March 3, 1849

United States Department of the Interior

GEOLOGICAL SURVEY
BOX 25046 . M.S. 403
DENVER FEDERAL CENTER
DENVER, COLORADO 80225-0046

IN REPLY REFER TO:

February 19, 1988

John H. Sass
U.S. Geological Survey
2255 N. Gemini Drive
Flagstaff, AZ 86001

Dear John:

While cleaning up a number of loose ends around here, I happened to give Ray Wallace a call about our Salton Sea work. He mentioned in passing a conclusion in your joint paper with Wilf about geophysical logging that appears to be overly pessimistic. This may in part stem from our own point of view in pushing tools to their temperature limit, and then publicizing the autopsy. Having the truck idle long enough over the previous year to let some things get into a poor state of repair probably didn't help either. But we feel that logging was a vital part of the SSSDP program, and contributed insights that could have not been obtained otherwise.

What exactly did logging contribute? Probably the most important contribution was the continuous profile of rock properties with depth. The depth-smoothed trends in electrical, acoustic, and gamma attenuation gave a unique snapshot of the clay mineral alteration profile. We could show this by recognizing the primary lithologic response on the logs as being driven by clay mineral properties. Local departure from that trend identified those few sands where brine-filled pores were significant enough to cause brine conduction to overwhelm clay mineral conductivity. We hope that knowlegde of the location of these zones and the measured resistivities of composite rock/solute mix will contribute to the interpretation of brine inclusions from cores. The suite of logs dwindled with depth and increasingly hostile environment, but we got more than enough data to extrapolate trends to total depth. The induction and epithermal neutron logs confirmed the rather uniform, nearly impermeable nature of the fully altered alluvial sediments below about 1800 m. Even without the deep caliper log (our one significant failure), it is rather easy to infer that all log response below 1800 m is attributed to hole size variations.

Fracture detection and characterization was another story. We felt we could have done an excellent job in that regard if hole conditions had been such that fracture apertures were intact when we logged. After a full week of attempts to control circulation, we found nothing more than giant caverns where the fractures used to intersect the borehole. In view of the many considerations involved, perhaps it was premature to expect to obtain good images of fractures in the well. But even in the worst case, good geophysical characterization of the unfractured wall rocks in the deep zone could be a vital contribution in the interpretation of fractures by means of surface seismics or VSP measurements. The larger sample volume and in situ measurements over large depth intervals offered by the logs cannot be obtained by a few core tests in the lab.

Without being fanatical, we would like to emphasize the importance of these contributions to the SSSDP, while pointing out the significance of having BOTH discontinuous core samples to test and disect, and continuous log profiles to glue the core analysis together with. There were real problems with logging in hostile environments below 2000 m at the SSSDP. We believe these problems constitute arguments for improving the ability to obtain vital geophysical log data under hostile conditions, rather than reasons for de-emphasizing logs in future geothermal projects.

Best regards,

Frederick L. Paillet

Roger Morin

Roger H. Morin

cc: W. Elders
R. Wallace

MINUTES OF MEETING ON COMPLETION OF THE SALTON SEA SCIENTIFIC DRILLING PROJECT

1. Kennecott will assume the cost of 9 days of the planned 30-day test or the same proportion of costs if the test is less than 30 days. The combined total amount of Kennecott's participation in the test will not exceed $50K. Kennecott has contributed an additional $50K towards costsharing, in conditioning the Imperial well for the test.

2. If actual and projected expenses exceed the amount budgeted by DOE to conduct testing, under the revised statement of work (SOW), DOE will terminate all testing activities and will commence orderly closeout of the project.

3. Best efforts by all parties will be made to include ancillary tests (see Table A) along with main production test, but these tests will not receive SSSDP funds unless so specified by DOE. Support for ancillary tests will be in the form of equipment, materials, or services also needed to conduct the main production test. Such support may include, but not be limited to brine samples, electric utilities, and instrument ports. All cost to the SSSDP for support activities will be identified. Ancillary tests will be included in the final test program only with the explicit approval of DOE. The results of all ancillary tests will be made freely available to the public within a reasonable period.

4. Preparation of the flow test facility for testing will include the following tasks: (see Table B)

5. Bechtel will be responsible for preparing a comprehensive final test plan to include:
    a. Test facility preparations (see item #4)
    b. Other physical preparations not included in item #4
    c. Identification and work plan for test operations contractor.
    d. Test integration plan (assure proper coordination of all tests and reporting of results).
    e. Task schedule.
    f. Task budget.
    g. Site cleanup procedures.
    h. Management organization

    Each task should be identified and described including: objective, responsible organization, duration, milestones, budget requirements. The test plan will be submitted for approval by DOE two weeks after execution of a revised statment of work (see item #10).

6. Setting of liner in the Imperial well and use of media filters are not a test requirement. Kennecott will use best effort to keep a well open and capable of performing as an injection well.

7. Duration of the production test will depend on availability of budgeted funds. Bechtel will be responsible for notifying DOE about current expenditures of funds and projected expenditures against the test program budget. Based on these notifications DOE may elect to implement item #2.

8. Costs to complete the final test program are estimated by Bechtel in its letter of March 18, 1988, to John Crawford, DOE/SAN. These costs constitute a reasonable basis for further contractual negotiations and completing the test plan specified in item #5. They are subject to modification as follows: (see Table C)

9. Within 45 days of release of site to Kennecott, Bechtel will submit a final report on performance of the test. Report will cover operational matters and include a general summary of data collected by all test experiments. In addition, an analysis of results of the main production test will be provided. Analytical results of ancillary tests will be reported separately by the responsible researcher/research organization unless otherwise specified by the test plan (item #5).

10. A revised SOW will be prepared jointly by the SSSDP project managers and submitted to the DOE Contracting Officer for approval as a final contract modification by April 1, 1988. The SOW will be consistent with and reflective of the other items of these minutes, especially item 5.

11. All parties will use best effort to meet the following schedule (see Table D).

Larry Grogan, Kennecott
3/24/88
Frank Cochran, Bechtel
John E. Crawford
John Crawford, DOE/SAN
Allan Jelacic, DOE/HQ

March 23, 1988

TABLE A. SSSDP - POTENTIAL ANCILLARY RESEARCH PROGRAM

ITEM	PERFORMER	COST TO SSSDP
Seismic survey	LLNL	
Petrologic studies of samples	UURI	
Precipitation kinetics of brine	UURI	
Brine thermodynamics	INEL	
Flow T/P; flowmeter survey	LBL	
Reservoir drawdown recovery	LBL	
Geochemical studies	USGS	
Equilibrium T/Openhole logs	USGS	
Downbhole fluid samples	LANL	
Bioleaching tests	BNL	
Fouling resistance of PCL tubes	BNL	
Crystallizer-clarifier experiments	EPRI	
Inline instrumentation tests	PNL	
Mobile Lab - Production brine chemistry.	EPRI	
Production brine chemistry	FREEPORT	
Downhole sampler test (if available).	KENNECOTT	
Production brine chemistry	UNOCAL	
Well logs	KENNECOTT	
State of California flow test requirement (PRC 6378.1)	KENNECOTT	

TABLE B SSSDP - COMPLETION OF FLOW TEST FACILITY

1. Install pumps, complete piping connections
2. Install, checkout all gauges, instrumentation
3. Tie down, support, insulate pipe
4. Blind flange unused pipe sections
5. Flush, pressure test system
6. Install divider curtain
7. Install compressor, connect controllers and checkout
8. Install rupture disk on separator
9. Reorient WKM valves (or install scaffolding for access)
10. Reinstall piping spools
11. Repair aweir in atmospheric flash vessel
12. Install additional lighting
13. Inspect, test injection pipe line
14. Remove fence around test equipment
15. Repair, replace gauges on separator pressure controller
16. Install level gauges (see #2)
17. Handle carryover from atmospheric flash vessel*
18. Review piping/pumping plans*
19. Install level gauge for brine pond

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*Potential problem area; needs consideration

TABLE C. POTENTIAL MODIFICATION TO COST ESTIMATE

1. Combine duties of well test engineering personnel to reduce costs by approximately $25K.
2. Evaluate cost/technical benefits of direct hiring by Bechtel of test operations support personnel (well test engineering).
3. Verify classification of waste by IT Corp. and determine cost impact, if any.

TABLE D TENTATIVE SCHEDULE

Cost proposal - complete package to DOE	April 1
DOE/Bechtel formal negotations	April 1 - April 15
Contract modification efforts	April 15 - April 20
Execution	April 20 - April 30
Begin operation on site	May 1
Prepare facility	May 1 - June 1
Conduct flow test	June 1 - July 1
Cleanup pond and mud pit	July 1 - August 1
Prepare final report	August 1 - Sept. 15
Accept report - close one	Sept 15 - Sept. 30

RHW
12/23/86
MR
12/23/86

United States Department of the Interior
GEOLOGICAL SURVEY
Branch of Igneous and Geothermal Processes, MS-910
345 Middlefield Road, Menlo Park, California 94025

30 October 1986

Memorandum

To: J.E. Mock, Geothermal Technology Division, DOE

From: A.H. Truesdell, IGP Branch, USGS

Subject: Thoughts on the Salton Sea drill hole

Ray Wallace tells me that you would like to know more about my opinion of the Salton Sea scientific drill hole (SSSDH). I should emphasize that my opinion is just that and is not a USGS opinion or even one of any of my colleagues. Also note that I am concerned only about the scientific side of this project and have no problems with the way it was managed.

The scientific plan for the SSSDH appeared to be well conceived, but in the execution the scientific balance and the cost seem to have gone wrong. In retrospect, it seems that the scientific objectives could have been achieved at a much lower cost by drilling at Cerro Prieto, where information from one deep hole could be integrated into existing detailed knowledge of the whole geothermal system rather than existing in isolation. This last suggestion would have involved cooperating with CFE in drilling a deep hole in the Cerro Prieto field, where there is experience in drilling similar holes, with several holes deeper than 3.5 kilometers and one to 4.4 kilometers. Deepening one of these 4-km± holes would have reached extraordinary depth, temperature, and metamorphic environment. Due to financial problems the information gained from recent deep Cerro Prieto wells is imperfect because there has been no money for geophysical logging or core drilling. If NSF, DOE and congress had put a small fraction of the cost of the SSSDH into improving the science of the 4.4-kilometer deep hole recently drilled at Cerro Prieto, all of the scientific objectives could have been met in a higher temperature and pressure environment in a field that already had quality geophysics, detailed stratigraphic and alteration mapping, comprehensive fluid chemistry, and many accessible production wells for experimentation.

Some of my negative feelings about the SSSDH come from the sensational way it has been promoted. I expressed these feelings in a recent letter to Leonard Johnson of the NSF (copy enclosed).

I hope that you will understand from this letter why I said what I did at the DOE review meeting. I suppose I should have kept quiet as the SSSDH redrill had apparently already been funded.

a.H.T.

Alfred H. Truesdell

United States Department of the Interior

GEOLOGICAL SURVEY

Branch of Igneous and Geothermal Processes, MS-910
345 Middlefield Road, Menlo Park, California 94025

9 December 1986

Dr. Leonard E. Johnson, Program Director
Continental Lithosphere
Division of Earth Sciences
National Science Foundation
Washington, D.C. 20550

Dear Leonard:

I finally have some time to look at the two NSF proposals on the Salton Sea drill hole. I don't think that NSF has any choice about funding Elders, so I am not too guilty about sending the review so late (I feel worse about McDowell's because it contains real science--it was sent to Douglas Rumble on December 8). I have not been impressed with Wilfred's scientific ethics in the past, but he will do an acceptable job in this instance. The decision to fund the deepening of the drill hole with reprogrammed DOE funds is deplorable for reasons I am putting into this letter and not in the review. I am also mentioning here matters of style which I think NSF should not allow in a proposal. Perhaps Elders should have been asked to reword the proposal so as to stick to the science and leave the hucksterism for his congressional activities.

This proposal is written in a sensational, self-congratulatory public-relations tone that I find very offensive. Perhaps it is effective with Congress but I doubt that the PI has furthered his reputation for effective communication, scientific ethics, and good taste through this proposal. As one of the "several hundred different (sic) scientists" involved in the SSSDH and part of the collaboration that was "forged in the fire," I have not been impressed with the scientific management of the program so far. The original idea of deepening a 10,000-foot deep hole to 16,000-18,000 feet with $6 million was excellent and would have reached a really new zone of great interest to a wide variety of scientists. The present hole breaks no new ground (sorry) in depth, salinity or temperature--there are several holes as hot in the Salton Sea field and dozens as hot and half a dozen deeper (one nearly 1.5 km deeper) in Cerro Prieto, Mexico, less than 70 miles away. The interest in the SSSDH came partly from public relations efforts like this proposal, partly from general ignorance of the existing research opportunities, and partly from the offer of NSF and DOE support. This background is really beside the point and should be kept separate from the proposal review, which is enclosed.

Thanks for sending the proposal. Before December 12 I will be in Mexico and hard to reach.

Best regards,

Enclosure

Alfred H. Truesdell

DOE CONTINENTAL SCIENTIFIC DRILLING REVIEW GROUP

DANIEL F. WEILL, NSF — CHAIRMAN

HAROLD WOLLENBERG, LBL — SECRETARY

KEIITI AKI, U. SO. CALIFORNIA

JAMES COMBS, GEOTHERMAL RESOURCES
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WILLIAM DOLAN, AMAX

JOHN EICHELBERGER, SNL-A

WILFRED A. ELDERS, U. CALIFORNIA AT RIVER SIDE

ROBERT A. FOURNIER, USGS (MENLO PARK)

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Design and Evaluation of Lost-Circulation Materials for Severe Environments

Glen E. Loeppke, David A. Glowka, SPE, and **Elton K. Wright,**
Sandia Natl. Laboratories

Summary. Lost-circulation materials (LCM's) for geothermal applications were analyzed with laboratory tools developed specifically for that purpose. Test results of commercial materials and mathematical models for evaluating their performance are presented. Physical attributes that govern the performance of LCM's in geothermal wells are identified and correlated with test results.

> **". . .particles outside an effective range for a fracture of interest do not contribute to a stable bridge, although they may act as filter material. Consequently, a tailored particle-size distribution for a narrow range of fracture widths should provide the best plugging capabilities."**

Introduction

As part of the U.S. DOE's Geothermal Technology Development Program, Sandia Natl. Laboratories conducted an extensive testing program to evaluate candidate LCM's to aid in solving the severe lost-circulation problems encountered in geothermal-well drilling.[1,2] Our work concentrated on high-temperature, fracture-dominated loss zones rather than the matrix loss zones more typical of oil and gas drilling. The results, however, are applicable to the petroleum industry, particularly because of the inevitable progression into hotter, more fracture-dominated petroleum reservoirs.

Mechanics of the Fracture-Plugging Process

The effectiveness of a plug in preventing fluid loss into a fracture depends on the mechanical strength of the plug as well as its permeability. The portion of the plug responsible for its mechanical strength is the bridge, and the portion that controls the plug permeability is the filter. The functional requirements for bridging and filter materials are sufficiently different that few materials would be expected to perform both functions adequately. As a result, a mixture of rigid, granular particles with more pliant flakes and/or fibers generally provides the best fracture-plugging characteristics in the laboratory tests reported here and in Ref. 3.

Single-Particle Bridging. If the dimension of a particle normal to the fracture direction is larger than the width of the fracture opening, b, single-particle bridging is possible (**Fig. 1**). This type of bridging can also occur inside a fracture at locations where it undergoes a sudden reduction in width. The particle is idealized as a beam of length L with a rectangular cross section of height h and depth D. The particle is held against the fracture wall by the pressure differential, p.

The maximum bending stress in the equivalent beam occurs at midspan and is compressive at the top of the beam and tensile at the bottom of the beam. When these stresses exceed the compressive or tensile strength, S, of the bridge material, the material undergoes irreversible strain (i.e., plastic deformation or brittle fracturing), and the bridge fails. The Appendix shows that the maximum allowable pressure differential based on *inelastic* collapse of a single-particle bridge is

$$(p_{I1})_{\max}=(4S/3)(h/b)^2. \quad\text{. . . . . (1)}$$

Some potential bridging materials are so elastic that bridge collapse caused by extrusion of the material into the fracture is possible without exceeding the material's tensile or compressive strength. In this case, bending deflection of the particle becomes so significant that the curved length of the particle is no longer capable of spanning the fracture width (**Fig. 2**), and the plug fails.

To analyze the elastic plug failure, the equivalent beam loading shown in Fig. 2 is assumed. Because of the large beam curvatures considered, the nonlinear form of the beam deflection equation must be used to determine whether the extruded shape of the particle is capable of spanning the fracture width. The nondimensional deflection equation developed in the Appendix was numerically integrated to produce an equation for the maximum allowable pressure differential based on *elastic* collapse of a single-particle bridge:

$$(p_{E1})_{\max}=E(h/b)^3 p_{fD1}, \quad\text{. . . . . (2)}$$

where p_{fD1}, the dimensionless elastic failure pressure for a single-particle bridge, is taken from **Fig. 3.** Fig. 3 indicates that for a given friction coefficient, K, the maximum allowable pressure differential increases sharply with increasing particle lengths slightly larger than the fracture width. Beyond a certain ratio of L/b, however, any further increase in particle length does not yield any further improvement in pressure capability. In this region, the particle is so highly deflected that further increases in pressure cause the bridge to become inherently unstable, regardless of the particle length. Greater friction between the particle and the fracture wall improves the pressure capability of the single-particle bridge. The minimum pressure value predicted by Eq. 1 or 2 is the maximum allowable pressure differential for a given one-particle bridge.

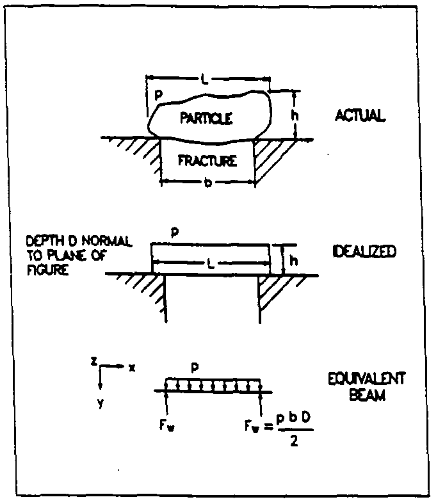

Fig. 1—Single-particle bridging at fracture entrance.

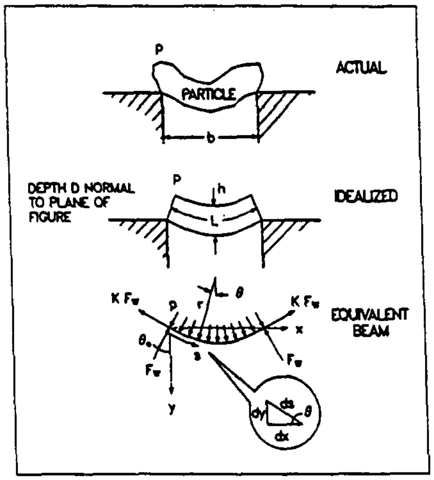

Fig. 2—Incipient failure of a single-particle bridge because of elastic deformation.

Multiple-Particle Bridging. If all particle dimensions are smaller than the fracture width, bridges are possible only when two or three particles interact to form a stable arch from one fracture wall to the other. Consider a two-particle bridge at the fracture entrance or in a region where the fracture undergoes a sudden reduction in width (**Fig. 4**). It is assumed for simplicity that the two particles are identical in shape, size, and mechanical properties.

As the two particles first contact each other and the fracture wall, the contact forces increase from zero at the moment of contact to some maximum value once stability of the bridge is achieved. During bridge formation, the particle orientation angle, α, decreases from its initial value, α_i, to its final equilibrium value, α_e. This particle rotation can occur only with an accompanying reduction in length, which in turn requires that a longitudinal force be imparted to each particle. At some point in the particle rotation, if conditions are favorable, these longitudinal forces will balance the pressure and wall-contact forces, yielding a stable bridge. This balance of forces is examined in the Appendix to derive an equation relating the equilibrium angle to other variables:

$$p_{D2}=2\tan\alpha_e[2(L/b)\cos\alpha_e-1], \quad . . (3)$$

where p_{D2} is the dimensionless differential pressure imposed across a stable two-particle bridge at equilibrium. Eq. 3 is valid only for $\alpha_e \leq 45°$. Larger angles require the force $(F_{wx})_e$ in Fig. 4 to be negative, which is physically impossible.

Eq. 3 is plotted in **Fig. 5** for a range of particle sizes greater than one-half the fracture width. To understand the trends in this figure, consider the effects of increasing pressure on the equilibrium angle of a stable bridge for which $L/b=0.7$. When the bridge first reaches equilibrium at an equilibrium angle near 44°, the pressure drop across the bridge may be only a fraction of its final value. As filter material accumulates behind the bridge to form a seal, the pressure drop may increase, resulting in a corresponding decrease in the equilibrium angle. The bridge will remain stable during the plug pressurization process as long as a finite increase in pressure differential results in a finite reduction in equilibrium angle—i.e., as long as $|\partial\alpha_e/\partial p|$ is finite. At the point where the curve for $L/b=0.7$ becomes vertical, however, $|\partial\alpha_e/\partial p|$ is infinite. This is the point of instability where the bridge is on the verge of collapse. Any further increase in pressure causes an unbounded decrease in equilibrium angle, and the bridge falls aparts. Similar behavior is experienced by particles with widths smaller than 0.7 *b*, although the maximum pressure that smaller particles can support is much lower.

Curves for particles with widths larger than 0.7 *b* display an interesting feature. Stability of the larger particles is not achieved unless the pressure differential is above some minimum value, which implies that the gradual plug pressurization scenario described above for smaller particles is not applicable here. Instead, the particles require the development of a significant pressure differential before the bridge stabilizes and filter material accumulates to form a seal. Such large pressure differentials in the absence of a seal can develop only with large dynamic fluid pressures acting upon the particles, as occurs in highly transient or other accelerating flows. Consequently, the probability is relatively low that particles with lengths larger than 0.7 *b* will develop two-particle bridges compared with the plugging probability for smaller particles. Furthermore, any bridge that does develop with large particles is likely to become unstable and collapse if the pressure differential imposed across the plug is subsequently reduced below the levels defined by the intersection of the curves with the upper dashed line in Fig. 5. Plugs composed of small particles are therefore more resilient to changes in the pressure differential, although their maximum pressure capability may not be as high as that of larger particles.

