for energy input to the channel has been derived. Experiments have included several different types of fluids, various electrode spacings and geometries, and two different types of discharge circuits.

Work remaining in this subtask includes investigation of the above results at elevated pressures, completion of pressure transducer development and gathering of data relating shock pressure and waveform to discharge circuit parameters.

Subtask Ib. Influence of Hydrostatic Pressure

Drilling with a liquid creates a bottom hole pressure of from 0.443 to 1 psi pressure per foot of depth depending on the density of the fluid being used. For this reason, it is necessary to determine the effects of hydrostatic pressure on the phenomena involved. A pressure vessel capable of a hydrostatic pressure of 10000 psi has been built and used for preliminary experiments. These

experiments will be continued during this subtask along with the adaptation and use of existing hydrodynamic computer codes to investigate the problem.

The primary effects that must be determined are the influence of pressure on the breakdown phenomena and bubble collapse. The effect of pressure on the voltage required for breakdown is important but the most dramatic effect should be on bubble collapse because of the increased energy stored in a bubble in a high pressure field.

The goal of this experiment will be to determine that the effect of hydrostatic pressure is not significantly detrimental to the spark drilling technique. To accomplish this result, high pressure arc discharge tests in the existing pressure vessel will continue with pressure transducer and camera coverage. A new electrical feed through and electrode system will be developed to allow voltage increases above those of the first experiments. The experiment will be simulated with hydrodynamic codes to study ideal bubble collapse for optimization of electrical parameters.

The results of these experiments will be used as a decision point to plan experiments in the drill system environmental test facility.

Subtask Ic. Active Rock Fracture Mechanisms

The goal of this subtask is to determine the failure mechanisms active in removing rock by the arc discharge technique. Initial work in this area includes rock fracture analysis and preliminary failure envelope studies. This information, which includes the pressure time inputs required to generate the stress profiles for failure of various rocks, will aid in designing optimum spark drilling systems. The strain rate and fatigue effects, along with other parametric variations, will be addressed. This research is currently being conducted by Texas A & M University under contract to Sandia Laboratories. It is planned that Texas A & M continue this subtask to completion.

Subtask Id. Preliminary Drill Bit Design

Drill bit design is an effort which will probably continue throughout the program as a greater understanding of the phenomena involved is obtained, as new materials and processes come to light, and as more knowledge and experience is gained in the fracturing of rock by this technique.

During Task I, preliminary designs will be fabricated and tested to verify basic concepts in electrode geometries, insulation techniques, self-damage prevention, life enhancement, penetration rate, and hole gage control. Innovative techniques in electric field distribution and control, and

in the use of fluid flow to enhance spark channel characteristics and fracture mechanisms, will also be tested if analysis indicates technical soundness.

Several basic designs have been tested thus far and have fallen short in general. The approach showing most promise at this time is the controlled field bit which relies on careful control of electric field gradients to eliminate the need for insulation near the electrode spark gap, where insulation deterioration and surface arc-over generally cause failure.

Other designs are also under investigation. This subtask should culminate in a suitable design for general use in spark drilling and in the prototype system.

Design refinements and improvements will be evaluated, tested and incorporated as they are identified.

Subtask 1e. Feasibility Assessment

This is a critical decision point in determining the future direction of the program. For the program to be continued, there must be an indication of the ability to drill rock with a feasible system at an economic saving over other methods. This indication will be drawn from the work that has been accomplished by the end of the first year of this five year plan, and will depend very strongly on the results of drilling tests using the Laboratory Experimental Drill System currently under construction. The results obtained with this system will

be assessed in light of the results of the other Task I subtasks and a feasibility statement with recommendations will be issued at the end of 3rd QTR FY-77. Other supporting analyses and experimentation with the Lab System will continue through 4th QTR FY-77.

The first two considerations are necessary conditions for continuance. The technique must have the ability to drill hard rock at depth. The present low energy drilling systems are least effective in drilling hard rock and drilling under high pressure. The second necessary assessment is the feasibility of building a down hole system with the required parameters.

If the system has the capability of achieving the drilling goals, then the economics of the system will be considered. This system will be compared with existing techniques in areas where it might be competitive.

This assessment will not be absolute but will rely on the achievements of the program to date. The most likely recommendations call for an expansion or contraction of the program rather than an all inclusive endorsement.

Task II - Design Analysis, Component Development and System

Definition

This task will be devoted to the design definition of a prototype system and related subtasks. The Drill System Analysis will be conducted parallel with the Feasibility Assessment of Task I. This analysis is an adjunct of the

feasibility study but it is separated into this task because the system analysis is a design function. Also included in this task will be the development of the special components and subsystems required for a down hole system. The completion of design and procurement of the pressure vessel/test chamber and related facility equipment, which represents a substantial capital expenditure, are also a part of this task.

The Task II effort will be carried out during FY-77 and FY-78, with funding requirements of 100K during 1977 and 610K during 1978.