The maximum pressure differential at which a two-particle bridge is elastically stable is obtained by differentiating Eq. 3 and setting $\partial p/\partial\alpha_e$ to zero, solving for the equilibrium angle at failure, and substituting this angle value back into Eq. 3. The result

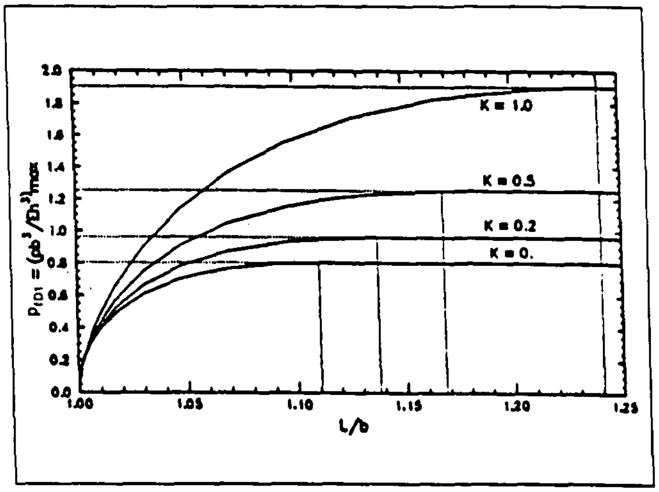

Fig. 3—Dimensionless elastic failure pressure for single-particle bridges.

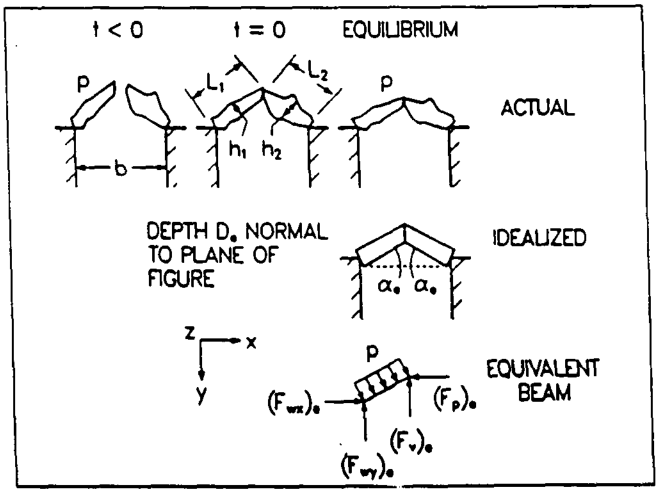

Fig. 4—Two-particle bridging at fracture entrance.

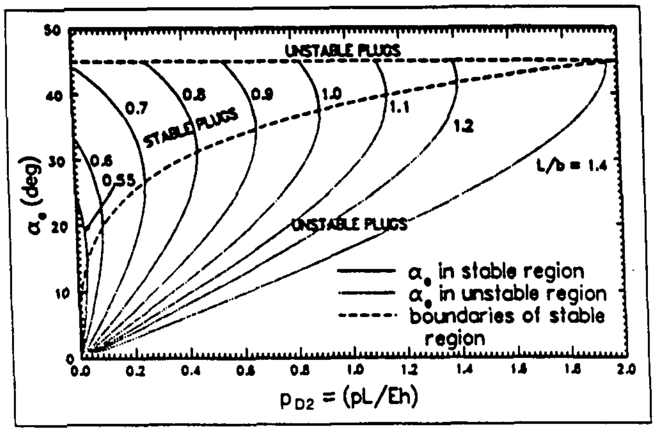

Fig. 5—Particle equilibrium-orientation angle as a function of applied dimensionless differential pressure for a two-particle bridge.

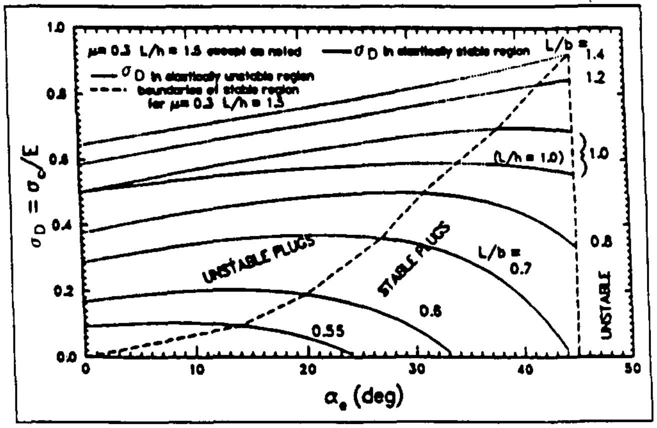

Fig. 6—Dimensionless particle stress for a stable two-particle bridge.

is an equation for p_{fD2}, the dimensionless elastic failure pressure for a two-particle bridge:

$$p_{fD2}=2\tan\alpha_{f2}[2(L/b)\cos\alpha_{f2}-1], \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\text{where } \alpha_{f2}=\cos^{-1}(b/2L)^{1/3}. \quad \ldots\ldots\ldots (5)$$

The maximum allowable differential pressure based on *elastic* failure of a two-particle bridge is thus

$$(p_{E2})_{\max}=E(h/L)p_{fD2}. \quad \ldots\ldots\ldots\ldots (6)$$

The minimum pressure differential at which a two-particle bridge can form is obtained by setting α_e in Eq. 3 to its maximum valid value of 45°:

$$(p_{E2})_{\min}=E(h/L)(p_{D2})_{\min}, \quad \ldots\ldots\ldots (7)$$

where $(p_{D2})_{\min}$, the dimensionless minimum pressure differential for a two-particle bridge, is

$$(p_{D2})_{\min}=2[(1.414L/b)-1]. \quad \ldots\ldots (8)$$

If the elastic limit of the material is relatively low compared with its elastic modulus, inelastic bridge failure can occur if the combined longitudinal and bending stresses in the particles exceed the compressive or tensile strength of the material. As the Appendix shows, the combined stress in each particle is

$$\sigma_c=E\sigma_D, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where σ_D, the dimensionless particle stress, is given by

$$\sigma_D=\{(h/L)\tan\alpha_e[2(L/b)\cos\alpha_e-1]\} \times\left\{\frac{L}{2h}\frac{b}{L}\frac{1}{\sin\alpha_e}\pm\frac{3}{2} \times\left[\frac{L}{2h}\frac{b}{L}\frac{1}{(\cos\alpha_e+\mu\cos\alpha_e-\mu b/2L)}\right]^2\right\}. \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The positive sign applies to the high-pressure side of the particle and the negative sign applies to the low-pressure side. In dimensionless terms, inelastic collapse of a two-particle bridge occurs if

$$|\sigma_D|>S/E. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Fig. 6 shows Eq. 10 with the positive sign plotted in a manner that shows the ranges of α_e for which the plug is elastically stable. It uses the equilibrium angle corresponding to an imposed dimensionless pressure differential and particle size of interest from Fig. 5 to determine σ_D and thus the particle stress. The pressure differential at which inelastic bridge failure occurs can be determined by setting σ_D to S/E for the material of interest and finding the value of α_e at failure from Fig. 6. This angle is then used in Fig. 5 to find $(p_{D2})_{\max}$ for calculation of the maximum allowable pressure differential based on *inelastic* failure of a two-particle bridge:

$$(p_{I2})_{\max}=E(h/L)(p_{D2})_{\max}. \quad \ldots\ldots (12)$$

The smaller of the two pressure values calculated with Eqs. 7 and 12 is the maximum allowable pressure differential for a given two-particle bridge.

Implications of Bridging Models. The mathematical models for the single- and two-particle bridges indicate that the particle size and shape play important roles in determining the maximum allowable pressure differential across the plug. This result has implications with respect to particle-size distribution and concentration in the drilling fluid.

A wide distribution of particle sizes makes available many combinations of particle sizes for bridging a wide range of fracture widths. The bridging models show that stable bridges can develop only with particles of certain dimensions relative to the fracture width. As a result, particles outside an effective range for a fracture of interest do not contribute to a stable bridge, although they may act as filter material. Consequently, a tailored particle-size distribution for a narrow range of fracture widths should provide the best plugging capabilities.

A higher particle concentration at the fracture site improves the probability of forming a bridge and decreases the volume of drilling fluid that passes through the fracture before a plug forms. Because only one, two, or three particles may be involved in any given bridge, a reasonable conclusion is that particle concentration does not significantly affect the pressure capability of any given plug. It does, however, improve the probability that bridges, including those with inherently higher pressure capabilities, will form.

Test Methods and Conditions

Three systems were developed for testing potential LCM's: a modified version of the bridging-materials tester defined in API *RP 13I*[4] (**Fig. 7**), a large-scale facility designed to provide a more realistic test of an LCM's plugging ability (**Fig. 8**), and a bench tester designed to measure LCM mechanical properties at ambient and elevated temperatures (**Fig. 9**).

Modified API Tester. The bridging-materials tester defined in API *RP 13I* was adopted as a standard after an industry survey in 1962.[4] In the API test procedure, a pressurized LCM-laden drilling fluid is imposed against a slotted steel disk that simulates a loss-zone fracture. Variables in the test include the slot size in the disk and the concentration of the LCM in a standard water-based bentonite mud with an apparent viscosity of 25±2 cp [25±2 mPa·s]. A prescribed 3,500-mL mud slurry is loaded in a test cell and forced through the slot by a nitrogen-driven piston. A pressure differential of 100 psi [690 kPa] is applied, and if a plug forms, the pressure is increased at a rate of 10 psi/sec [69 kPa/s] until the plug fails or until 1,000 psi [6895 kPa] is reached. If no plug forms, the test ends when the 3,000-mL mud slurry has passed through the slot. The accumulated filtrate and pressure are manually recorded as measures of the LCM's performance.

To improve the quality of data obtained with the tester, modifications were made to the standard hardware: (1) 6-in. [15.24-cm] -deep slots were used instead of the ¼-in. [0.635-cm] -deep disks, (2) smooth surfaces or rough-surface plates simulating fractures with three different rugosities were used in the 6-in. [15.24-cm] slots, (3) a closed fil-

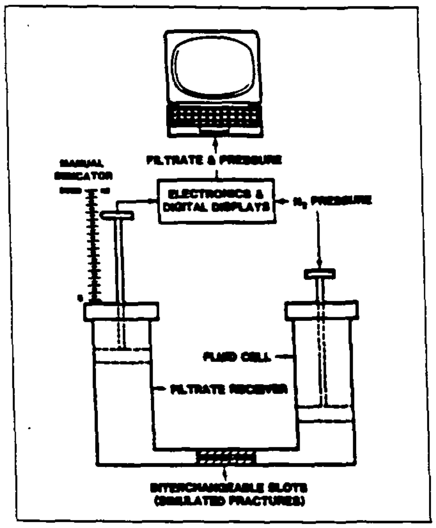

Fig. 7—Modified API bridging materials tester.

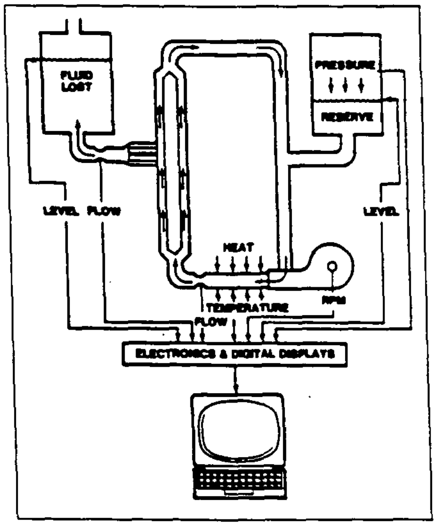

Fig. 8—Lost-circulation test facility.

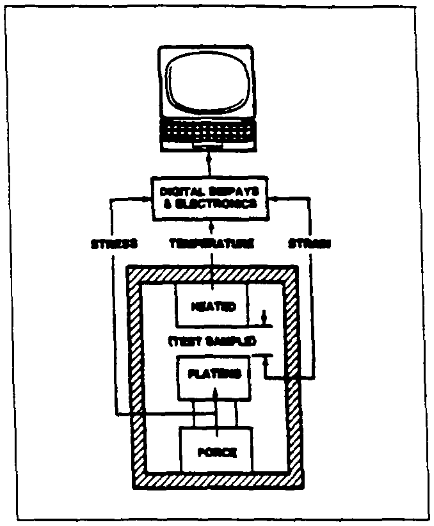

Fig. 9—Particle material-properties tester.

trate receiver similar to the test cell was used to catch and measure the fluid passing through the simulated loss zone, and (4) the test system was instrumented and coupled to a computer to provide a menu-driven test procedure and real-time data acquisition. Another important improvement was the sieving and accurate control of the LCM particle-size distribution that went into each test batch. A standard particle-size distribution was also developed during that time.

For plug formation to occur in our laboratory tests, a few large particles had to be available to bridge the slot so that a plug would start to form. Smaller sizes and shapes would then follow to form a liquid-tight plug. If too few large particles were available, the repeatability of the test suffered. Laboratory experiments showed that shifting the distribution to a higher percentage of larger particle sizes (**Fig. 10**) resulted in better repeatability, reduced data scatter, and lower filtrate loss. This particle-size distribution (SAN-2) is now used as a baseline for all material tests. **Table 1** compares results for tests conducted with the SAN-2 distribution and a commercial product in the original and the modified API testers. These data demonstrate the reduced filtrate and standard deviation of the tests conducted with each evolution of the test system.

Lost-Circulation Test Facility. The large-scale lost-circulation test facility (LCTF) uses essentially the same test procedures as the modified API tester, except for a few fundamental differences in the facility hardware and test conditions. In the LCTF dynamic test a much larger volume of slurry (272 times that in the API tester) is circulated through a full-scale vertical annulus that simulates the wellbore flow geometry. A simulated loss zone is installed near the center of this flow section at the annular surface normal to the flow. This loss zone can consist of a permeable matrix material or interchangeable slots.

After a standard annular flow velocity of 1.3 ft/sec [0.4 m/s] is established, a valve is opened to apply a 100-psi [690-kPa] pressure differential across the slot. If a plug develops, the pressure is maintained for 10 seconds and then increased in increments to the maximum 1,000 psi [6895 kPa]. A continuous record of filtrate and pressure differential vs. time is made during the test to determine when plugs develop in the slot to evaluate the LCM's effectiveness.

The 60-gal [0.23-m^3] usable filtrate is 75 times larger than that of the API tester. This difference, and possibly the circulating mud system, improves the plugging probability of the LCM in many cases. The LCTF has three other advantages.

1. More realistic flow conditions are created.
2. LCM's can be tested at elevated temperatures up to 400°F [204°C], whereas the API test is run at ambient temperature after the mud slurry is temperature-aged in a roller oven. (The roller-oven test, discussed later, is an ineffective measure of high-temperature performance.)
3. Test control and data acquisition are handled by a computer.

Because of its size and the volume of mud used, the LCTF is impractical for parametric studies. The API tester is therefore used to screen materials, and promising candidates are then tested in the LCTF under more realistic conditions.

Particle Material-Properties Tester. The particle material-properties tester (PMPT) is a simple compression tester designed to measure the compressive strength, elastic and resilience moduli, and softening temperature of potential LCM particles. These properties can be used with the bridging models to evaluate LCM's before slot tests are conducted. It would be convenient to use handbook values for these properties, but they are not available for all materials and may not be a measure of manufactured products. To provide repeatable test results, about 20 particles must be used, each selected for uniform shape and size and each measured to determine its height and surface area subjected to the applied force.

The elastic modulus and unconfined compressive strength of a material are measured by placing the particles on the bottom platen of the PMPT and forcing the platens together with a hydraulic ram while the platen displacement and compressive force are

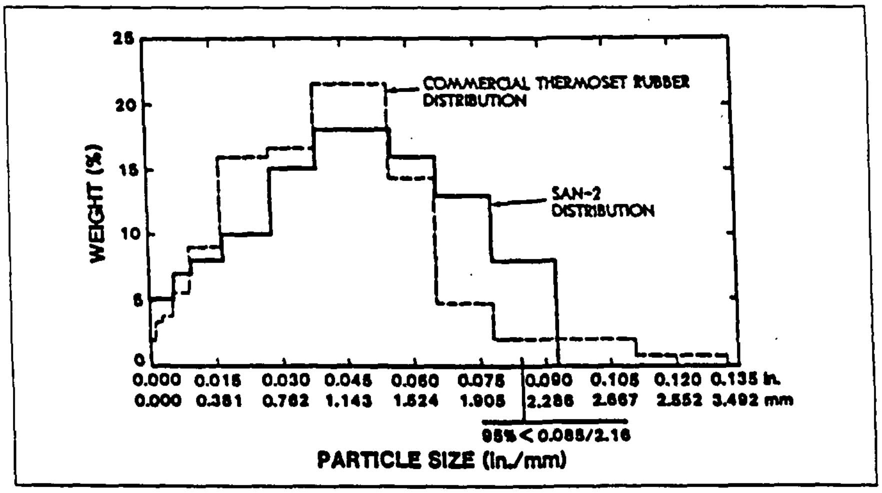

Fig. 10—Commercial and SAN-2 particle-size distributions.

TABLE 1—TEST SYSTEM COMPARISON (Data from 50 test runs with thermoset rubber)

	Particle-Size Distribution		
	Commercial Blend		SAN-2 Distribution
	Original API Tester	Modified API Tester	Modified API Tester
Maximum pressure, psi	1,000	1,000	1,000
Filtrate at maximum pressure (10 seconds), cm^3	1,625	1,446	521
Standard deviation	556	398	153
Filtrate at maximum pressure (10 minutes), cm^3	1,775	1,836	644
Standard deviation	842	424	301

TABLE 2—LCM TESTED

			Test System			
Material	Type	Size Distribution	API	LCTF	PMPT	Commercial Source
Thermoset rubber	granular	four grades	x	x	x	Poly Cycle Industries
Coal	granular	medium grade	x	x	x	McCabe Woody Co.
Gilsonite	granular	medium grade			x	American Gilsonite
Expanded aggregate	granular	fine grade	x	x	x	Intl. Drilling Products
Mixed nut shells	granular	sized			x	Magcobar
Black walnut	granular	sized			x	Generic
Alder wood	fiber	<0.75 in.	x			Weyerhaeuser Co.
Perlite	granular	10 mesh		x		unknown
Mica	flake	medium grade	x			NL Baroid
Plastic	flake	medium grade	x			Conoco
Composite with thermoset rubber	granular					
Expanded aggregate	granular	fine grade		x		Intl. Drilling Products
Mineral wool	fiber	random/short	x			Lost Circulation Specialists
Fiberglass	fiber	½ in.	x			Owens Corning
Graphite	fiber	½ in.	x			Generic
Thermoset plastic	flake	random	x	x		Poly Cycle Industries

measured. The resulting stress-strain relationship yields the desired properties. The resilience modulus, the area under the stress/strain curve, is a measure of toughness.

The softening temperature of a material is measured by placing the particles under compression in the linear portion of the stress/strain curve and heating the platens slowly to increase the particle temperature. At the softening temperature, the particle strain at a constant force increases markedly and continues with further temperature increases until complete failure occurs. This test indicates the useful temperature range of the LCM in a field application.

LCM Tests

Table 2 shows the materials and material combinations that were tested with each system. Materials were selected for testing if they appeared to have high-temperature capabilities. Previous tests of many conventional (mostly cellulosic) LCM's showed that all were degraded by temperature aging in the roller oven.[5]

The modified API tester was first used to investigate the LCM's plugging characteristics as functions of concentration, size distribution, etc. Promising candidates were then tested in the large-scale LCTF at elevated temperatures. The PMPT was used to measure mechanical properties at ambient temperatures and at elevated temperatures beyond the capability of the LCTF.

Material-Properties Test Results. Table 3 lists the material properties measured in this study. In addition to the mechanical properties determined with the PMPT, the specific gravity, bulk density, void fraction, and percentage of swelling were also measured.

Fig. 11 shows the results for a typical softening temperature test with thermoset rubber (ground automobile-battery casings). This type of plot was found to be relatively insensitive to minor fluctuations in applied force over the course of a test and yet very sensitive to actual changes in the particles' elastic modulus with temperature. For thermoset rubber, the elastic modulus gradually declines over a range of 110 to 192°F [43 to 89°C], the softening temperature range for this material (Table 3).

The results for the other materials indicate that coal, expanded aggregate, Gilsonite®, and perlite are all relatively brittle materials. Coal and Gilsonite softened at elevated temperatures. The coal disintegrated, and the Gilsonite, an asphaltic, melted. Expanded aggregate showed no deleterious effects of temperature up to 500°F [260°C]. Mixed-nut and black-walnut shells displayed excellent temperature stability and very high compressive strengths and elastic and resilience moduli.

The next section demonstrates that the material-test results may be used with the bridging models to predict material performance under a given set of conditions by comparing the theoretical predictions with the experimental slot-plugging results.

TABLE 3—RELATIVE MATERIAL PROPERTIES

Material	Type	Specific Gravity (advertised/measured)	S (psi)	E (psi)	S/E	Softening Temperature Range (°F)	Resilience Modulus (lbf/in.^{2})	Bulk Density (lbm/ft^3)	Void Fraction (%)	Swelling 24-Hour (water soak) (%)
Thermoset rubber	granular	1.10/1.48	2030	6,330	0.32	110 to 192	333	65.48	31	0
Coal	granular	1.30/2.30	210	1,880	0.11	250 to 330	12	82.17	43	0
Expanded aggregate	granular	2.20/2.60	860	6,410	0.13	>500	60	100.20	39	0
Gilsonite	granular	1.06/0.75	340	1,740	0.20	345 to 375	34	33.23	29	0
Mixed nut shells	granular	/1.20	8230	28,500	0.29	380 to 480	1,443	40.80	45	5
Black walnut shells	granular	/1.10	9870	20,500	0.48	360 to 500	2,271	34.00	48	11
Perlite	granular	/0.54	190	830	0.22		20	14.89	56	0

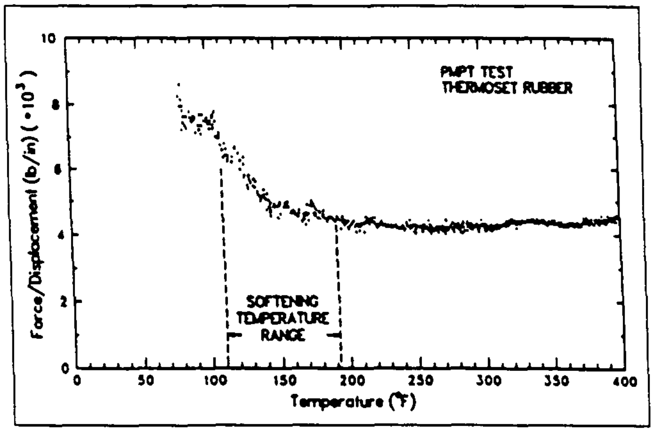

Fig. 11—Softening temperature results for thermoset rubber in PMPT.

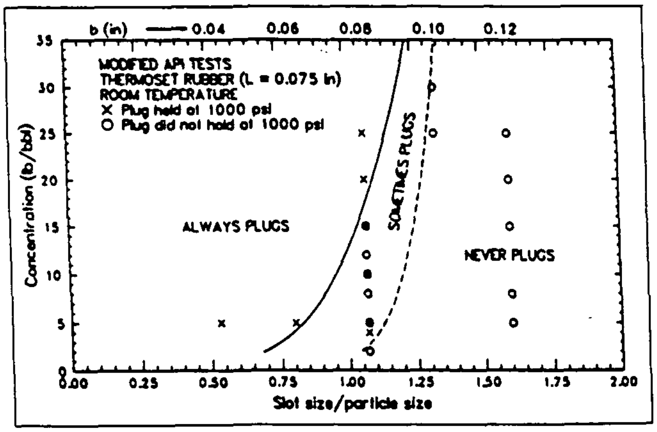

Fig. 12—Plugging performance plot for thermoset rubber in modified API tester.

Slot-Plugging Test Results. When the API tester and the LCTF are used, five and four test runs, respectively, are made for each set of test conditions. This provides the quantity of data required to show the effects of the controlled test variables. All slot tests reported here used the smooth, 6-in. [15.24-cm] -deep slot design.

A plugging performance plot of concentration vs. a pluggable slot/particle-size ratio was developed so that different LCM's or different LCM grades could be compared. This dimensionless ratio compares the slot width with the maximum particle size of the LCM, which is defined as the "95% size" of the LCM particle distribution—i.e., 95 wt% of the particles are smaller than that size. The 95% size is 0.085 in. [2.16 mm] for the SAN-2 particle-size distribution and 0.075 in. [1.91 mm] for the commercial thermoset rubber distribution (Fig. 10).

Fig. 12 shows a typical plugging performance curve for thermoset rubber particles in the modified API tester. All five tests for a given particle size and concentration are plotted (75 tests in total). If a plug formed and held a 1,000-psi [6895-kPa] differential pressure in a given test, the plug was considered successful, and Data Point X was plotted. If the plug failed in the test, Data Point 0 was plotted. Thus, three regions on this plot can be identified: the region where the plugs always held at 1,000 psi [6895 kPa], the region where the plugs always failed, and the region where plug stability at 1,000 psi [6895 kPa] was variable. The plugging performance curve is defined as the boundary of the region where the plugs always held.

This data presentation is a worst-case analysis because not all field applications require such a high pressure capability. It is a useful tool for material comparisons, however, because the effect of increasing concentration is clearly shown. For granular materials such as this, very little can be gained with concentrations above 20 lbm/bbl [57.1 kg/m^3]. Consequently, if a field application with a reasonable concentration of a particular grade of material is unsuccessful, then that particular material is probably unsuitable for the application. A different size, grade, or type of material should be tried rather than more of the same, as is often done.

Thermoset Rubber. Thermoset rubber was tested in both the modified API tester and the LCTF. The results shown in Fig. 12 confirm that the performance of this LCM as a bridging material is a function of the slot or fracture width. At slot/particle-size ratios less than 1, single-particle bridges composed of the largest particles are possible. As the slot size increases beyond the maximum particle size (0.075 in. [1.9 mm] in this case), the plugging capability suffers because the plugs must rely on two- and three-particle bridges. Successful multiple-particle plugs that hold pressure differentials of 1,000 psi [6985 kPa] or more occur at concentrations as low as 5 lbm/bbl [14.3 kg/m^3], but the probability of success is much lower than the virtual certainty associated with single-particle plugs of this material. The primary effect of increased concentration at a given particle size is to increase the probability of achieving 1,000-psi [6895-kPa] plugs. A secondary effect is to reduce the volume of filtrate that passes through the slot or fracture before plugging is achieved. Measured filtrate volumes at 20 lbm/bbl [57 kg/m^3] were approximately 20% of those measured at 5 lbm/bbl [14.3 kg/m^3].

Tests conducted with a mix of granular thermoset rubber particles and a commercial blend of thermoset plastic flakes demonstrated dramatically improved performance, with a greatly increased probability of developing 1,000-psi [6895-kPa] plugs and reducing filtrate loss. The flakes apparently interact with the granular particles to help stabilize and promote multiple-particle bridging.

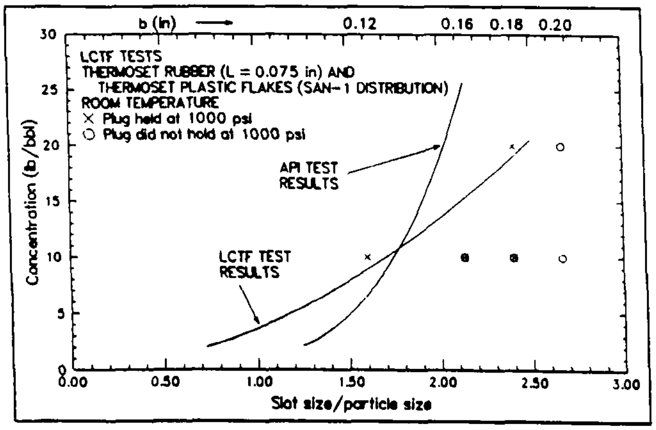

Fig. 13—Plugging performance plot for a combination thermoset rubber and thermoset plastic flake (SAN-1 distribution) in the LCTF and modified API tester.

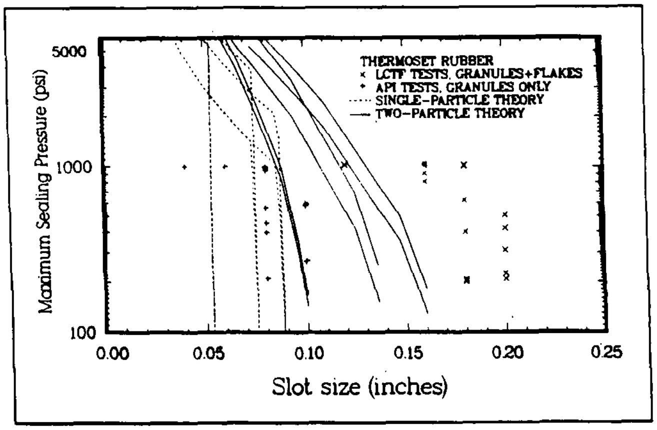

Fig. 14—Comparison of experimental and theoretical plugging pressure for thermoset rubber.

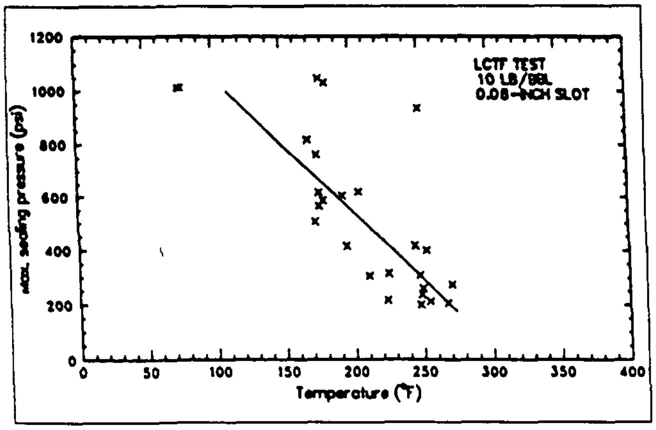

Fig. 15—Effects of temperature on thermoset-rubber plugging capability.

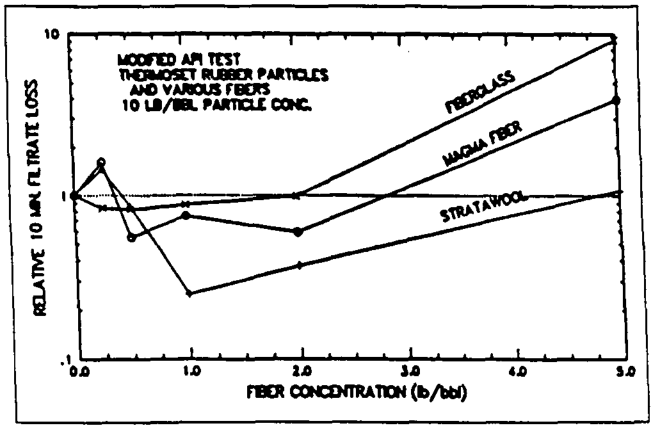

Fig. 16—Relative filtrate loss for three fiber additives to thermoset rubber granules in the modified API tester.

Moreover, the flakes are extremely pliant and are therefore easily extruded into the gaps between the granular particles to form an effective filter.

To take advantage of this synergistic effect of granules and flakes, tests were conducted to determine the optimal blend of the two material shapes. The results indicate that a 4:1 weight ratio of granular to flake particles with a 1:2 size ratio provides the minimum filtrate loss. This weight and size combination is known as the SAN-1 distribution for composite materials.

Fig. 13 shows the results of tests conducted in the LCTF and the modified API tester with the SAN-1 distribution. Under the dynamic flow conditions of the LCTF, a slightly larger slot size is pluggable with this elastic material combination than in the more static API test. Note that reliable plugging at 1,000 psi [6895 kPa] was obtained in the LCTF with slots that are well over twice the size of the granular particles. Three-particle bridging is apparently a high-probability event with the higher concentrations of this granule/flake mixture.

Fig. 14 shows the effects of slot size on the maximum allowable pressure differential for this combination of bridging materials in the LCTF. For comparison, the results of API tests with granular thermoset rubber particles only are also shown. It is apparent that the granule/flake mixture promotes higher-strength bridges capable of spanning wider fractures than those pluggable by the granular particles alone.

The predictions of the bridging models for this case (the curves in Fig. 14) were calculated by assuming that the largest 5% of the particles in a distribution control the plug strength. The dimensions of the controlling particles are then such that the middle dimension is equal to the 95% size used to characterize the LCM grades tested. In this case, particle dimensions of 0.088×0.075×0.053 in. [0.224×0.191×0.135 cm] were used. By assuming that the particles arrive at the fracture in a random orientation, a range in calculated plugging characteristics is expected. For example, if a particle arrives with its smallest dimension spanning the fracture, the maximum allowable pressure differential for the bridge will be different from that calculated when the particle arrives with its longest dimension forming the bridge. With this simplified particle geometry assumed, six different particle orientations are possible in the context of the bridging models. Thus, the random-orientation assumption produces six different curves each for the single- and the two-particle bridging theories. (The details of the calculations are presented in Table 4 of Ref. 6. Note that P_2 in Table 4 should be P_3.)

The theoretical results agree remarkably well with the experimental data. The random-orientation assumption accounts for the apparent scatter in the laboratory data. As Ref. 5 concluded, most of the variability in controlled slot-plugging tests results from the inherent variability of the plugging process itself, not inadequate laboratory procedures.

The predictions of the bridging models are most accurate for the API tests with granules only. This is expected because the models consider only one- and two-particle bridges. The higher pressure capability of the combination LCM in the larger slots results from three-particle bridging. This material was the only material tested that demonstrated significantly strong three-particle bridges. Note that the slot-plugging tests were limited by equipment capabilities to a maximum pressure differential of 1,000 psi [6895 kPa] across the plugs. Thus, some of the plugs that held at this pressure may have been capable of holding much higher pressures.

An inherent shortcoming of thermoset rubber is its tendency to soften at temperatures as low as 110°F [43°C]. Tests conducted in the modified API tester at room temperature after the material aged for 4 hours at 400°F [204°C] in a roller oven did not reveal any degradation in plugging performance because the particles are not significantly stressed during the thermal aging and thus recover to perform well at low temperatures. The behavior of the material under stress is quite different, as Fig. 11 shows. Tests run in the LCTF with granular thermoset rubber particles confirmed the effects of thermal loading (**Fig. 15**). There is an excellent correlation between the thermal effects on particle strain in the heated compression tests and thermal effects on plugging pressure in the slot tests. Tests conducted at various concentrations indicate that the degraded performance at elevated temperatures is not improved with higher concentrations of material; i.e., increased concentrations of a degraded material do not compensate for reduced particle strength. This supports the hypothesis that concentration plays little or no role in determining plug strength beyond an improvement in the probability of forming a plug.

Fig. 16 shows the measured filtrate volumes for several composite LCM's that use thermoset rubber. In these tests, various fibrous filter materials combined with granular thermoset rubber particles were evaluated in the modified API tester. All data represent successful, 1,000-psi [6895-kPa] plugs. Small concentrations of fiberglass, magma fiber, and Stratawool^{TM} all reduced filtrate loss from that measured with the thermoset rubber particles alone. At concentrations of 5 lbm/bbl [14.3 kg/m^3], however, the fibers increased filtrate loss, a problem commonly encountered with the static API tester. At high additive concentrations, the fibrous or flake material congregates in the tester throat and filters out the particles necessary to bridge the slot, resulting in higher filtrate loss. This may also indicate, however, that excessive fiber content can interfere with bridge formation in actual application.

Ground Coal. Ground coal was tested in both the modified API tester and the LCTF. **Fig. 17** shows the plugging performance curve from the API tester. Note that only single-particle bridges (slot/particle size < 1) were possible with this extremely brittle material. The effects of aging the coal at 400°F [204°C] for 4 hours before testing were small.

In the LCTF, the ground coal was able to plug only the 0.04-in. [1-mm] slot reliably at a 1,000-psi [6895-kPa] pressure differential, even though a coarser grade of coal was used (typical 95% size particle dimension = 0.174 ×0.119×0.11 in. [0.442×0.302×0.279 cm]). With larger slots, plugs formed at lower pressures but ruptured before the maxi-

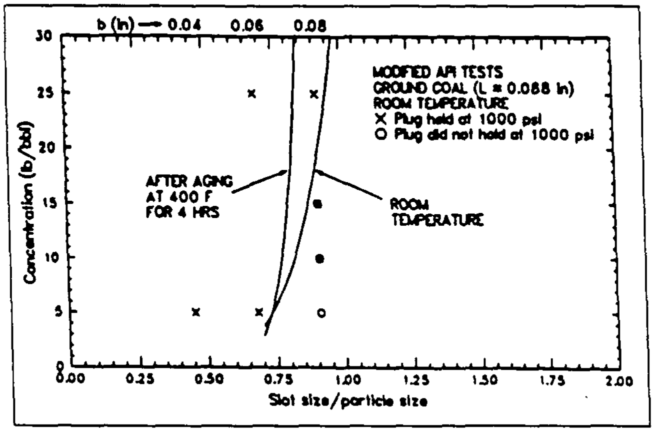

Fig. 17—Plugging-performance plot for ground coal in the modified API test before and after thermal aging in a roller oven.

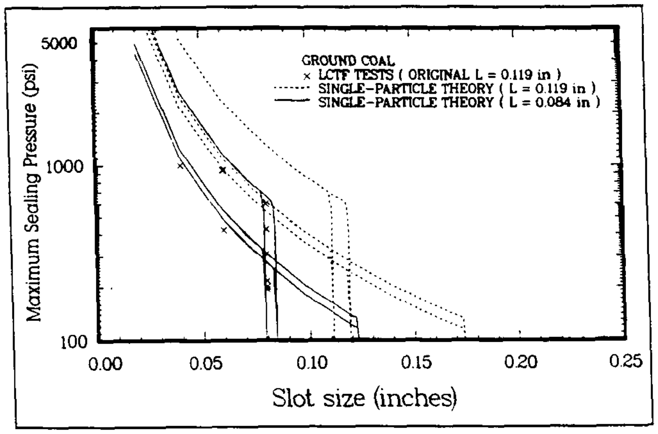

Fig. 18—Comparison of experimental and theoretical plugging pressure for ground coal.

mum 1,000 psi [6895 kPa] was reached. This was caused by significant particle breakage during circulation and bridging, as evidenced by discoloration and increased viscosity of the mud. **Fig. 18** plots the maximum sealing pressures obtained with coal as a function of slot width. Also shown are the predictions of the single-particle bridging models with both the original particle dimensions and dimensions reduced by an assumed 30%. Excellent agreement is attained between the experimental results and the bridging model predictions, particularly the results calculated with the degraded particle dimensions.

The effects of temperature on ground-coal performance were evaluated in LCTF tests conducted at temperatures up to 330°F [166°C]. The results indicate ~30% reduction in maximum pressure differential at the higher temperatures, which agrees with the softening temperature test results listed in Table 3. As with the thermoset rubber, increased concentrations of the ground coal did not compensate for reduced particle strength at elevated temperatures.

Expanded Aggregate. Expanded aggregate was also tested in the modified API tester and the LCTF. This heat-expanded rock—which can be a slate, shale, or clay according to the patent—has no observable temperature sensitivities over the range tested (75 to 500°F [24 to 260°C]) and has proven to be effective at low concentrations.

Fig. 19 shows the plugging performance curve derived from the API tests. The data indicate that multiple-particle bridging with this material is not always successful in forming 1,000-psi [6895-kPa] plugs. Consequently, to obtain a reliable plug, the slot or fracture size must be smaller than the largest particles in the size distribution.

In the LCTF, the maximum pluggable slot size was reduced to only 0.06 in. [1.52 mm] because of the breakage of brittle particles under the dynamic flowing and bridging conditions of the LCTF. A gradual reduction in plugging performance was noted when the same mud/LCM batch was circulated over a period of time.

The specific gravity of the expanded aggregate (2.2 to 2.6) made it difficult to keep the material in suspension. The yield point and gel strength of the base mud were raised to 18 and 30 lbf/100 ft^2 [8.62 and 14.4 Pa], respectively, to keep the LCM suspended in the static API test. Also, the abrasive nature of this material had a very deleterious effect on the LCTF equipment. Finally, the concentration and particle-size distribution of the expanded aggregate used in these tests were typical of drill cuttings found in the wellbore during drilling (5 lbm/bbl [14.3 kg/m^3] and medium-coarse size). This points out the possible importance of drill cuttings in modifying the performance of LCM's.

Other LCM's. Other LCM's underwent preliminary tests, but were dropped from consideration for various reasons. A promising plastic flake (possibly a cellulose derivative) tested well at room temperature, but turned to a paste when subjected to the high-temperature roller oven. Attempts to test a commercial mica-flake LCM in the API tester failed because the specific gravity was so high that the material settled to the bottom of the test cell. An engineered wood fiber tested in the API tester performed well at room temperature but was permanently degraded in the 400°F [204°C] roller-oven test.

Discussion

Although the laboratory tests were conducted with LCM particles of a given size range for each material, the results should be applicable to other particle sizes of the same materials as long as the particle shapes (i.e., aspect ratios), material properties, and sizes relative to the fracture are similar. This conclusion was derived from the bridging models, which indicate that the maximum sealing pressure of a bridge plug is a function of the particles' mechanical properties and their sizes and shapes relative to the fracture, but not of their absolute dimensions. A plot such as Fig. 19, which compares the performance of the materials on the basis of the slot/particle-size ratio, should therefore be generally applicable for those materials.

The ability of a material to plug a large fracture seems to correlate well with the ratio of the compressive strength of the material to its elastic modulus, *S/E*. The values for coal (0.11), expanded aggregate (0.13), and thermoset rubber (0.32) increase in apparent agreement with the pluggable slot size in Fig. 19. This also agrees with the bridging models, which include the *S/E* ratio as a variable.

With the *S/E* ratio as a guide to suitability of materials as LCM's, Table 3 shows that

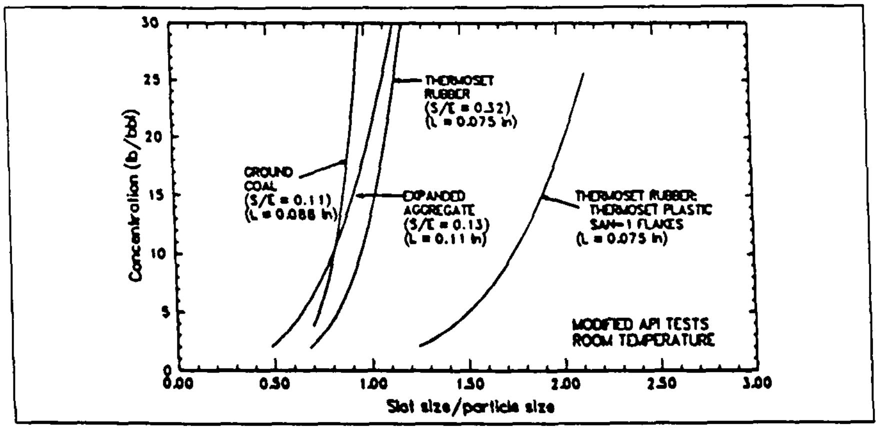

Fig. 19—Comparison of plugging performance curves for LCM's tested in the modified API tester.

both the mixed-nut (S/E=0.29) and black-walnut shells (S/E=0.48) should be excellent LCM's, as confirmed by their common use in petroleum drilling applications. Their relative temperature stabilities suggest that these materials may have utility in environments more severe than those that most common cellulosic materials can tolerate. The high-temperature plugging capabilities of these materials will be tested in the future.

Our research and field experience revealed that product quality control is an area that requires much improvement. In our work we sieve random samples from each product received and invariably find a size distribution and sometimes product properties significantly different from the product specification. Field experience reported to us cites examples of LCM applications that resulted in plugged or burned bits, where a different batch of the same product had previously been used successfully. This product variation is especially evident in blended materials, where substitutions often appear to be made on the basis of availability.