Task IIa. Drill System Analysis

The goal of this subtask is to determine the required design parameters for the prototype drilling system. The environment that the system will operate in must be defined. The system cooling technique and capabilities must be analyzed to insure that the thermal environment of the components can be controlled. Energy transmission and storage techniques must be selected to meet the required arc discharge characteristics. The system configuration layout will be initiated during this period.

Task IIb. Special Development Activities

These efforts range throughout Task II to aid in the design and construction of the prototype system. Included in this subtask is the completion of a laboratory experimental drill system and construction of a high pressure

test chamber. Both of these devices are necessary to evaluate the spark drilling technique. The remaining portions of this subtask are involved with component and subsystem design. Capacitors that meet the performance requirements will be designed. A high voltage converter and distributor are to be developed under this subtask. A contract will be placed with a commercial firm experienced in down hole mud turbine and motor/generator technology to develop a mud turbogenerator to serve as the primary source of down hole electrical power. The progress and results of the GE/Cullen cable system field tests will be closely monitored for potential application as a back-up for the turbogenerator. The latter is considered the primary method, since it eliminates the need for cable, handling equipment, and added handling time during tripping operations.

Subtask IIc. Prototype System Definition

This element of Task II finalizes design of the prototype drill system. If any component or subsystem is inadequate, the problem will be solved before the program advances. This subtask will also serve as a decision point for the project.

Task III - Prototype Fabrication and Development Test

This test includes the important tasks of procuring components, assembling the system, lab testing, and finally field testing. The effort will begin in 1st QTR FY-1979 and extend through 3rd QTR FY-1980, with a funding requirement of \$761K in FY-79 and \$300 K in FY-80.

Subtask IIIa. Procurement and Fabrication

The individual components are to be procured as standard items or specially fabricated items. Certain items may be fabricated at Sandia Laboratories but most items will be ordered from external suppliers.

Subtask IIIb. Subassembly Test and System Integration

This subtask involves assembly and system operational check out.

Subtask IIIc. System Test

The system test will be divided into three parts. The first test will be conducted in the high pressure system test chamber as a basic check out procedure. Following the completion of these tests, a shallow drilling experiment will be conducted by Sandia at a local site to evaluate field capability. Upon successful completion of these tests, a drilling test under normal operating conditions will be arranged. This test will determine field applicability of the system.

Subtask IIId. Feasibility Reassessment and Update Costs

The practicality of a spark drill system will be reviewed at this time. The future program direction will be determined at this time. If the system drills successfully, an update cost analysis must be made to determine the financial competitiveness of a spark drill.

Task IV - Feasibility Demonstration

This task includes the planning, coordinating, execution and reporting of demonstration drilling activities designed to prove the feasibility of spark drilling under actual field conditions. Successful completion of this task should bring the program to a point where industry would be both willing and able to proceed with product development and utilization of the technique, aided by transfer of all related technology to them.

This phase will begin in 4th QTR 1979 and continue through 3rd QTR 1981, with a funding requirement of \$1275K.

Subtask IVa. Feasibility Demonstration Planning

A comprehensive plan will be developed outlining the detailed objectives of the demonstration and the way in which each objective will be accomplished. An industry briefing will be held where the plan and schedule will be presented and industry inputs incorporated. Candidate site data will be collected, analyzed and a selection of prime and backup sites

will be made, based on program objectives, timetable, and projected drilling conditions at the various sites.

Final coordination of plans with affected industry members will be carried out and the necessary legal and financial agreements will be negotiated.

This subtask will yield a firm, industry approved plan with related schedule and cost data, for demonstration of the feasibility of the spark drilling technique.

Subtask IVb. Feasibility Demonstration

In accordance with the approved plan, the prototype drill system will be transported to the various industry sites selected and will be utilized in drilling operations representing the desired variety of conditions called for by the plan.

It is anticipated that industry observers will be present to evaluate system performance. In any case, operational and performance data will be taken in sufficient detail to support analyses and conclusions as to the effectiveness and cost of spark drilling operations in comparison with conventional methods.

Subtask IVc. Demonstration Results, Briefings and Publications

Upon completion of the demonstration activities, a comprehensive report will be prepared which will present

the detailed results of the demonstration tests, along with all data taken. Analyses based on the data will be included to support conclusions as to the feasibility and cost effectiveness of the technique in various drilling situations.

A briefing will be held for industry members in which the results of the demonstration drilling operations will be reviewed and the report distributed. Efforts will be made to publish the results in industry-oriented journals and periodicals.

This subtask will set the stage for the key decision on the part of industry, i.e., whether or not to proceed with product development and utilization.

Task V - Technology Transfer to Industry

This final phase of the program will encompass those activities necessary to provide the industry with the technical and operational information and assistance required to bring the spark drilling technique into commercial availability and use.

Task V will be carried out during the final three QTRs of FY-81, and will require funding in the amount of \$155K.

Subtask Va. Documentation Upgrade/Update

Engineering drawings and specifications for the prototype system will be upgraded and updated to accurately reflect the detailed design and fabrication of the system.