Conclusions

1. The modified version of the API bridging materials tester improves the data quality of slot tests, making it a more effective tool for screening potential LCM's.
2. The large-scale LCTF more accurately simulates dynamic flowing conditions prevalent in fracture-plugging applications. Significant differences in plugging performance are noted between the LCTF and the API tester with some materials.
3. The PMPT complements the slot tests by measuring the material properties important in bridge-plugging mechanics and has proved valuable in measuring the elastic modulus, compressive strength, and softening temperature of LCM particles. The softening temperature correlated well with the effects of temperature on laboratory slot-plugging performance.
4. Effective theoretical models of one- and two-particle bridging mechanics were developed that predict the maximum pressure differential sustainable by a plug. Variables in the models include the size and shape of the bridging particles relative to the fracture width as well as the mechanical properties of the particles. The models were shown to provide accurate predictions of slot-plugging test results.
5. Plugging performance plots that allow the comparison of LCM's of different particle sizes and different types in fractures of known width can also help to determine the potential for plugging bit nozzles in field LCM applications. Plugging performance plots developed for several commercial LCM's have potential in severe, fracture-dominated, underpressured loss zones.
6. Concentrations of granular LCM particles as high as 20 lbm/bbl [57.1 kg/m^3] can reduce filtrate loss and improve the probability of forming a high-pressure plug; however, higher concentrations are not beneficial and and may be detrimental.
7. An optimal granule/flake LCM mixture with a 4:1 weight ratio and a 1:2 size ratio, respectively, developed for thermoset rubber (ground automobile battery casings) was found to be superior to all other LCM's tested at low temperature, but displayed reduced performance at temperatures above 150°F [66°C].
8. Particle-size distribution is an important factor in the bridge-plugging process. Quality control is important in the LCM manufacturing process to ensure economical use of materials with consistent results in field applications.
9. Brittle LCM's tend to degrade in size during exposure to dynamic flowing conditions and can contribute to unwanted changes in drilling-fluid properties and plugging characteristics.
10. The random orientation of particles at the plug location is a plausible explanation for the apparent variability in laboratory slot-plugging performance and perhaps field performance.
11. The possibility that drill cuttings may modify the plugging characteristics for a given LCM treatment should always be considered. If applied during drilling, the LCM should complement the effects of rigid rock particles present in the drilling fluid.

Nomenclature

b = fracture width, in. [cm]
D = particle depth, in. [cm]
E = particle elastic modulus, psi [kPa]
F_L = longitudinal force on particle, lbf [N]
F_p = contact force between particles, lbf [N]
F_v = vertical contact force between particles, lbf [N]
F_w = particle/wall contact force, lbf [N]
h = particle height, in. [cm]
I = particle moment of inertia, in.^{4} [cm^4]
K = particle/fracture-wall friction coefficient
L = particle length, in. [cm]
M_b = bending moment, lbf-in. [N·m]
p = pressure differential across plug, psi [kPa]
p_{D2} = dimensionless pressure differential across a stable two-particle bridge, psi [kPa]
p_{fD} = dimensionless elastic failure pressure, psi [kPa]
r = particle radius of curvature, in. [cm]
s = distance along deflected beam at any point, in. [cm]
S = particle compressive or tensile strength, psi [MPa]
α = particle orientation angle, degrees
α_e = particle equilibrium angle in a stable two-particle bridge, degrees
α_{f2} = elastic failure angle of a two-particle bridge, degrees
ϵ = longitudinal particle strain
θ = single-particle bridge deflection angle, degrees
θ_0 = deflection angle at particle ends, degrees
μ = Poisson's ratio for particle material
σ_b = particle bending stress, psi [kPa]
σ_c = combined stress in two-particle bridge, psi [kPa]
σ_D = dimensionless particle stress
σ_L = longitudinal particle stress, psi [kPa]

Subscripts

e = equilibrium
E = elastic
f = failure
i = initial
I = inelastic
max = maximum
min = minimum
1 = single-particle bridge
2 = two-particle bridge

References

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2. Caskey, B.C., Loeppke, G.E., and Satrape, J.V.: "Lost Circulation in Geothermal Wells: Research and Development Status at Sandia," *Trans.*, Geothermal Resources Council (Aug. 1985) **9,** 97–102.
3. Messenger, J.U.: *Lost Circulation,* PennWell Publishing Co., Tulsa (1981).
4. *RP 131, Recommended Practice for Laboratory Testing Drilling Fluids,* API, Dallas (April 15, 1984) Sec. 7.
5. Hinkebein, T.E., Behr, V.L., and Wilde, S.L.: "Static Slot Testing of Conventional Lost Circulation Materials," report SAND82-1080, Sandia Natl. Laboratories, Albuquerque, NM (Jan. 1982).
6. Loeppke, G.E, Glowka, D.A., and Wright, E.K.: "Design and Evaluation of Lost-Circulation Materials for Severe Environments," paper SPE 18022 presented at the 1988 SPE Annual Technical Conference and Exhibition, Houston (Oct. 2-5).

SI Metric Conversion Factors

bbl	× 1.589 873	E−01	=	m^3
°F	(°F−32)/1.8		=	°C
in.	× 2.54*	E+00	=	cm
in.^{3}	× 1.638 706	E+01	=	cm^3
lbf/in.^{2}	× 6.894 757	E−03	=	MPa
lbm/ft^3	× 1.601 846	E+01	=	kg/m^3
psi	× 6.894 757	E+00	=	kPa

*Conversion factor is exact.

Provenance

Original SPE manuscript, **Design and Evaluation of Lost Circulation Materials for Severe Environments,** received for review Oct. 2, 1988. Paper accepted for publication Aug. 16, 1989. Revised manuscript received June 27, 1989. Paper (SPE 18022) first presented at the 1988 SPE Annual Technical Conference and Exhibition held in Houston, Oct. 2-5.

JPT

Appendix—Bridging Model Development

With single-particle bridging, the maximum bending stress in the equivalent, simply supported beam of Fig. 1 occurs at midspan and is

$$\sigma_b = \tfrac{3}{4}p(b/h)^2. \quad \text{(A-1)}$$

Inelastic failure occurs when $\sigma_b = S$. Inserting this relation into Eq. A-1 and solving for p gives the result shown in Eq. 1.

For the single-particle bridge in Fig. 2, the wall-contact force is found by balancing forces in the y direction:

$$F_w = pbD/2(\cos\theta_0 + K\sin\theta_0). \quad \text{(A-2)}$$

The moment in the beam at any Point x is

$$M_b = F_w[x\cos\theta_0 + y\sin\theta_0 + K(x\sin\theta_0 - y\cos\theta_0)] - (pD/2)(x^2 + y^2). \quad \text{(A-3)}$$

The radius of curvature of the deflected beam at any Point x is

$$r = EI/M_b. \quad \text{(A-4)}$$

Inserting Eqs. A-2, A-3, and the relation $I = (h^3D)/12$ into Eq. A-4 gives

$$r/b = \tfrac{1}{6}(p_{fD1})^{-1}\{(x/b) + (y/b) \times [(\sin\theta_0 - K\cos\theta_0)/(\cos\theta_0 + K\sin\theta_0)] - (x/b)^2 - (y/b)^2\}^{-1}, \quad \text{(A-5)}$$

where $p_{fD1} = (p/E)(b/h)^3$. The distance s along the deflected beam at any point is

$$s = \int_0^s ds \approx \int_{\theta_0}^{\theta} r\,d\theta. \quad \text{(A-6)}$$

The corresponding values of x and y are

$$x = \int_0^x dx = \int_0^s \cos\theta\,ds \quad \text{(A-7)}$$

and $$y = \int_0^y dy = \int_0^s \sin\theta\,ds. \quad \text{(A-8)}$$

Eqs. A-5 through A-8 are a set of nonlinear, integral equations that must be solved to determine the beam length required to span the fracture. The boundary conditions on the beam deflection are $y=0$ at $x=0$, $\theta=\theta_0$ at $x=0$, and $\theta=0$ at $x=b/2$.

These equations were solved numerically over a range of the parameters p_{fD1} and K. The results are plotted in Fig. 3.

With a two-particle bridge, a sum of the equilibrium moments acting about the z axis on the equivalent beam in Fig. 4 yields

$$(F_p)_e = pL_eD_e/2\sin\alpha_e. \quad \text{(A-9)}$$

A sum of the equilibrium forces acting in the x direction yields

$$(F_{wx})_e = pL_eD_e[(1/2\sin\alpha_e) - \sin\alpha_e]. \quad \text{(A-10)}$$

Because $(F_{wx})_e$ as shown in Fig. 4 must not be negative, Eq. A-10 yields $\alpha_e \leq 45°$. Thus, a stable two-particle bridge cannot form unless the length and elastic characteristics of the particles are such that the final equilibrium angle is less than 45°. If a stable bridge does form, the longitudinal deflection of each particle from its original length, L, to its equilibrium length, L_e, in the stable bridge position (because $\epsilon = \sigma_L/E$) is

$$L - L_e = (F_L)_eL/hDE, \quad \text{(A-11)}$$

where $$(F_L)_e = (F_p)_e\cos\alpha_e = pL_eD_e/2\tan\alpha_e. \quad \text{(A-12)}$$

Geometry considerations give

$$L_e = L\cos\alpha_i/\cos\alpha_e, \quad \text{(A-13)}$$

where $$\alpha_i = \cos^{-1}(b/2L). \quad \text{(A-14)}$$

Inserting Eqs. A-12 through A-14 into Eq. A-11 and assuming that $D_e = D$ (because of lateral confinement of the particle from neighboring bridges) yields Eq. 3, where $p_{D2} = pL/Eh$. The longitudinal particle stress at equilibrium is

$$\sigma_L = (F_L)_e/hD, \quad \text{(A-15)}$$

and the bending stress at particle midpoint is

$$\sigma_b = \tfrac{3}{4}p(L_e/h_e)^2. \quad \text{(A-16)}$$

The particle height is assumed to vary with the longitudinal strain according to Poisson's ratio, μ:

$$(h_e - h)/h = \mu[(L - L_e)/L]. \quad \text{(A-17)}$$

The combined stress is maximum at particle midpoint according to the relation

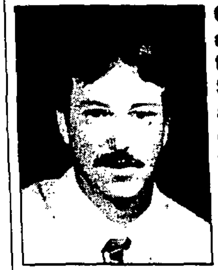
$$\sigma_c = \sigma_L \pm \sigma_b, \quad \text{(A-18)}$$

where the positive sign applies to the high-pressure side of the particle and the negative sign applies to the low-pressure side. Substituting Eqs. A-12 through A-18 into Eq. 9 produces Eq. 10.

Authors

Loeppke

Glowka



Wright

Glen E. Loeppke is a member of the technical staff at Sandia Natl. Laboratories in Albuquerque, NM. Since joining the Geothermal Research Div. in 1981, he has concentrated primarily on particle lost-circulation materials R&D and has developed new testing systems, including an improved model of the API bridging-materials tester. David A. Glowka, a senior member of the technical staff at Sandia Natl. Laboratories since 1978, researches geothermal drilling and nuclear waste disposal. He holds BS and MS degrees in mechanical engineering from the U. of Texas at Austin. Elton K. Wright has worked under contract with K-Tech Corp. for the Geothermal Research Div. of Sandia Natl. Laboratories since 1987, concentrating on test equipment used in the evaluation of lost-circulation materials.

Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

March 8, 1985

Dr. John E. Mock
Department of Energy
Forrestal Building, CE-325
1000 Independence Ave., SW
Washington, D.C. 20585

Subject: Bechtel Reports on Well Design and Geothermal Evaluation
for the Salton Sea Scientific Drilling Project

Dear Ted:

We are enclosing two copies each of the Bechtel reports on well design and geothermal evaluation for the Salton ~~Sea~~ Scientific Drilling Project. These reports were received today from Bechtel, at a briefing which they made to SAN on project status.

It must be emphasized that issues of flow tests, fluid samples, cores and cuttings have been addressed in these reports and represent one contractor's opinions. We recognize there may be some different viewpoints from those presented by Bechtel, and we are willing to accommodate any recommendations you may have in this regard.

We do want to stress, however, that the scientific criteria submitted by the Scientific Experiments Committee in memoranda form to SAN, have been provided our contractor for review and consideration in developing the well design and the geothermal evaluation program. The enclosed reports should take into account the scientists needs, insofar as is technically and economically feasible.

We look forward to meeting with you in Washington next week and discussing these reports and other SSSDP issues.

Sincerely,

Terry A. Vaeth, Director
Fossil, Geothermal, and Solar
Energy Programs Division

Enclosure

DISTRIBUTION:

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Colorado School of Mines
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Geology Department

July 15, 1986

Mr. John E. Mock, Director
Geothermal Technology Division
Conservation and Renewable Energy
Department of Energy
1000 Independence Avenue S.W.
Washington, D.C. 20585

Dear Ted:

Thank you for sending me additional information about geothermal energy. These data will be of help to the SESP as we continue to evaluate the energy resources available to the U.S., especially in the time frame of 5 to 15 years. All projections in this time frame that I have seen about U.S. suppy and demand show geothermal to represent a low percent of the total energy supply (hydro and geothermal combined to be less than 10%). If these figures are incorrect, perhaps you have additional information that would be of help to us.

The work of the Panel is going quite well and we still plan to have some type of a final report finished evaluating the solid earth science research programs by November. If we need additional information about geothermal I shall be in contact with you.

Sincerely yours,

Bob W.

Robert J. Weimer, Chairman
Solid Earth Sciences Panel

RJW:bb

cc: L. D. McGinnis
John Schoettler

7/22/86

Ray W.
We lost.
Ted

Department of Energy
Washington, DC 20585

Dr. Robert J. Weimer
Chairman, Solid Earth Science Panel
Professor Emeritus
Department of Geology
Colorado School of Mines
Golden, CO 80401

Dear Dr. ~~Weimer~~ Bob:

By happenstance, I recently received a copy of the attached letter to you from Dr. Lyle McGinnis. I would like to take this opportunity to correct certain statements made in Lyle's letter. Lyle has had a long and close association with oil and gas resource development, so it is understandable that he may be less familiar with geothermal energy. His statement, "geothermal energy is recognized as being a resource that will never play a major role in national or international energy needs," is not supported by the facts. Geothermal energy is already significant in the western United States and in several foreign countries.

Fact: California leads the nation in geothermal resource development and now obtains 5.5% of its electricity from geothermal resources, up from 4.5% last year. In the same period coal utilization for power generation decreased from 12.5 to 7%, while nuclear increased from 7.5 to 15% as the Diablo Canyon power plant came on line (see attachment 2). Geothermal use would have been higher had it not been for PG&E's policy of using Diablo Canyon as base power and only using geothermal for peaking. Note in the attachment that other renewables have played an insignificant role in California's energy mix. California has declared geothermal to be its preferred energy source, and the utility industry has announced specific plans to increase installed geothermal power from 1830 to 3180 MWe, a 74% increase, most of which is to come on line before 1989 (see attachment 3).

Fact: Nevada will have over 100 MWe on line by the end of 1987. Hawaii has completed its definition of geothermal utilization areas, and has an aggressive program to use geothermal energy to reduce its serious dependence on imported oil. A total of 13 states in the US have resources capable of providing electric power generation; most are waiting only for the increase in demand that must surely arise when the reductions through conservation have played out.

Fact: Geothermal utilization in the world has been increasing at 17% per year, much of it in third world countries that have no oil or that prefer to sell their oil. The Philippines has installed 894 MWe since 1980, providing over 20% of the country's total electricity, and has plans to increase this to 2000 MWe by 1995. Mexico has 645 MWe and plans to double this by 1993. El Salvador has 95 MWe on line, allowing the country to stop importing oil for power generation, and has plans to add a further 85 MWe. Nicaragua is currently completing its second 35 MWe installation. Indonesia has 32 MWe on line, 110 under construction and firm plans for 855 MWe more by 1994. In all, world utilization of geothermal energy for electricity production will increase from the present 4760 MWe in 17 countries to over 10,000 MWe in 24 countries by 1995, even if no new plans are formulated.

Fact: US geothermal technology leads the world, in spite of heavy government funding in Japan, France and Italy.

Fact: The royalties to the Treasury from geothermal development on federal lands more than pay for the research and development program of the Geothermal Technology Division. California splits its 50% share of royalties with county authorities, 30% to the county and 20% to the state. The state share is used for geothermal projects, and for the past two years the royalty revenues have exceeded $10 million a year.

Fact: In spite of the growth of geothermal utilization in the US, the private sector is struggling economically. Funds are used to acquire leases, to conduct exploration and to install power plants, but there is little margin for funding research. The fraction of the known resources that are economic today is quite small, and a strong government role in research in both geosciences and geothermal engineering would not only vastly increase the economically exploitable resource, but would provide a positive return on investment to the U. S. Treasury through enhanced royalties from geothermal leases on federal land.

You can see from the above examples that it is not true that geothermal energy will never play a major role -- it is already doing so, and it is important for the Panel to be aware of the great potential of hydrothermal resources. We are investigating the even greater potential of magma, hot dry rock and geopressured resources, areas deserving strong Federal support in the next decade.

If you would like further information on these points I will be pleased to provide it to you and to the members of the Panel.

Sincerely,

Ted

John E. Mock, Director
Geothermal Technology Division
Conservation and Renewable Energy

Attachments

cc:L. D. McGinnis
J. Schoettler

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

Attachment 1

May 9, 1986

Dr. Robert J. Weimer
Panel Chairman
Professor Emeritus
Department of Geology
Colorado School of Mines
Golden, CO 80401

Dear Bob:

The enclosed preprint by Bernard and Santini from Argonne bears heavily upon the arguments you and John Schoettler have been expounding for the last several months. The manuscript, submitted to Science, provides powerful ammunition for a national energy policy that is built upon objective economic arguments. If you and John feel all panel membership (perhaps even ERAB membership) should see it, I can run off more copies.

The ERAB meeting of May 6 has brought out fundamental inconsistencies in DOE's energy plan. I found it incredible that JoAnne Elfring should be touting three areas of highest priority, i.e. conservation, coal, and nuclear, while DOE's basic research in the geosciences is almost totally oriented toward geothermal resources. This becomes more anomalous yet, when geothermal energy is recognized as being a resource that will never play a major role in national or international energy needs.

The logic of the current DOE policy toward DOSECC is equally mysterious. DOSECC provides a unique opportunity for DOE to conduct fundamental research in frontier areas of oil and gas research with the collaboration of NSF and the USGS. If DOE would not only embrace the DOSECC plan for drilling into basins, overthrusts, continental margins, and ancient rifts on the continent, but provide some direction and funding as well, all three agencies would benefit by orders of magnitude. DOE should aggressively pursue a position of comprehensive collaboration with DOSECC in all of the U.S. rather than try to carve out only a small niche in the geothermometry of the far west.

Sincerely,

L. D. McGinnis, Technical Advisor
Solid Earth Science Panel

LDM:jr

cc: J. Schoettler

TABLE S1

CALIFORNIA ELECTRIC UTILITIES GENERATION RESOURCES
(MEGAWATT-HOURS)

PLANT FUEL OR TYPE	JULY 1985	AUGUST 1985	SEPTEMBER 1985	1985 THIRD QUARTER	1984 THIRD QUARTER	PERCENT CHANGE
DISTILLATE-COMBST TURBINE	14,559	10,235	4,450	29,244	35,929	-18.6
-COMBINED CYCLE	4,902	1,359	-110	6,151	3,125	96.8
-INT COMBUSTION	1,763	1,834	1,540	5,137	5,169	-.6
-COGENERATION	34	8	38	80	740	-89.2
TOTAL DISTILLATE:	21,258	13,436	5,918	40,612	44,963	-9.7
HEAVY OIL-CONVENTIONAL	131,741	156,139	81,085	368,965	308,738	19.5
-COGENERATION	22,482	0	13,582	36,064	105,355	-65.8
TOTAL HEAVY OIL:	154,223	156,139	94,667	405,029	414,093	-2.2
HYDROPOWER-LARGE(>30MW)	2,482,340	2,232,977	1,929,723	6,645,040	11,148,292	-40.4
-SMALL(<30MW)	303,104	342,116	323,064	968,284	1,223,295	-20.8
-PUMPED STORAGE	702	41,876	14,624	57,202	-150,798	-137.9
TOTAL HYDRO:	2,786,146	2,616,969	2,267,411	7,670,526	12,220,789	-37.2
NATURAL GAS-CONVENTIONAL	7,400,764	6,727,245	4,809,304	18,937,313	18,672,041	1.4
-COMBST TURBINE	8,982	5,599	3,441	18,022	18,088	-.4
-COMBINED CYCLE	180,292	157,795	62,778	400,865	386,729	3.7
-COGENERATION	42,996	43,244	40,044	126,284	130,359	-3.1
TOTAL NATURAL GAS:	7,633,034	6,933,883	4,915,567	19,482,484	19,207,217	1.4
NUCLEAR	2,199,843	1,924,396	1,687,467	5,811,706	3,249,227	78.9
COAL	830,492	845,052	1,000,070	2,675,614	5,301,033	-49.5
GEOTHERMAL	698,845	739,900	705,243	2,143,988	1,914,741	12.0
BIOMASS	490	757	704	1,951	0	.0
WIND	160	154	338	652	757	-13.9
SOLAR	0	0	0	0	200	-100.0
TOTAL OTHER:	3,729,830	3,510,259	3,393,822	10,633,911	10,465,958	1.6
GRAND TOTAL	14,324,491	13,230,686	10,677,385	38,232,562	42,353,020	-9.7

NOTE: INCLUDES GENERATION INSIDE AND OUTSIDE OF CALIFORNIA FROM FACILITIES OWNED BY CALIFORNIA UTILITIES.
INCLUDES ESTIMATED DATA FOR CITY OF BURBANK, LADWP, AND SACRAMENTO UTILITY DISTRICT.

From CALIFORNIA ENERGY COMMISSION
Energy Watch

Attachment 2

Attachment 3

EPRI Annual Geothermal Meeting, San Diego, California, June 1985

WORLDWIDE GEOTHERMAL POWER DEVELOPMENT

by

Ronald DiPippo(1)

Mechanical Engineering Department
Southeastern Massachusetts University
North Dartmouth, Massachusetts 02747
617-999-8541

SUMMARY OF POWER PLANT DEVELOPMENT Up to the year 1978, geothermal power development had progressed with an average annual growth rate of about 8.3% [1]. From 1978 to the present the growth rate has been about 17%, as can be seen from Fig. 1. Most of the increase has been due to power plant activity in three countries: the Philippines, the United States, and Mexico. If that rate of growth were to continue, then there would be about 10,000 MW of geothermal power on-line by the end of this decade. However, there are indications that a significantly lower growth rate will take hold for at least the next five years.

Table 1 gives a summary of the present status (i.e., through 1985) and projected developments out to the year 1994 for those countries that now have operating plants and those that might reasonably be expected to have plants during the next 10 years. Based on information available at this time, the cumulative potential geothermal power capacity is about 10,114 MW. Since 1970 MW of this is classified as "planned", i.e., without a specific date (for the United States and the Philippines beyond the year 1989) it is clear that 10,000 MW cannot be achieved by the year 1990. Indeed, it seems likely that an annual growth rate of about 6% will apply for the rest of the 1980s. The rate could increase in the 1990s should the Philippines resume their initial rapid development of their impressive geothermal resources.