Design modifications in the nature of improvements resulting from experience during the System Test and Feasibility Demonstration phases, will be incorporated.

Technical documents will be generated to address the areas of design, theory of operation, fabrication and testing, and operation and maintenance, from the industry viewpoint.

These and all other related documentation will be made available to industry.

Subtask Vb. Industry Orientation

A series of workshops will be conducted, dealing with design, fabrication and operation of the spark drill system.

Consultation services by Sandia Laboratories engineers will be provided as necessary to help resolve any problems which might arise during the development of commercial hardware, or during the early stages of utilization by the drilling industry.

TABLE 1
SPARK DRILLING FIVE YEAR PLAN

		FY-77				FY-78				FY-79				FY-80				FY-81				
QTR		76A	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
TASK I	Ia - Schock Wave Generation in Liquid by Electrical Discharge Dependence on Channel Energy Density Parameter Measurements				Δ																	
	Ib - Influence of Hydrostatic Pressure Growth/Collapse Dynamics VS Energy & Pressure Collapse/Testing Stresses VS Static Pressure Code Adaptation to Problem				Δ																	
	Ic - Active Rock Fracture Mechanisms Rock Static & Dynamic Properties VS P & T Predominant Failure Modes Determination Specefic Energy Experimentation									Δ												
	Id - Preliminary Drill Bit Design Optimization of Electrode Geometry Materials Investigation & Selection Identify Areas Receiving Additional Development										Δ											
	Ie - Feasibility Assessment				Δ	*1	Δ															
TASK II	IIa - Spark Drill System Analysis Define Enviromental Specifications Define Spark Parameter Requirements Power Transmission & Energy Storage Trade-offs Cooling Techniques Analysis				Δ					Δ												
	IIb - Special Development Activities Laboratory Experimental Drill Pressure Vessel/Test Chamber Down Hole Power Source & Converter Down Hole H.V. Power Distributor													Δ								
	IIc - Prototype System Definition Engineering Design Release Drawings & Specifications Review & Release for Fabrication									Δ	*2	Δ										
	IIia - Procurement & Fabrication RFQs to Vendors Procure Fabricated Parts Inspection & Test													Δ		Δ						
	IIITb - System Integration Subassembly Inspection & Test Integrated System Functional Test																		Δ	*3	Δ	

*See next page

*See next page

TABLE 1 (cont.)

SPARK DRILLING FIVE YEAR PLAN

		FY-77					FY-78				FY-79				FY-80				FY-81			
QTR		76A	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
TASK III	<u>IIIc - System Test</u>																					
	Chamber Operational/Environmental Test																					
	Shallow Drilling Operational Test																					
	Deep Drilling Test-Industry Hole																					
	Incorporate Necessary Design Modifications																					
	<u>IIId - Feasibility Assessment & Cost Analysis Update</u>																					
TASK IV	<u>IVa - Feasibility Demonstration Planning</u>																					
	Plan & Objectives Development																					
	Industry Briefing																					
	Site Selection & Industry Coordination																					
	<u>IVb - Feasibility Demonstration</u>																					
	<u>IVc - Demonstration Results Briefings & Publication</u>																					
TASK V	<u>Va - Documentation Update/Upgrade</u>																					
	Incorporate Necessary Design Modifications																					
	Update Drawings & Specifications																					
	Generate Technical Manuals																					
	<u>Vb - Industry Orientation</u>																					
	Conduct Design/Fab/Operation Workshops																					
	Provide Consultation Services																					
Operation Cost																						
By Fiscal Year (\$ x 1000)		158		500			610				861				975				655			
*Key Dates:																						
1. Initial Feasibility Statement																						
2. Prototype Final Design Review																						
3. Chamber & Field Test Go Ahead																						
4. Feasibility Demonstration Go Ahead																						
5. Industry Product Development Go Ahead																						
6. Assessment of Need for Further ERDA/SLA Participation																						

TABLE 2
FUNDING REQUIREMENTS
LONG TERM SPARK DRILLING DEVELOPMENT PLAN
BY FISCAL YEAR

	FY-76A	FY-77	FY-78	FY-79	FY-80	FY-81
Personnel:						
Scientific	6	7	7	8	8	6
Other Direct	1	1	1	1	1	0
Cost: (\$ x 1000)						
Loaded Salaries	82.5	356	400	475	490	375
Materials, Services, Other						
Direct Charges, Subcontracts, etc.	75.5	144	210	386	485	280
<u>Total Budget Outlay (BO)</u>	<u>158</u>	<u>500</u>	<u>610</u>	<u>861</u>	<u>975</u>	<u>655</u>
Purchase & Contract Carryover	20	50	200	100	50	0
<u>Total Budget Authority (BA)</u>	<u>178</u>	<u>530</u>	<u>760</u>	<u>761</u>	<u>925</u>	<u>605</u>
Capital Equipment	30	200	200	100	0	0

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3. "Drilling Research on the Electrical Detonation and Subsequent Cavitation in a Liquid Technique (Spark Drilling)," Sandia Laboratories Report SAND76-0086, April 1976.

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