In this paper we will focus on geothermal power plant activities in the following countries: the United States, Mexico, Japan, New Zealand, Nicaragua, and Indonesia. A thorough worldwide survey has been written for the 1985 International Symposium and will soon be available [2].

United States Tables 2-4 summarize the status of plants at The Geysers (CA), the Imperial Valley (CA), and the rest of the U.S., respectively. The planned expansion at The Geysers should reach 2660 MW within the next ten years, using only the dry-steam portion of the field. The foreseeable expansion of the plants in the Imperial Valley may lead to an installed capacity of about 414 MW. For the rest of California and the states of Hawaii, Nevada, Oregon, and Utah, the total capacity could reach 257 MW if all plans are fulfilled. Thus, a grand total of 3331 MW is currently "in the pipeline", if not "under the wellhead", for the U.S. in the foreseeable future.

In the Imperial Valley there are five projects that are about to come into being: (1) the Heber Binary Demonstration Plant; (2) the Heber Flash Plant; (3) Magma Power Company's Vulcan Power Plant; (4) Ralph M. Parsons' Niland Geothermal Energy Program; and (5) Ormat's Ormesa Modular Binary Project at East Mesa.

This year electricity will begin to flow into the grid from the world's largest binary plant, the Heber Binary Demonstration Plant, a 65 MW (gross), 45 MW (net) power plant that uses a mixture of isobutane and isopentane as its working fluid. A demonstration of success, both on technical and economic grounds, will go a long way toward opening up a large number of low-to-moderate temperature geothermal resources. Binary plants are one of the most non-polluting types of power plant that can be conceived, a major advantage in environmentally sensitive areas. However, binary plants still require an independent supply of cooling water, a limitation that could either hamper development or force designers to resort to dry (i.e., air) cooling which generally is more expensive than wet cooling.

Roughly one mile to the east of the Heber binary plant, the Heber Flash Plant of the Heber Geothermal Company will also reach the production stage during 1985. It will be a double-flash plant with a net rating of 49 MW. Since these two plants will draw fluid from the same general reservoir, it will be interesting to see if their operations affect one another. They will also serve to show the relative advantages and/or disadvantages of a flash versus a binary plant.

The hostile, high-temperature, high-salinity brines of the Salton Sea/Niland/Brawley areas are being tamed through the adoption of flash

---

(1) Also, Div. of Engineering, Brown University, Providence, Rhode Island 02912.

TABLE 1 STATUS AND PROJECTED DEVELOPMENT OF WORLDWIDE GEOTHERMAL POWER

COUNTRY	MW as of 1985	MW to be installed each year 1986	1987	1988	1989	1990	1991	1992	1993	1994	Unspec.
United States	2022.11	137.62	115.0	241.4	--	--	--	--	--	--	815.0
Philippines	894.0	--	--	55.0	92.5	--	--	--	--	--	1155.0
Mexico	645.0	50.0	50.0	55.0	55.0	110.0	55.0	220.0	50.0	--	--
Italy	519.2	--	--	--	--	--	--	--	--	--	380.0
Japan	215.1	--	--	--	--	--	--	--	--	--	108.0
New Zealand	167.2	--	--	116.2	--	--	--	--	--	--	--
El Salvador	95.0	--	--	--	--	--	--	--	--	--	85.0
Kenya	45.0	--	--	--	--	--	--	60.0	--	--	--
Iceland	39.0	--	--	--	--	--	--	--	--	--	--
Nicaragua	35.0	35.0	--	--	--	--	--	--	--	--	--
Indonesia	32.25	--	55.0	55.0	110.0	110.0	110.0	110.0	195.0	110.0	110.0
Turkey	20.6	--	--	--	--	--	--	--	--	--	--
China	14.321	--	--	--	--	--	--	--	--	--	0.55
Soviet Union	11.0	--	--	--	--	80.0	--	--	--	--	150.0
France (Guadeloupe)	4.2	--	--	--	--	--	--	--	--	--	--
Portugal (Azores)	3.0	--	--	--	--	--	--	--	--	--	--
Greece (Milos)	2.0	--	--	--	--	--	--	--	--	--	--
Costa Rica	0	--	--	--	--	50.0	--	--	--	--	--
Guatemala	0	--	--	--	--	--	--	--	--	--	15.0
Chile	0	--	--	--	--	--	--	--	--	--	15.0
Saint Lucia	0	--	--	--	--	--	--	--	--	--	30.0
India	0	--	--	--	--	--	--	--	--	--	1.0
Romania	0	--	--	--	--	--	--	--	--	--	1.0
Australia	0	--	--	--	--	--	--	--	--	--	0.5
Totals, each year		222.62	220.0	522.6	257.5	350.0	165.0	390.0	245.0	110.0	2866.9
Cumulative total	4763.981	4986.6	5206.6	5729.2	5986.7	6336.7	6501.7	6891.7	7136.7	7246.7	10113.6

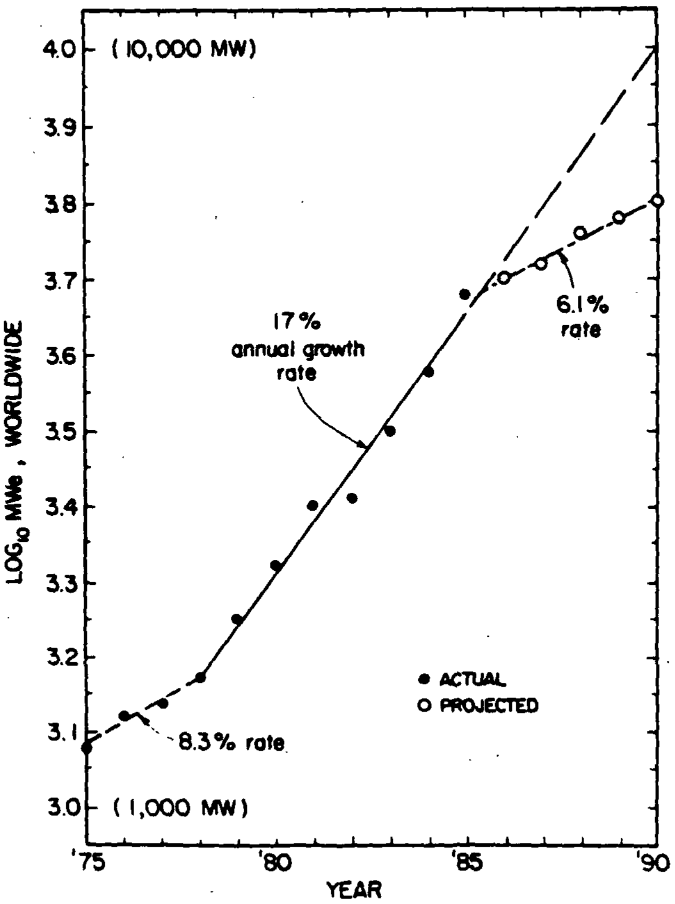

FIG.1 GROWTH OF GEOTHERMAL POWER: 1975-1990.

crystallizers and reactor-clarifiers. Magma Power company, the holder of patents on this process, is building the Vulcan Power Plant at the site of the old Dept. of Energy Geothermal Loop Experimental Facility (GLEF). The plant, scheduled to begin operating late in 1985, will produce 34.5 MW of saleable power which will be purchased by SCE. The power system is a double-flash type with separate high- and low-pressure turbines each with its own generator; the turbines are being supplied by Mitsubishi Heavy Industries, Ltd. The turbines will have the following technical specifications:

HP turbine:
  rating, 27.73 MW
  maximum capability, 30.16 MW
  speed, 3600 rpm
  steam inlet conditions:
    pressure, 517.1 kPa
    temperature, 162.7°C
    gas content, 1.3% by wt.
    flow rate, 58.3 kg/s
  exhaust pressure, 6.77 kPa
  last-stage blade height, 584.2 mm
  type:
    double-flow
    impulse-reaction
    6 stages per flow.

LP turbine:
  rating, 8.88 MW
  maximum capability, 9.56 MW
  speed, 3600 rpm
  steam inlet conditions:
    pressure, 100.3 kPa
    temperature, 107.2°C
    flow rate, 31.5 kg/s
  exhaust pressure, 6.77 kPa
  last-stage blade height, 635 mm
  type:
    single-flow
    impulse-reaction
    3 stages.

The Ralph M. Parsons Company is constructing a double-flash plant at Niland, the Niland Geothermal Energy Program (NGEP). The first phase will produce 38.6 MW of net power, and should be completed in mid-1986. Clean, high-pressure steam will be generated using a separated-steam condenser/reboiler arrangement that removes the large amount of noncondensable gases (9% by weight of steam). Additional HP steam will be flashed from the liquid portion of the geofluid separated at each wellhead. A low-pressure flash vessel will generate LP steam for use in the lower stages of the turbine being supplied by Fuji Electric Company. The two turbines will have separate condensers. The design specifications for phase 1 call for steam inlet conditions of 167.7°C, 689.5 kPa (HP) and 117.5°C, 124.1 kPa (LP); exhaust pressures of 5.42 kPa (HP) and 7.72 kPa (LP). After at least one year of operation, 31.4 MW may be added to the plant through additional wells and some modification to the turbine. The HP steam pressure and temperature would remain unchanged, but the LP conditions would be modified to 124.2°C, 155.8 kPa, and the condensers would operate at 6.91 kPa (HP) and 12.29 kPa (LP). Parsons is the owner of the wells, the brine processing equipment, and the power plant; SCE will purchase the power through the Imperial Irrigation District (IID).

At the East Mesa field, the portion originally under lease to Republic Geothermal, Inc. is about to be developed by Ormat Systems, Inc. through a partnership called Ormesa Geothermal. The plan is to install 26 individual, modular binary units, each with a gross rating of 1.25 MW, to produce 20 MW of net saleable power. The power units are under construction at Ormat's manufacturing facility although not all pieces of the agreement are yet in place. It is expected that the equipment for cooling and electrical systems will be on site during 1985, and that power will come on line in 1986.

Outside California, activity has picked up in Nevada and Utah. About 105 MW is scheduled to be on line in Nevada by 1987; about 30% of this capacity will be in binary units. In Utah, 41.5 MW should be on line by 1986 in two fields: Roosevelt Hot Springs and Cove Fort/Sulphurdale.

The first power generated from geothermal energy in Nevada came from a 60 kW binary unit at Wabuska Hot Springs in 1984. The plant is a skid-mounted unit manufactured by Ormat and has logged over 4000 hours of operation at this writing. The resource temperature is 106°C; the well is about 107 m deep; a 75 kW pump assists production, boosting the flow rate from an artesian flow of about 9 kg/s to 45 kg/s; and cooling water is handled in a spray pond and recirculated to the plant's condensers. The power equipment was delivered to the site in April 1984, preliminary runs were made in July 1984, and in September the plant was on line. The owner of the plant is Tad's Enterprises of Orinda, CA; power is sold to Sierra Pacific at 5.1 cents/kWh.

Another binary power project is under construction at Brady Hot Springs, NV by Munson Geothermal, Inc., of Reno. MGI holds about 12,480 acres under lease at Brady and plans to install 2.8 MW by the end of 1985 with a follow-on of 5.5 MW through the rehabilitation of the Raft River Dual-Boiling Binary Plant. The 2.8 MW will be achieved by running 6-9 modular units from Ormat. Reservoir fluid temperature is about 149°C, and the wells will probably be pumped. Power will be sold to Sierra Pacific.

TABLE 2 GEOTHERMAL POWER PLANTS AT THE GEYSERS, CA, USA

PLANT(1)	YEAR	MW	STATUS
PG&E Geysers:			
Unit 1	1960	11	Operational
Unit 2	1963	13	Operational
Unit 3	1967	27	Operational
Unit 4	1968	27	Operational
Unit 5-6	1971	2x53	Operational
Unit 7-8	1972	2x53	Operational
Unit 9-10	1973	2x53	Operational
Unit 11	1975	106	Operational
Unit 12	1979	106	Operational
Unit 13	1980	133	Operational
Unit 14	1980	109	Operational
Unit 15	1979	59	Operational
Unit 16	1985	114	Under construction
Unit 17	1982	114	Operational
Unit 18	1983	114	Operational
Unit 19	n.a.	55	Preliminary planning
Unit 20	1985	114	Under construction
Unit 21	1988	140	Advanced planning
Unit 22	n.a.	114	Preliminary planning
Unit 23	n.a.	114	Preliminary planning
Unit 24	n.a.	114	Preliminary planning
Wild Well	1985	1.2	Advanced planning
NCPA 2	1983	110	Operational
SMUDGEO No. 1	1983	72	Operational
Bottlerock	1985	55	Operational
OXY 1	1984	80	Operational
NCPA 3	1985	2x55	Under construction
Modesto GEO	n.a.	110	Preliminary planning
South Geysers	n.a.	55	Advanced planning
SMUDGEO No. 2	1987	55	Preliminary planning
CCPA No. 1	1988	55	Under CEC review
CCPA No. 2	n.a.	55	Preliminary planning
	Totals:	1792	Operational(2)
		2660.2	Oper., u.c., or planned

---

(1) All units are dry-steam type except Wild Well unit which will be a binary plant.

(2) Includes plants under construction and scheduled for completion in 1985.

TABLE 3 GEOTHERMAL POWER PLANTS IN THE IMPERIAL VALLEY, CA, USA

PLANT	YEAR	TYPE	MW	STATUS
East Mesa:				
B.C. McCabe No. 1	1979	Binary	12.5	Operational
Magma Unit 2	n.a.	Binary	25.0	Planned
Magma Unit 3	n.a.	Binary	25.0	Planned
ORMESA (Ormat)	1986	Binary	26x0.77	Under construction
Salton Sea:				
Geothermal Electric Project (Union/SCE/SPLC/MPC)	1982	1-Flash	10.0	Operational
Vulcan Power Plant (Magma/SCE)	1985	2-Flash	34.5	Under construction
Niland (NPN Partnership)	n.a.	2-Flash	49.0	Planned
Niland Geothermal Energy Program (Parsons):				
Phase 1	1986	2-Flash	38.6	Under construction
Phase 2	1988	2-Flash	31.4	Planned addition
Heber:				
Binary Demo Plant	1985	Binary	45.0	Under construction
Flash Plant (HGC)	1985	2-Flash	49.0	Under construction
North Brawley	1980	1-Flash	10.0	Operational
Westmorland	1988	Binary	15.0	Planned
South Brawley (CU I)	n.a.	Flash	49.0	Planned
		Totals:	32.5	Operational*
			219.6	Operational or u.c.
			414.0	Oper., u.c., or planned

---

*Includes plants under construction and scheduled for completion in 1985.

TABLE 4 GEOTHERMAL POWER PLANTS IN THE UNITED STATES (EXCLUDING THE GEYSERS AND THE IMPERIAL VALLEY)

PLANT	YEAR	TYPE	MW	STATUS
California				
Coso:				
Unit 1	1986	1-Flash	25.0	Under construction
Unit 2-3	n.a.	1-Flash	2x25.0	Advanced planning
Mammoth:				
Mammoth-Pacific	1984	Binary	2x3.5	Operational
Chance Ranch (Wood & Associates)	1985	Binary	5x0.6	Under construction
Honey Lake	1987	Hybrid: wood-geothermal	20.0	Under construction
Hawaii				
Puna No. 1	1982	1-Flash	3.0	Operational
Idaho				
Raft River	1982	Binary	5.0	Being moved to Brady H.S., NV
Nevada				
Wabuska Hot Springs	1984	Binary	0.6	Operational
Beoware	1985	2-Flash	17.0	Under construction
Brady Hot Springs:				
Phase 1	1985	Binary	2.8	Under construction
Phase 2	1986	Binary	5.5	Under construction
Steamboat Springs	1985	Binary	5.5	Planned
Fish Lake	1986	Binary	15.0	Planned
Big Smokey Valley	1986	Flash (?)	10.0	Planned
Desert Peak	1985	Total Flow/ 2-Flash	9.0	Under construction
Spring Creek	1987	2-Flash	20.0	Planned
Dixie Central	1987	Flash	20.0	Planned
Oregon				
Hammersly Canyon:				
Unit 1-3	1983	Binary	3x0.30	Operational
Unit 4-6	1984	Binary	3x0.37	Operational
Utah				
Milford:				
Blundell Unit I	1984	1-Flash	20.0	Operational
Wellhead No. 1	1986	Total Flow/ 2-Flash	14.5	Under construction
Cove Port-Sulphurdale:				
Phase 1	1985	Binary	4x0.675	Operational
Phase 2	1985	Binary	2x1.0	Under construction
Phase 3	1986	Dry steam	2.3	Advanced planning
		Totals:	69.11	Operational*
			134.11	Operational or u.c.
			256.91	Oper., u.c. or planned

---

*Includes plants under construction and scheduled for completion in 1985.

Binary plants are also being planned for Steamboat Springs and Fish Lake in Nevada. At Steamboat Springs, Geothermal Development Assocs. plans to install seven modular Ormat units: four 1200 kW units and three 800 kW units. A net power of about 5.5 MW is expected. Reservoir fluid temperatures are 160°C at 152 m; wells will be pumped to prevent flashing. A 10-year power purchase agreement is in place with Sierra Pacific.

At the Fish Lake prospect, the fluid temperature is in the range 188-200°C as determined by the discovery well drilled in 1984 and the confirmation well completed in January 1985. Although a binary-type plant has been decided upon, the manufacturer has yet to be selected. A total of 15 MW is expected to be installed by the end of 1986.

Two 20 MW flash plants are in the planning stage for Dixie Valley (Spring Creek and Dixie Central) by Trans-Pacific Geothermal Company. They may be on line by 1987.

The Beoware resource will be tapped by a double-flash steam plant. Mitsubishi Heavy Industries, Ltd. has the turbine/generator under construction and expects to have the 17 MW on line by the end of 1985. The plant will be owned by Chevron USA Beoware. Power will be purchased by Southern California Edison through Sierra Pacific.

An innovative 9 MW double-flash plant incorporating a rotary separator turbine is under construction at Desert Peak. The power conversion equipment will be built by Transamerica Delaval Inc.--Biphase Energy Systems. The Biphase double-flash system proved more efficient and cost effective than competitive energy conversion systems. Ground was broken for the plant in January 1985 and the plant should be completed late in 1985.

Two resources in southern Utah are being developed but in different ways. A 20 MW single-flash plant, Blundell Unit I, came on line in 1984 at Milford (Roosevelt Hot Springs). Because of the high temperature of the resource (260°C), the geofluid carries a significant amount of silica (510 ppm) and silica scaling has been a concern during operation. A wellhead unit is under construction at Milford that will use the Biphase rotary separator expander in conjunction with a dual pressure steam turbine to generate a net power of 14.5 MW.

Mother Earth Industries (Cove Creek Geothermal) will have four Ormat binary units in place at its Cove Fort-Sulphurdale prospect by June 1985. Each unit has a gross output of 800 kW and the net power for sale from the first four units will be about 2.7 MW. Power will be purchased by the City of Provo. Phase 2 of the project will involve the installation of two more units, each 1 MW net, by the end of 1985. Phase 3, to be completed in 1986, envisions the addition of a steam turbine in a topping mode to make efficient use of the dry steam being produced by the wells. The energy of the exhaust from the turbine will be harnessed by the binary units from Phases 1 and 2, which will then be operating in a bottoming mode. Altogether the six binary units and one steam turbine should produce about 6.5 MW net.

Mexico Table 5 lists the geothermal projects in Mexico; these include plants at three fields--Cerro Prieto, Los Azufres, and Los Humeros. A total power capacity of 1290 MW is planned for these areas by the year 1993. This vigorous development program has propelled Mexico into third place among those countries generating electricity from geothermal energy. Other fields, such as La Primavera, are being explored and may eventually reach the production stage.

Japan There are nine geothermal power plants in Japan, ranging in size from 0.1 MW at the Kirishima Kokusai Hotel to 55 MW at the double-flash Hatchobaru plant. The plants are located on three of the Japanese islands: Honshu, Kyushu, and Hokkaido. The total rated capacity is 215.1 MW including 22 MW from a dry-steam plant (Matsukawa), 88.1 from six single-flash plants (Otake, Onuma, Onikobe, Kakkonda, Suginoi Hotel, and Kirishima Kokusai Hotel), and 105 MW from two double-flash plants (Hatchobaru and Mori). Expansion of some of the existing plants is being given serious consideration. Step-out drilling is underway, for example, at Hatchobaru in preparation for the construction of another 55 MW unit. The situation is summarized in Table 6.

The newest geothermal plant in Japan is at the Kirishima Kokusai Hotel. Roughly 20% of the power requirements of this hotel are supplied by a single-flash geothermal unit having a 100 kW non-condensing turbine. The plant came on line in February 1984; the turbine-generator was built by Fuji Electric Co., Ltd. The turbine runs at 3600 rpm; steam inlet conditions are 127°C, 247 kPa (saturated) with 0.06% noncondensable gases (by volume); exhaust pressure is 117 kPa. The generator is air-cooled and rated at 125 kVA at 440 V. Hot water from the wellhead separator is piped to the hotel for use in a bathing spa. The facility is located in Kagoshima in the southern part of Kyushu within the scenic Kirishima National Park.

A 50 MW double-flash plant known as Mori was put on line in November 1982 at the Nigorikawa area in Mori-machi on the southwest part of Hokkaido. See Fig. 2. The plant is operated by the Hokkaido Electric Power Co., Ltd.; the steam field was developed by Dohnan

TABLE 5 GEOTHERMAL POWER PLANTS IN MEXICO

PLANT	YEAR	TYPE	MW	STATUS
Pathe	1959	1-Flash	3.5	De-commissioned
Cerro Prieto I:				
Unit 1-2	1973	1-Flash	2x37.5	Operational
Unit 3-4	1979	1-Flash	2x37.5	Operational
Unit 5	1981	2-Flash	30.0	Operational
Cerro Prieto II:				
Unit 1-2	1984	2-Flash	2x110	Operational
Cerro Prieto III:				
Unit 1	1985	2-Flash	110	Under construction
Unit 2	1985	2-Flash	110	Under construction
Cerro Prieto IV:				
Unit 1-2	1992	2-Flash	4x55.0	Planned
Los Azufres:				
W.H. Unit 1-2	1982	Dry Steam	2x5.0	Operational
W.H. Unit 3-5	1982	1-Flash	3x5.0	Operational
Unit 1	1986	2-Flash	50	Under construction
W.H. Unit 6-12	1987	1-Flash	7x5.0	Advanced planning
Unit 2	1988	2-Flash	55	Advanced planning
Unit 3	1989	2-Flash	55	Advanced planning
Unit 4	1990	2-Flash	55	Advanced planning
W.H. Unit 13-22	1993	1-Flash	10x5.0	Advanced planning
Los Humeros:				
W.H. Unit 1-3	1987	1-Flash	3x5.0	Under construction
Unit 1	1990	2-Flash	55	Advanced planning
Unit 2	1991	2-Flash	55	Advanced planning
		Totals:	425	Operational
			710	Operational or u.c.
			1290	Oper., u.c. or planned

TABLE 6 GEOTHERMAL POWER PLANTS IN JAPAN

PLANT	YEAR	TYPE	MW	STATUS
Matsukawa	1966	Dry Steam	22.0	Operational
Otake	1967	1-Flash	12.5	Operational
Onuma	1973	1-Flash	10.0	Operational
Onikobe	1975	1-Flash	12.5	Operational
Hatchobaru	1977	2-Flash	55.0	Operational
Kakkonda	1978	1-Flash	50.0	Operational
Otake Pilot	1978	Binary	1.0	Dismantled
Nigorikawa Pilot	1978	Binary	1.0	Dismantled
Suginoi Hotel	1981	1-Flash	3.0	Operational
Mori	1982	2-Flash	50.0	Operational
Kirishima Kokusai Hotel	1984	1-Flash	0.1	Operational
Hatchobaru II	n.a.	2-Flash	55.0	Advanced planning
Kakkonda II	n.a.	Flash	50.0	Advanced planning
Suginoi II	n.a.	1-Flash	3.0	Early planning
		Totals:	215.1	Operational
			323.1	Operational or planned

Geothermal Energy Co., Ltd., with the cooperation of Japan Metals Chemicals Co., Ltd.[3].

The site is characterized by a relatively flat basin of about $3.75\ km^2$ at 100 m above sea level surrounded by hills rising to about 250 m. Roughly 60 hot springs exist in the basin; six resort hotels use the hot water for bathing spas, and greenhouses are supplied with hot water.

Permeability was discovered in fractures extending along the caldera wall. Seventeen deep wells have been drilled: six are used for production, seven for injection, and four were unsuccessful. Two more wells (D-7 and D-8) are scheduled for drilling. The fractures associated with the caldera wall are being used as injection sites whereas production wells are drawing from fractures associated with a northeast-trending fault and through the Pre-Tertiary formation within the basin itself. See Fig. 3.

The wells are clustered in four areas, drilling sites B, C, D and F. See Fig. 4. All successful wells have been directionally drilled. Data on the successful wells are shown in Tables 7 and 8. Two-phase pipelines carry the geofluid from wells F-1 and F-9 to the separator/flasher station located at well-site D. Short two-phase pipelines run from wells D-1, D-3, D-5 and D-6 to the separators. Three vertical, bottom-outlet-cyclone separators can each produce 56 kg/s of steam; three horizontal flash vessels can generate 22 kg/s of low-pressure steam. The HP and LP steam are transmitted to the plant via separate pipelines, a distance of about 1.5 km. There are about 600 m of two-phase piping and 1700 m of hot water piping.

Owing to the high levels of noncondensable gases, mainly carbon dioxide, it is necessary to use a turbo-driven centrifugal compressor to remove the gases from the condenser. This is also the reason for the rather high condenser pressure. Furthermore, the production wells have been subject to calcite plugging at the flash horizon due to CO_2 liberation. In fact, soon after the plant started operating, the plugging was so severe as to reduce the plant output from 50 MW to 15 MW. Initially the problem was addressed by re-drilling to remove the deposits and by treatment of the wells with acid. More recently, a scale inhibitor has been successfully injected into the flowing wells below the flash horizon. The inhibitor interrupts the association of calcium and carbonate ions. Through this technique, power production has been restored to about 35 MW. Full production should be achieved with the completion of the new production wells in well-pad D.

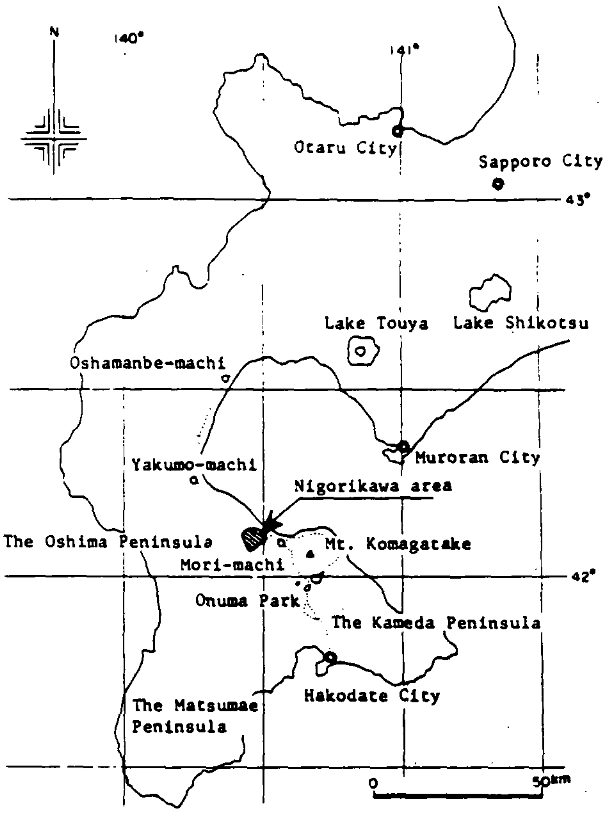

FIG.2 SW HOKKAIDO SHOWING NIGORIKAWA AREA.

Design specifications for the power plant are given in Table 9. Three site photographs are presented in Plates 1-3 [Courtesy of Dr. H. Nakamura, Japan Metals & Chemicals Co., Ltd.].

New Zealand The principal geothermal generating facility in New Zealand is at Wairakei, the site of the world's first commercial geothermal power plant using fluid from a liquid-dominated resource. Only 11 of the original 13 power units (installed from 1959-1963) are still in operation. However, the two units that have been removed from service because of the decline in reservoir pressure and the loss of high-pressure steam (Units 5 and 6) are being rehabilitated for use at the Ohaaki double-flash power plant now under construction. These two 11.2 MW back-pressure turbines will be matched with two new 56.9 MW machines to be supplied by Mitsubishi Heavy Industries, Ltd., to give the Ohaaki plant a rated capacity of 116.2 MW.

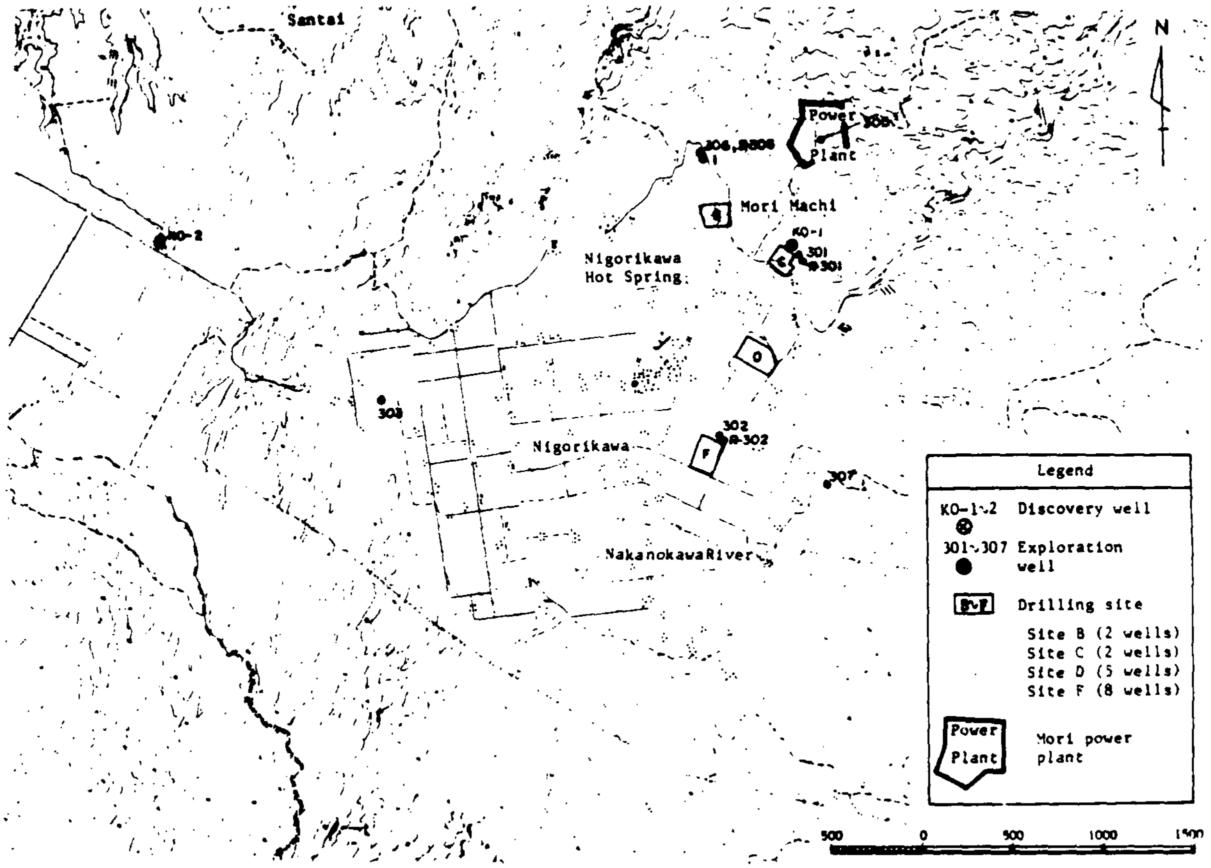

FIG.3 NIGORIKAWA AREA SHOWING SITES OF MORI POWER PLANT AND WELL PADS.

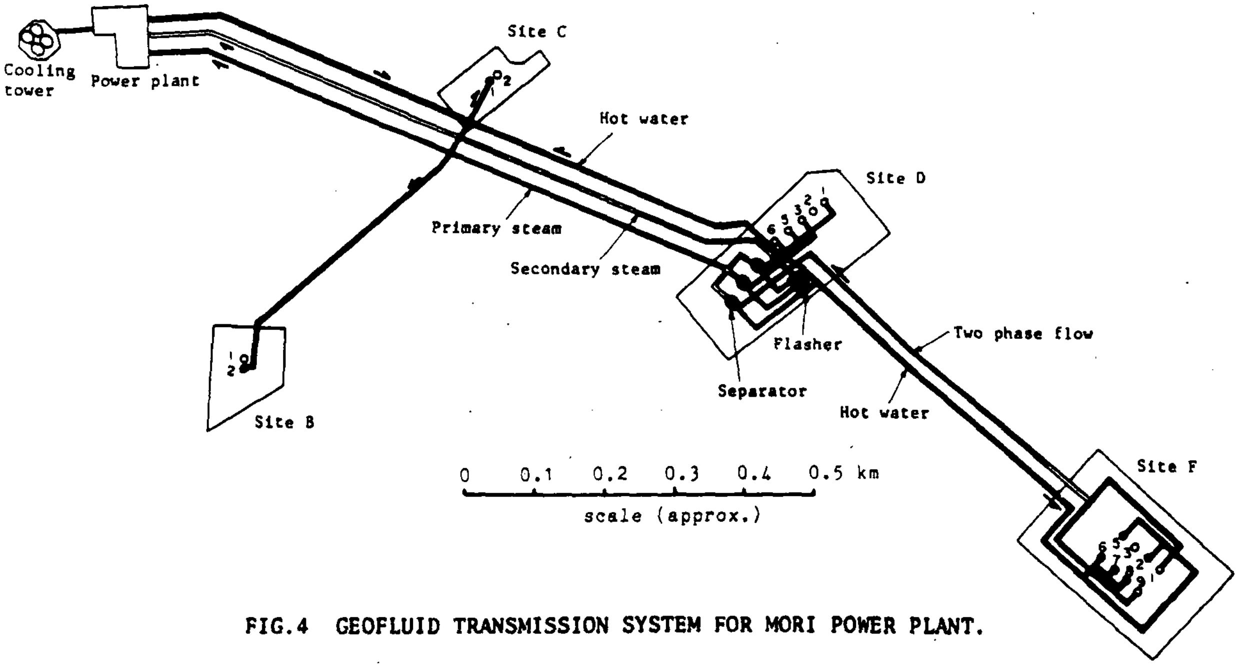

FIG.4 GEOFLUID TRANSMISSION SYSTEM FOR MORI POWER PLANT.

TABLE 7 PRODUCTION WELL DATA AT MORI, JAPAN

Well	Total depth m	Total depth m	Flow Rates, kg/s Main steam[1]	Secondary steam[2]	Residual water	NC Gases % (vol.) of steam
D-1	2400	2143.5	16.9	6.3	72.8	0.53
D-3	2320	2089.0	36.8	11.9	136.7	4.80
D-5	736	683.9	21.7	15.1	173.3	2.50
D-6	2205	2106.3	15.6	3.6	41.9	0.91
F-1	2464	2355	36.8	9.7	111.7	3.99
F-9	2340	2221.7	18.9	7.1	81.4	1.23
		Totals:	146.7	53.7	617.8	

---

[1] Pressure = 786.5 kPa; [2] Pressure = 266.7 kPa.

PLATE 1 MORI POWER PLANT.

TABLE 8 INJECTION WELL DATA AT MORI, JAPAN

Well	Total depth m	Vert. depth m	Flow rate[1] kg/s
B-2	1973	1552.5	27.1
C-1	1773	1732.9	32.2
F-2	2025	1945.8	115.0
F-5	998	975.3	118.9
F-6	2383	2229.6	102.8
F-7	1464	1359.7	102.8
F-8	1785	1708.4	54.5
		Totals:	476.9

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[1] Pressure = 639.4 kPa.

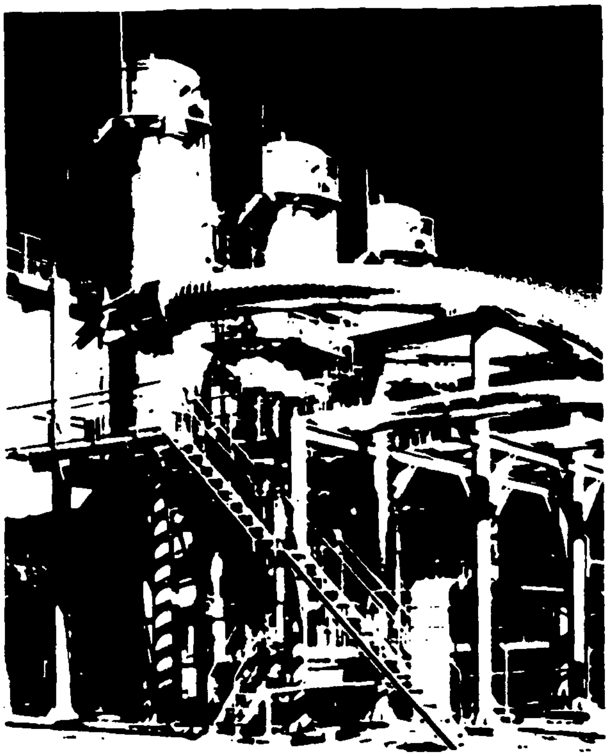

PLATE 2 CYCLONE SEPARATORS FOR MORI PLANT.

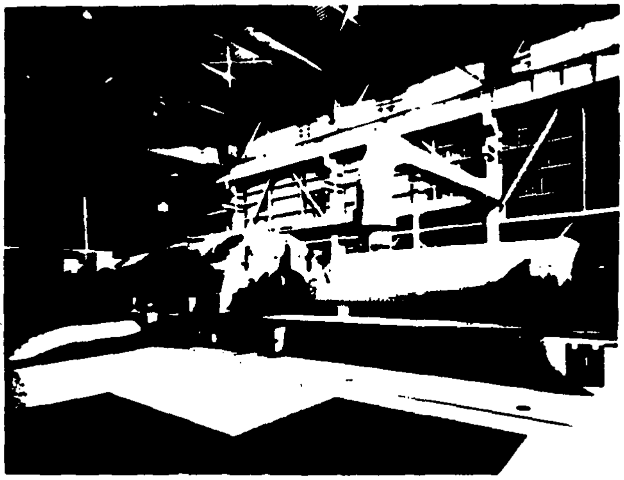

PLATE 3 TURBINE HALL FOR MORI PLANT:
(R-L) TURBOCOMPRESSOR, TURBINE,
GENERATOR, EXCITER.

TABLE 9 DESIGN SPECIFICATIONS FOR MORI POWER PLANT

Date of start-up	November 1982
Plant type	Double flash
Plant operator	Hokkaido Electric Power Co., Ltd.
No. production wells	6
No. injection wells	7
Turbine data:	
Manufacturer	Toshiba Corporation
Rated capacity	50 MW
Type	Single-cylinder, double-flow, impulse blading, 5x2
Speed	3000 rpm
Main steam pressure	686.7 kPa
Main steam temperature	164.2°C
Main steam flow rate	146.7 kg/s
Secondary steam pressure	193.6 kPa
Secondary steam temperature	119.2°C
Secondary steam flow rate	53.7 kg/s
Exhaust pressure	17.6 kPa
Last stage blade height	508 mm
Generator data:	
Capacity	55,600 kVA
Voltage	11,000 V
Frequency	50 Hz
Speed	3000 rpm
Condenser data:	
Type	Low-level, direct-contact
Pressure	17.6 kPa
Cooling water flow rate	2085 kg/s (approx.)
Cooling water inlet temperature	25°C
Gas extractor data:	
Type	Centrifugal compressor, driven by turbine shaft
Power requirement	3,100 kW
Cooling tower data:	
Type	Counterflow, mechanically induced draft, octagonal shape
Water flow rate	2640 kg/s (approx.)
Water inlet temperature	53.6°C
Water outlet temperature	25.0°C
Design wet-bulb temperature	17.0°C
No. fans	4

TABLE 10 GEOTHERMAL POWER PLANTS IN NEW ZEALAND

PLANT	YEAR	TYPE	MW	STATUS
Wairakei:				
Unit 1	1959	SCSF-IP-NC	11.2	Operational
Unit 2	1958	SCSF-HP-NC	6.5	Dismantled
Unit 3	1959	SCSF-HP-NC	6.5	Dismantled
Unit 4	1959	SCSF-IP-NC	11.2	Operational
Unit 5-6	1962	SCSF-HP-NC	2x11.2	To be installed at Ohaaki
Unit 7-8	1959	SCSF-LP-C	2x11.2	Operational
Unit 9-10	1960	SCSF-LP-C	2x11.2	Operational
Unit 11	1962	2-Flash	30.0	Operational
Unit 12-13	1963	2-Flash	2x30.0	Operational
Kawerau	1961	1-Flash	10.0	Operational
Ohaaki:				
Unit 1	1988	2-Flash	2x11.2 2x46.9	Under construction
		Totals:	167.2	Operational
			283.4	Operational or under construction

The new turbines will have the following characteristics:

- rating, 46.9 MW
- speed, 3000 rpm
- inlet steam conditions:
  - pressure, 446.8 kPa
  - temperature, 147.1°C
  - gas content, 5.6% (by weight)
  - flow rate, 94.4 kg/s
- exhaust pressure, 8.24 kPa
- last-stage blade height, 584.2 mm
- type:
  - double-flow
  - impulse-reaction
  - 5 stages per flow.

A study is being made of generating an additional 5 MW at Wairakei by using a bottoming binary cycle powered by the waste hot water that is now discharged to the Waikato River. All together 167.2 MW is now on line in New Zealand at two sites; by 1988 there should be 283.4 MW on line. See Table 10. Of the numerous geothermal areas in New Zealand, those with the brightest prospects for power development are: Mokai, Rotokawa, and Tauhara.

Nicaragua [Note: The following account is based largely on a paper entitled "Estado Actual del Proyecto Geotermico de Nicaragua" by the Instituto Nicaraguense de Energia (INE) presented at a meeting of Latin American countries and reported in "Estado Actual de la Geotermia en America Latina", Seminario Latinoamericano Exploracion Geotermia, Quito, Ecuador, Sept. 1983, OLADE/BID/INECEL; in Spanish.]

The first geothermal plant in Nicaragua, the 35 MW single-flash plant at Momotombo, began producing power in September 1983. It is located close to the shore of Lake Managua in its northwest area and on the southern flank of the Momotombo volcano. This is only one of many geothermal areas that stretch along Nicaragua's southwest zone, roughly 50 km inland from the Pacific Ocean. See Fig. 5.

A site photograph is shown in Plate 4 [Courtesy of ELC-Electroconsult, Milan, Italy].

Exploration for geothermal anomalies dates from 1966 when the Italian firm ELC-Electroconsult conducted a preliminary study. In 1969 a study by Texas Instruments resulted in a listing of ten areas with geothermal potential. The fumaroles of the south Momotombo volcano were considered the best prospect when the study was completed in 1971. A power potential of at least 35 MW was established as a result of these studies. The San Jacinto area was also deemed a good prospect for commerical development.

Following the devastating Managua earthquake of December 23, 1972, all geothermal development work was temporarily halted. In May 1974 the Nicaraguan electric authority, then called the Empresa Nacional de Luz y Fuerza (ENALUF), rehired the original consulting firm, ELC-Electroconsult, to complete the feasibility study at Momotombo. At the same time, a contract was signed with the Belgian drilling company Foramines to construct four dual-purpose wells to serve as both exploration and, if successful, production wells.

Following this phase, ENALUF began the production drilling phase by hiring

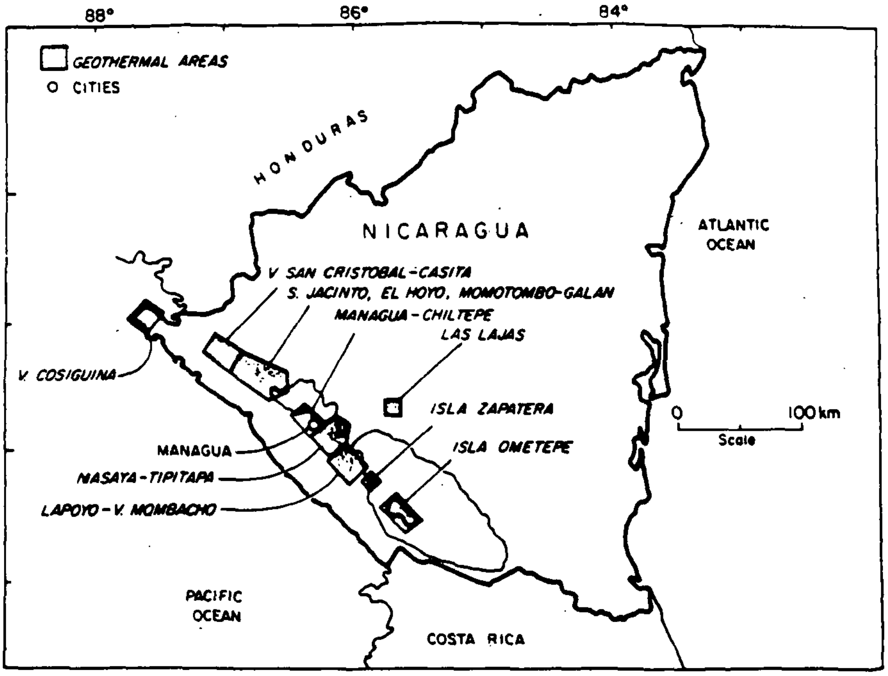

FIG.5 MAP OF NICARAGUA SHOWING GEOTHERMAL AREAS.

PLATE 4 MOMOTOMBO POWER PLANT, LOOKING S-SE TOWARD LAKE MANAGUA.

Energeticos, S. A. and the California Energy Company to drill 12 wells and to manage the drilling program, respectively. By 1978, this task was complete.

In 1980 the current electric authority, Instituto Nicaraguense de Energia (INE), secured financing for the project through the Organizacion Latinoamericana de Energia (OLADE) with the aid of a special OPEC fund. The decision was reached in 1981 to build a 35 MW plant at Momotombo.

The wells were drilled in two stages: Stage 1 from November 1974 to August 1978; Stage 2 from October 1982 to June 1983. During Stage 1, 32 wells were drilled resulting in 20 production wells and 4 injection wells. During Stage 2, three wells were completed: one producer (for the anticipated second power unit) and two injectors. Generally the wells for exploitation are constructed using the following casing schedule: 20" conductor casing from 0-20 m; 13-3/8" anchor casing from 20-250 m; 9-5/8" production casing from 150-350 m; and 7" slotted liner from 350-600 m. Table 11 contains some data on the production wells. Reservoir temperature is in the 230°C range.

TABLE 11 PRODUCTION WELL DATA AT MOMOTOMBO, NICARAGUA

Well	Wellhead elevation m, asl	Total depth m	Flow rates steam kg/s	Flow rates water kg/s	Enthalpy kJ/kg
MT-2	-	-	12	48	1100
MT-3	-	-	18	77	1100
MT-4	-	-	8	8	2700
MT-9(1)	80	616	13	57	1100
MT-10	-	-	7	7	2700
MT-12(1)	69	402	20	20	2700
MT-17	-	-	8	32	1100
MT-19	-	-	4	16	1100
MT-29(1)	85	310	32	32	2700
MT-21	-	-	6	28	1100
MT-22	-	-	11	49	1100
MT-23(1)	68	821	16	69	1100
MT-25	-	-	10	45	1100
MT-26	-	-	17	73	1100
MT-27(1)	87	442	26	114	1100
MT-31	-	-	12	98	950

(1) = supplying Unit 1.

There are two production horizons in the field, one shallow and one deeper. Most of the wells intercept the shallow zone which is much better understood than the deeper zone. It will be necessary to exploit the deeper reservoir in a carefully integrated manner with the shallow zone in order to expand the power production of the field beyond the current rating of 35 MW. The deep zone may have temperatures considerably in excess of 230°C.

The production wells are outfitted with individual bottom-outlet-cyclone separators. Steam is gathered from the wells and delivered to the plant via two main steam lines. The separated hot water is collected and distributed to the four injection wells that are located to the south and east of the main production area. See Fig. 6. Some data on the injection wells is given in Table 12.

TABLE 12 INJECTION WELL DATA AT MOMOTOMBO, NICARAGUA

Well	Wellhead elevation m, asl	Total depth m
MT-6	109	580
MT-15	66	649
MT-18	74	1124
RMT-2	63	1170

The power plant consumes a total of 77.81 kg/s of steam (main steam plus ejector steam) at 165°C, saturation conditions. The gross specific steam consumption is about 8 kg/kW·h; the [illegible] consumption is 8.5 kg/kW·h. Assuming an average wellhead dryness fraction of 26.8% and a reservoir condition of saturated liquid at 230°C, the plant would have a Second Law utilization efficiency of 55.7% (gross), or 52.2% (net). The auxiliaries require 2.2 MW of power.

Efficiencies this high are more often associated with plants of the dry-steam type such as those at The Geysers in California. Several of the wells, in fact, have been observed as tending toward dry steam. The wellhead enthalpy of 1100 kJ/kg seems to indicate a deeper parent reservoir in the temperature range 250-255°C. The shallow wells apparently intercept a two-phase aquifer from which the steam phase is produced preferentially, thus leading to higher than expected wellhead qualities; i.e., if the main reservoir consisted of saturated liquid at 230°C, one would expect wellhead enthalpies in the 990 kJ/kg range and dryness fractions of about 14%.

Table 13 lists the design specifications for the first power unit at Momotombo. Financing for a duplicate second unit has been arranged, and construction should begin soon.

<u>Indonesia</u> The ultimate geothermal power potential of Indonesia is estimated to be 10,000 MW, an impressive figure by any standards. Exploration and/or development are taking place at 18 areas in Sumatera, 29 areas in Java, 16 areas in Sulawesi, and 14 areas in Bali, Lesser Sunda Islands and Moluccas. An ambitious program is underway to get power plants on line in eight different areas by the year 1994. See Table 14.

At present, there are two wellhead units (2.25 MW, total) and one central station (30 MW) in operation. The next plants to be built

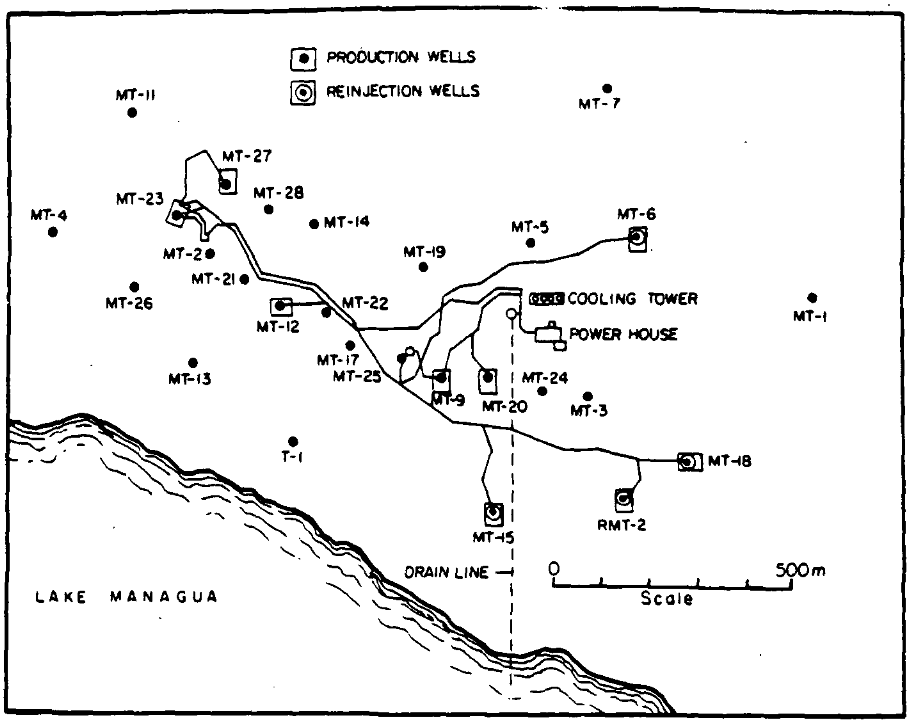

FIG.6 FIELD LAYOUT FOR MOMOTOMBO UNIT 1.

TABLE 13 DESIGN SPECIFICATIONS FOR UNIT 1 MOMOTOMBO POWER PLANT

Date of start-up	September 1983
Plant type	Single-flash
Plant owner	INE
No. production wells	5
No. injection wells	4
Turbine data:	
Manufacturer	Franco Tosi (Italy)
Rated capacity	35 MW
Maximum capacity	40.37 MW
Main steam pressure	700 kPa
Main steam temperature	165°C
Main steam flow rate	73.37 kg/s
Exhaust pressure	12.5 kPa
Condenser data:	
Type	Low-level, direct-contact
Pressure	12.5 kPa
Gas extractor data:	
Type	Steam jet ejectors
Steam consumption	4.44 kg/s
Cooling tower data:	
Type	Counterflow, mechanically induced draft
No. cells	4

TABLE 14 GEOTHERMAL POWER PLANTS IN INDONESIA

PLANT	YEAR	TYPE	MW	STATUS
Kamojang:				
Wellhead Unit	1978	Dry Steam	0.25	Operational
Unit 1	1982	Dry Steam	30.0	Operational
Unit 2	1987	Dry Steam	55	Under construction
Unit 3	1988	Dry Steam	55	Under construction
Unit 4-5	n.a.	Dry Steam	2x55	Preliminary planning
Dieng:				
Wellhead Unit	1980	1-Flash	2.0	Operational
Unit 1	1988-89	Flash	55	Advanced planning
Unit 2	1989-90	Flash	55	Advanced planning
Darajat:				
Unit 1	1991	Flash	55	Planned
Unit 2	1992	Flash	55	Planned
Salak:				
Unit 1	1988-89	Flash	55	Advanced Planning
Unit 2	1989-90	Flash	55	Advanced planning
Unit 3	1992	Flash	55	Planned
Unit 4	1993	Flash	55	Planned
Lahendong:				
Unit 1-2	1992-93	Flash	2x15	Planned
Cisolok:				
Unit 1	1993	Flash	55	Planned
Unit 2	1994	Flash	55	Planned
Banten:				
Unit 1	1993	Flash	55	Planned
Unit 2	1994	Flash	55	Planned
Bedugal:				
Unit 1	1990-91	Flash	55	Planned
		Totals:	32.25	Operational
			142.25	Operational or u.c.
			997.25	Operational, u.c. or planned

will be Units 2 and 3 at Kamojang (2 x 55 MW) and are scheduled to begin operation in the middle of 1987 and early 1988, respectively. Power plants are scheduled for the following areas by 1994: Dieng (112 MW by 1990), Darajat (110 MW by 1992), Salak (220 MW by 1993), Lahendong (30 MW by 1993), Cisolok (110 MW by 1994), Banten (110 MW by 1994), and Bedugal 55 MW by 1994). The reservoir at Kamojang produces dry steam; the others are liquid-dominated.

Acknowledgements The author is happy to acknowledge the help of a large number of people in compiling this report:

Ken Boren, GeoProducts, Inc.
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Hezy Ram, Ormat Systems
Margaret Rands, Imperial County Public Works Dept.
Tom Seesee, Ralph M. Parsons
Russ Tenney, Magma Power Company
Bill Teplow, Trans-Pacific Geothermal, Inc.
Jack Wood, Wood & Associates

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3/12/85

SALTON SEA SCIENTIFIC DRILLING PROJECT

PROJECT STATUS

- DELIVERABLES TO DATE
    - RESOURCE DEFINITION; PROGRAM PLAN, SCHEDULE AND COSTS
    - DEEP WELL AND INJECTION WELL; DESIGNS, SPECIFICATIONS, COSTS
    - SURFACE FACILITIES; PLANS AND FLOW SHEET FOR TREATMENT OF BRINES, COSTS (Bechtel Product)
    - KENNECOTT TECHNICAL DATA (Publishable w/ their credit line)
    - QA/QC PROGRAM PLAN (In ESQUA Div of DOE/SAN)
    - NUMEROUS PERMITS, LICENSES, AUTHORIZATIONS AND APPROVALS
    - REFINED, DETAILED, SUBSTANTIATED COSTS
- SITE PREPARATION ON HOLD
- LONG LEAD-TIME PURCHASING ON HOLD csg; well head, etc. (2-3 mos)

* Are going to need a Comprehensive flow chart (milestones).
Bechtel has, on computer

SALTON SEA SCIENTIFIC DRILLING PROJECT

BACKGROUND

- CONGRESS AUTHORIZED DOE $5.3 MILLION IN FY84 TO INVESTIGATE SALTON SEA THERMAL REGIME
- DOE INTERPRETED AUTHORIZATION TO MEAN A GEOTHERMAL RESOURCE DEFINITION PROGRAM IS REQUIRED
- GHTD DIRECTED SAN TO INCLUDE A RESOURCE DEFINITION PROGRAM IN RFP AND CONTRACT NEGOTIATIONS
- THIS GEOTHERMAL PROGRAM, INDEPENDENT OF SCIENCE EFFORT, WAS ANNOUNCED PUBLICLY BY GHTD AT OGLE MEETING, EL CENTRO MEETING
- DURING LAST SIX MONTHS, THIS POLICY HAS BEEN ADHERED TO BY SAN AS PER HEADQUARTERS INSTRUCTIONS, AND BY ITS CONTRACTOR, BECHTEL, AS PER THE SCOPE OF WORK
- SCIENTISTS RESPONSIBLE FOR ACQUIRING FUNDS FOR THEIR WORK, OUTSIDE THE $5.3 MILLION

SALTON SEA SCIENTIFIC DRILLING PROJECT

SAN POSITION/ROLE

- SAN OFFICE HAS HIGH DEGREE OF COMPETENCE IN MANAGING MAJOR CONTRACTS IN THE MILLIONS OF DOLLARS RANGE
- THE SAN CONTRACTS OFFICE AND PROGRAM OFFICE HAVE STAFF EXPERIENCED IN HANDLING LARGE GEOTHERMAL PROJECTS
- THE SAN PROGRAM OFFICE HAVE APPLIED STAFF TO THIS PROJECT WHO HAVE YEARS OF PERTINENT EXPERIENCE IN ENGINEERING, GEOSCIENCES, AND BUSINESS MANAGEMENT, IN GOVERNMENT/INDUSTRY
- SAN WANTS TO CARRY OUT DIRECTION OF HEADQUARTERS AND ARE HERE TO SEEK DECISIONS
- THE PROJECT IS AT AN IMPORTANT CROSSROAD. POLICY ACTIONS ARE NECESSARY

SALTON SEA SCIENTIFIC DRILLING PROJECT

PROJECT SUMMARY

o	PRIME CONTRACTOR - BECHTEL; GENERAL PROJECT MANAGEMENT	$5.3M
o	SUBCONTRACTOR - GEOTHERMEX; RESOURCE DEFINITION, Can back out @ cost to date	$368K To date?
o	SUBCONTRACTOR - BERKELEY GROUP; WELL DESIGN,	$ 40K±
o	CONSULTANT TO DOE - WELL PRODUCTION TESTING, DRILLING,	$300K MAX.
O	PROJECT COSTS TO MARCH 1;	$706K EST.

SALTON SEA SCIENTIFIC DRILLING PROJECT

ESTIMATED BASE LINE COSTS*

1)	DEEP WELL (INCLUDES LOGGING)	$4,132,909	4.1
2)	INJECTION WELL	1,277,835	1.3
3)	SURFACE FACILITIES	1,542,438	1.5
	SITE SUPPORT	48,863	
	ENVIRONMENTAL (INCLUDES ABANDONMENT)	665,238	
	SITE OPERATIONS/MAINTENANCE	727,222	
4)	RESOURCE EVALUATION	414,010	.4
	QUALITY ASSURANCE/SCIENCE LIAISON	97,759	
	PROJECT MANAGEMENT (BECHTEL HEADQUARTERS) spread this out?	576,520	
		$9,482,794	

* THIS IS BECHTEL COMPANY CONFIDENTIAL INFORMATION AND IS RESTRICTED TO USE BY PERSONS WITHIN DOE WITH AN ABSOLUTE NEED TO KNOW. IT IS NOT TO BE DIVULGED TO DOE GOCO'S, CONTRACTORS, AND OUTSIDE SOURCES, AS PER BECHTEL'S INSTRUCTIONS

* Refined -- no suprise

* These costs are in renegotiation now.
Bechtel doesn't want to be handled.

* 1-4 rounded to nearest $100K?

SALTON SEA SCIENTIFIC DRILLING PROJECT

BASIC SCOPE OF WORK

EXPLORE DEEP GEOTHERMAL RESOURCE OBTAIN GEOHYDROLOGICAL DATA
PROVIDE FOR SCIENTIFIC EXPERIMENTS

SALTON SEA SCIENTIFIC DRILLING PROJECT

PARTICIPANTS

PRIME CONTRACTOR

BECHTEL INTERNATIONAL, INC.

SUBCONTRACTOR

BGI

WELL DESIGN PROGRAM

GEOTHERMEX

DATA ANALYSIS AND RESOURCE EVALUATION PROGRAM

OTHERS

KENNECOTT

LEASE HOLDER
EXPLORATION AND PROSPECTIVE PERMITS
PROVIDED DATA ON SHALLOW CORE HOLES

INDUSTRIAL ADVISORY COMMITTEE

REVIEW WELL DESIGN AND DRILLING ACTIVITIES

DOE/SAN CONSULTANT

REVIEW WELL DESIGN ON-SITE DRILLING ADVICE

Jim Robison WRD/Denver on Core.

SALTON SEA SCIENTIFIC DRILLING PROJECT

MAJOR COMPONENTS

DEEP WELL $4,132,909 *

↖ includes liner

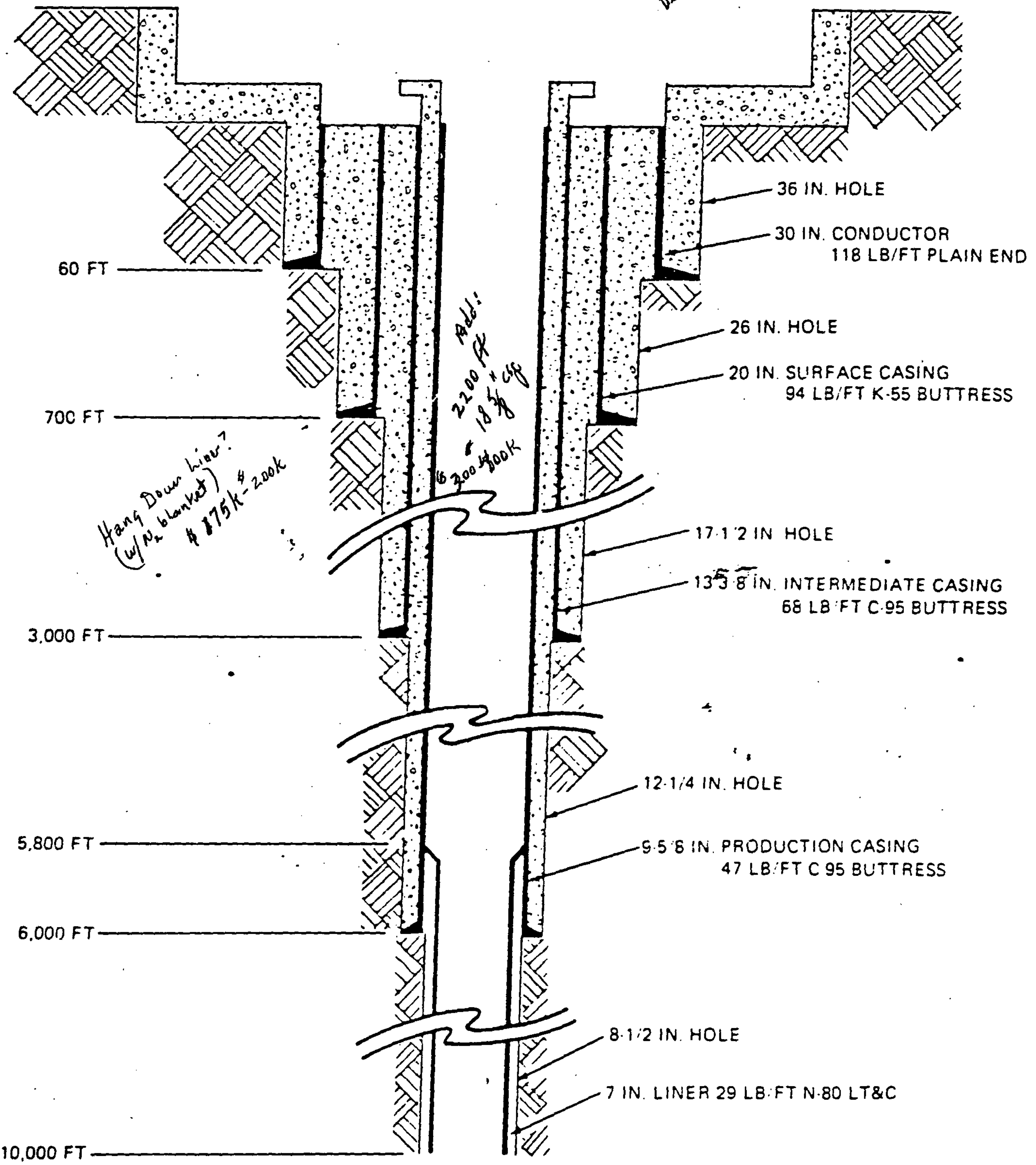
DOG requires liner pulling before Abdn!

- DEPTH 10,000 FEET
- BOTTOM HOLD DIAMETER 8 1/2-INCHES - uncased (w/o 7" liner)
- ESTIMATED DRILLING TIME 195 DAYS

INCLUDES 15 DAYS FOR SCIENTIFIC EXPERIMENTS
INCLUDES 25 DAYS FOR POTENTIAL FISHING OEPRATIONS
INCLUDES PROVISION FOR LOSS CIRCULATION
INCLUDES ACQUISITION OF CUTTING AND MUD SAMPLES
INCLUDES A~~CQUISITION~~TTEMPT OF 1,500 FEET OF CORE
INCLUDES ACQUISITION OF PRODUCTION AND GEOPHYSICAL LOGS $250k
out (in site ops) X INCLUDES 30 DAY FLOW TEST AND FOR FLUID ANALYSIS AT TOTAL DEPTH
DOES NOT INCLUDE MAJOR REDRILLING COSTS
DOES NOT INCLUDE INTERMEDIATE FLOW TESTS

*THIS IS BECHTEL COMPANY CONFIDENTIAL INFORMATION AND IS RESTRICTED TO USE BY PERSONS WITHIN DOE WITH AN ABSOLUTE NEED TO KNOW. IT IS NOT TO BE DIVULED TO DOE GOCO'S, CONTRACTOR'S, AND OUTSIDE SOURCES, AS PER BECHTEL'S INSTRUCTIONS.

Nicholson approach
Moly-glass plug
w/o Hang-down liner



Add!
2200 ft
18 5/8 csg
$ 300 400K

Hang Down liner?
(w/N2 blanket)
$175K - $200K

Figure 1-2 PRELIMINARY CASING DESIGN FOR THE DEEP WELL

SALTON SEA SCIENTIFIC DRILLING PROJECT

MAJOR COMPONENTS

INJECTION WELL 1,277,835*

- DEPTH 4,000 FEET
- BOTTOM HOLE DIAMETER 8 1/2-INCH
- DRILLING TIME ESTIMATED AT 41 DAYS

INCLUDES 6 days DAYS FOR FISHING
INCLUDES PROVISION FOR LOSS CIRCULATION
INCLUDES ACQUISITION OF CUTTINGS AND MUD SAMPLES
INCLUDES ACQUISITION OF PRODUCTION AND GEOPHYSICAL LOGS
INCLUDES FLOW TEST FOR CLEANUP
DOES NOT INCLUDE MAJOR REDRILLING COSTS

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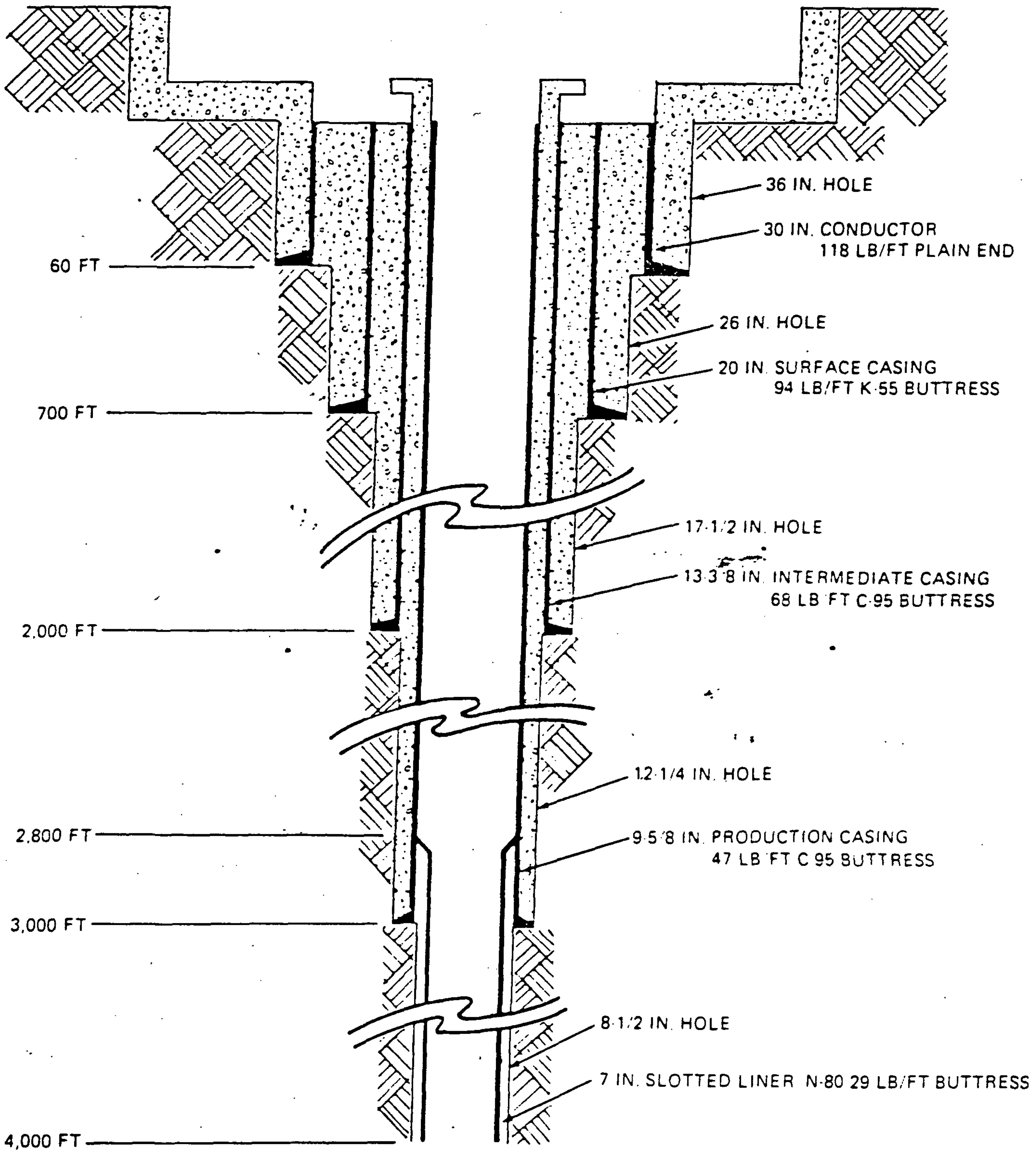

Figure 1-4 PRELIMINARY CASING DESIGN FOR THE INJECTION WELL

SALTON SEA SCIENTIFIC DRILLING PROJECT

MAJOR COMPONENTS

<u>SURFACE FACILITIES</u> $1,542,438*

PROVIDES THE NECESSARY SEPARATORS, TANKS, FILTERS, SILENCER AND OTHER EQUIPMENT AND PIPING TO MEASURE PRODUCED FLUID PROPERTIES AND VOLUMES AND TO STABLIZE SPENT FLUIDS FOR INJECTION

*THIS IS BECHTEL COMPANY CONFIDENTIAL INFORMATION AND IS RESTRICTED TO USE BY PERSONS WITHIN DOE WITH AN ABSOLUTE NEED TO KNOW. IT IS NOT TO BE DIVULGED TO DOE GOCO'S, CONTRACTORS, AND OUTSIDE SOURCES, AS PER BECHTEL'S INSTRUCTIONS

CA Reg qW Bd demanded smaller pond size.

short fluid prod. time = less pristine samples

SALTON SEA SCIENTIFIC DRILLING PROJECT

MAJOR COMPONENTS

ENVIRONMENTAL $665,238*

PROVIDES FOR SERVICES ASSOCIATED WITH ENVIRONMENTAL COMPLIANCE AND FOR PLUG AND ABANDONMENT COSTS ASSOCIATED WITH DEEP WELL INJECTION WELL AND SITE DECONTAMINATION

*THIS IS BECHTEL COMPANY CONFIDENTIAL INFORMATION AND IS RESTRICTED TO USE BY PERSONS WITHIN DOE WITH AN ABSOLUTE NEED TO KNOW. IT IS NOT TO BE DIVULGED TO DOE GOCO'S, CONTRACTORS, AND OUTSIDE SOURCES, AS PER BECHTEL'S INSTRUCTIONS

Monitor H_2S release
" subsidence

SALTON SEA SCIENTIFIC DRILLING PROJECT

SITE OPERATION AND MAINTENANCE $727,222*

COST ASSOCIATED WITH PROVIDING UTILITIES, HOUSING AND SITE SECURITY INCLUDING DECOMMISSIONING COSTS

*THIS IS BECHTEL COMPANY CONFIDENTIAL INFORMATION AND IS RESTRICTED TO USE BY PERSONS WITHIN DOE WITH AN ABSOLUTE NEED TO KNOW. IT IS NOT TO BE DIVULGED TO DOE GOCO'S, CONTRACTORS, AND OUTSIDE SOURCES, AS PER BECHTEL'S INSTRUCTIONS

SALTON SEA SCIENTIFIC DRILLING PROJECT

MAJOR COMPONENTS

- DATA ANALYSIS AND RESOURCE EVALUATION $414,010*
    - CORE ANALYSIS
    - PRODUCED FLUID ANALYSIS
    - PRODUCTION LOGS AND ANALYSIS
    - GEOPHYSICAL LOGS AND ANALYSIS

*THIS IS BECHTEL COMPANY CONFIDENTIAL INFORMATION AND IS RESTRICTED TO USE BY PERSONS WITHIN DOE WITH AN ABSOLUTE NEED TO KNOW. IT IS NOT TO BE DIVULGED TO DOE GOCO'S, CONTRACTORS, AND OUTSIDE SOURCES, AS PER BECHTEL'S INSTRUCTIONS

$368K GEOTHERMEX *

SALTON SEA SCIENTIFIC DRILLING PROJECT

INVOLVED REGULATORY AGENCIES

1. CALIFORNIA STATE DEPARTMENT OF OIL AND GAS
    - WELL DESIGN MUST PASS DEPARTMENT REVIEW
2. CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
    - LIMITS SIZE AND VOLUME OF PONDS OR SUMPS
    - DETERMINE PERMITS AND REQUIREMENTS ARE MET
3. IMPERIAL COUNTY AIR RESOURCES BOARD
    - ENVIRONMENTAL REGULATIONS
4. IMPERIAL COUNTY PLANNING DEPARTMENT
    - PERMITS
5. IMPERIAL COUNTY PUBLIC WORKS DEPARTMENT
    - PERMITS
6. CALIFORNIA DEPARTMENT OF FISH AND GAME
7. STATE LANDS COMMISSION
8. CALIFORNIA OSHA : Limits # of people on Drill Rig

SALTON SEA SCIENTIFIC DRILLING PROJECT

POLICY ISSUES

- COSTS - HOW TO CARRY OUT MANDATE OF CONGRESS RECOGNIZING PROJECTED COSTS ARE IN EXCESS OF THE $5.3 MILLION
- SCIENCE PROGRAM - HOW DO WE GET AN AUTHORIZED SCIENCE PROGRAM, PLAN, SCHEDULE AND LOGISTICS TO ASSURE ADEQUATE SUPPORT BY SAN

SALTON SEA SCIENTIFIC DRILLING PROJECT

PROJECT ISSUES

- WELL FLOW TESTS - WHAT CONSTITUENTS AN ACCEPTABLE EVALUATION TO: STATE LANDS COMMISSION; KENNECOTT; BECHTEL; IMPACT ON PROJECT : Now down to matter of hours.

- HEALTH/SAFETY - CONTROL OF ON-SITE PERSONNEL. A MATTER OF LIABILITIES. CALIFORNIA OSHA, SAN/ESQA REQUIREMENTS

- ENVIRONMENTAL RISKS - SENSITIVITY OF AREA TO CONTAMINATION. CALIFORNIA FISH AND GAME CONCERNS; CARE NECESSARY

- CORE, CUTTINGS, FLUID SAMPLES. QUANTITIES NEEDED, MANAGEMENT OF SAMPLES, ACQUISITION OF REPRESENTATIVE SPLITS BY SAN CONTRACTOR. AN APPARENT PROBLEM AREA

- DIRECTION OF DRILLING - CONTRACTORS POSITION CANNOT BE COMPROMISED; DRILLER TAKES ORDERS FROM BECHTEL; DOE CONSULTANT PROVIDES ADVICE, RECOMMENDATIONS OF SCIENTISTS WILL BE CONSIDERED

SALTON SEA SCIENTIFIC DRILLING PROJECT

NEXT STEPS

- RENEGOTIATE BECHTEL CONTRACT - DOE/SAN fact!
- CONTINUE TO SEEK ADDITIONAL FUNDS - [DOE HEADQUARTERS] DOE/SAN work this. ok
- REVIEW BECHTEL REPORTS ON WELL DESIGN AND GEOTHERMAL EVALUATION - SUBMIT FORMAL REPORT OF FINDINGS - SEC/SCC/ESC
- FORMULATION OF SCIENTIFIC PROGRAM, AWARD OF GRANTS TO PROPOSERS - DOE/OBES, NSF, USGS
- BEGIN INTEGRATE~~ION OF~~ SCIENCE PROGRAM AND ~~INTO~~ DRILLING AND ENGINEERING PROGRAM [- SAN]

SALTON SEA SCIENTIFIC DRILLING PROJECT

ALTERNATIVES

- ALTERNATIVE NUMBER ~~1~~ 4.

  LOOK FOR ANOTHER SITE WITH OR WITHOUT EXISTING WELL

- ALTERNATIVE NUMBER ~~2~~ 1

  CONDUCT FULL GEOTHERMAL/SCIENTIFIC PROGRAM AT KENNECOTT SITE

- ALTERNATIVE NUMBER ~~3~~ 2

  CONDUCT SCIENTIFIC PROGRAM ONLY AT KENNECOTT SITE

- ALTERNATIVE NUMBER ~~4~~ 3

  SCIENTIFIC DEEP HOLE PLUS OPTIONS AT KENNECOTT SITE

SALTON SEA SCIENTIFIC DRILLING PROJECT

ALTERNATIVES

ALTERNATIVE NUMBER 1

o LOOK FOR ANOTHER SITE WITH OR WITHOUT EXISTING WELL

  * CANCEL BECHTEL CONTRACT
  * ISSUE RFP
  * NEGOTIATE CONTRACT
  * CARRY OUT SCOPE OF WORK WITHIN BALANCE OF DOLLARS
  * RECOGNIZE UNKNOWNS IN SITE ACQUISITION

SALTON SEA SCIENTIFIC DRILLING PROJECT

ALTERNATIVES

ALTERNATIVE NUMBER 2

CONDUCT FULL GEOTHERMAL/SCIENTIFIC PROGRAM AT KENNECOTT SITE

- ALL OBJECTIVES OF AUTHORIZED PROJECT ARE MET
- ALL PERMITS, LICENSES, APPROVALS, WAIVERS VIRTUALLY IN HAND
- BUT SIGNIFICANT ADDITIONAL FUNDS NEEDED

SALTON SEA SCIENTIFIC DRILLING PROJECT

ALTERNATIVES

ALTERNATIVE NUMBER 3

- CONDUCT SCIENTIFIC PROGRAM ONLY AT KENNECOTT SITE
  - PROBABLY CAN BE DONE WITHIN EXISTING FUND LEVEL
  - WILL MEET MOST OF SCIENTIFIC OBJECTIVES
  - WILL [NOT] MEET ~~FEWER~~ SOME GEOTHERMAL OBJECTIVES [CONGRESSIONAL AUTHORIZATION]
  - [COULD] VOIDS EXISTING EXPLORATORY PERMIT, ADDITIONAL PERMITTING REQ
  - MINIMAL SCHEDULE IMPACT
  - [POSSIBLE] PROBABLE KENNECOTT OBJECTIONS

"Cleanest"

SALTON SEA SCIENTIFIC DRILLING PROJEC

ALTERNATIVES

ALTERNATIVE NUMBER 4

o SCIENTIFIC DEEP HOLE PLUS OPTIONS
  - ENHANCES SCIENTIFIC PROGRAM
  - MAY ALLOW MEETING SOME OR ALL GEOTHERMAL EVALUATION PROGRAM AT LATER DATE
  - ALLOWS TIME TO SEEK ADDITIONAL FUNDING WITHOUT TERMINATING EXISTING CONTRACT
  - MINIMAL SCHEDULE IMPACT
  - ALLOWS POTENTIAL INDUSTRIAL PARTICIPATION
  - WILL REQUIRE MORE MANPOWER -- EXTENSION OF PROGRAM
  - COULD VOIDS EXISTING EXPLORATORY PERMIT
  - SURFACE FACILITIES AND INJECTION WELL ~~W~~COULD BE CONSTRUCTED LATER
  - MEETS ALL OF SEC'S REQUIREMENTS

Scientific Community's

SALTON SEA SCIENTIFIC DRILLING PROJECT

DOE/SAN RECOMMENDATION

- PROCEED WITH SCIENTIFIC DEEP HOLE PLUS OPTIONS

official use only
internal DOE

Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

January 24, 1985

Bechtel, Inc.
Fifty Beale Street
San Francisco, CA 94119

Attn: Neil Harlan, Contracting Officer

SUBJECT: DOE/Bechtel Contract No. DE-AC03-84SF12212 - "Geothermal Deep Drilling Project in the Salton Sea Geothermal Area"

Dear Mr. Harlan:

The report to John Crawford, FGS/SAN, dated January 21, 1985 by Tom Lindemuth indicating the probable cost overrun on Subject Contract estimated to be at $7,793,000 to complete or up to $9.4M as an outside "approximate cost" is being evaluated by DOE contract Management and DOE Program Management.

As per telephone discussions with Jane Hadly, there is presently a projected cost estimate exceeding the total contract amount. Contract overrun estimates on this project have fluctuated from $1.5M to $4.5M.

The scheduled meeting for Thursday, January 24, 1985 will discuss the projected cost estimates; the break down of those costs; the deliverables and quality of the work as presently addressed in the subject contract; and the critical path schedule of the project as proposed by Bechtel's Program Manager, Tom Lindemuth. It is necessary to arrive at a mutually agreed "stop-work" point to give DOE/SAN and DOE Headquarters time to evaluate the funding requirements of the project.

DOE Program Managers, John Crawford and Harold Lechtenberg, believe it prudent to continue with the project direction as outlined by Tom Lindemuth. Further evaluation in regards to the Subcontracts awards and preparation of the site will continue by DOE.

official use only
Internal DOE

At this time, DOE/SAN anticipates work to continue on the site preparation. This includes field operations necessary to prepare the site location to the point that the site would be acceptable for the drilling rig, but not to include costs or subcontracts associated with the site security or drilling.

Until further review is made by DOE, the project direction and costs pertinent to such direction, the present "Limitation of Cost" and the Statement of Work within the Contract remain in effect.

Please contact Jane Hadly, Contract Specialist at 415/273-4182, if you have questions or require additional information.

Sincerely,

Aundra Richards

Aundra Richards
Contracting Officer
Contracts Management Division

cc: Jane Hadly, CM/SAN
John Crawford, FGS/SAN
Harold Lechtenberg, FGS/SAN

ROUGH DRAFT

FIELD PROCEDURES MANUAL

SAMPLE HANDLING
SALTON SEA SCIENTIFIC DRILLING PROJECT

Sue Goff, Los Alamos National Laboratory
Jim Mehegen, University of California, Riverside
Don Michels, Consultant

This Field Procedures manual is the comprehensive operations guide that was used to curate samples obtained from the Salton Sea Scientific Drilling Project (SSSDP). Samples recovered from the SSSDP are being curated following the Policy Guidelines (Goff, 1986) established for the Department of Energy/Office of Basic Energy Sciences (DOE/OBES) Continental Scientific Drilling Program (CSDP)/Thermal Regimes effort, which recognizes the uniqueness and site specific nature of each drilling project. The SSSDP is a rotary drilling project that has provided cuttings and spot cores as well as liquid and gas samples. This manual provides details on handling of all these sample types.

All personnel handling samples at the drill site were familiar with DOE/CSDP curation procedures and the details of this field manual and worked under the direction of the Chief Scientist for the project (Wilf Elders) or his representatives (Jim Mehegen, Don Michels), in conjunction with the On-Site Science Manager (John Sass) or his representatives.

On site it was the responsibility of the Chief Scientist in communication with the Curatorial Office Manager (Sue Goff) to assure that all curatorial policy and sample handling procedures were followed.

The sample handling procedures detailed in this manual were modified from procedures worked out for DOE/OBES drill sites in the Valles Caldera and Inyo Domes (Goff, 1986), and procedures developed by the International Crustal Research Drilling Group (Robinson and Schmincke, 1978; IRDP, 1979).

I. SUMMARY OF DUTIES

The on-site curation staff will be made up of a University of California-Riverside (UCR) crew, assisted when necessary by an On-Site Science Manager's staffer. The primary responsibility of the UCR crew is to provide well-site coverage in support of coring, cuttings collection, and liquid and gas sampling. A UCR crew member must be on location for all activities that are related to these operations. Other testing and drill hole operations may have to be supported on "as needed" basis.

II. DAILY ACTIVITY LOG[1]

A daily well-site activity log will be kept on site as a narrative record of curation activities. It is essential that all entries in the log be clear and precise (and preferably in ink). The log will be the primary record of well site activity during the curation crew members shift. It will be the means by which the following curation crew member will become acquainted with the activities of the previous shift. The initial entry should document the shift change. Some items which should be recorded are:

A. Rig shut-downs; record the time, reason and depth. Enter the time when drilling resumes (with the date when applicable).

B. Borehole fluid circulation records.

C. Changes in the drilling plan or the well-site procedures; documenting the time, date, reasons, and name of the person making the change recorded.

D. Any information that the curation crew member feels may affect the completion of the drill hole or the data from and related to the drill hole.

E. Data obtained or sought; time, type, individual, organization, success, or samples.

F. Interruptions in progress; time, cause, etc.

G. Rig-ups of service company equipment; type, objective, rig-downs, and success.

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[1] For the SSSDP a Daily Activity Log was the responsibility of John Sass (USGS), Bechtel (Site Manager), and the Drilling Supervisor.

III. COMMUNICATIONS PROCEDURES[2]

A. It is the responsibility of the curation staffer going off shift to make the curation staffer coming on shift aware of any changes in procedure or drilling plan and to relay any special instructions.

B. A brief description of what occurred during the previous shift should be communicated to the curation staffer coming on shift.

C. All changes in well-site procedures, core handling or sampling criteria, or approved revisions in drilling criteria should be communicated orally, recorded in the daily log, and posted in a secure place (bulletin board).

D. If possible, the curation staffer on duty should contact the curation staffer going out to the well site if any supplies are needed. The curation staffer on duty should attempt to inform the curation staffer preparing to come on shift if, for some reason, he is not required on site.

E. The curation staffer on shift will participate in the daily on-site staff meetings.

IV. SAMPLE RECORDS

On-site logs will be kept of sampling operations. A separate form will be used for each sample type: core, cuttings, water, etc. (Figs. 1, 2, 3). Forms will be self-explanatory and include all pertinent information with emphasis being placed on data that will be lost if it is not recorded at the time of sampling. These logs should be factual accounts and questionable entries should be noted as such. Information should include:

A. Sequence number. For core, this is the run number.

B. Sample number assigned by collector.

C. Depth - the location from which the sample is obtained. In some instances, such as core, this will be an interval. For surface fluid samples, the bottom hole depth at the time of sampling.

D. Recovery - this can mean a percent for core or some quantitative number for other sample types.

E. Sample description (lithology) - a brief description only to be used as an on-site reference.

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[2] Done in accordance with the On-Site Science Manager (USGS).

Figure 1

CORE LOG

Hole SSSDP#1

Date ________________

Curation Crew Member(s) ______________________________

Run #/Box #	Depth Interval (ft)	Core Measurement (ft)	Amount Drilled (ft)	Amount/ Recovered (%)	Interval Wrapped/ Piece #	Lithology	Sample Splits		Comments
							Interval (ft)	Requestor/ Organization	

Figure 2

Page ___ of ___

BIT CUTTINGS LOG

Hole SSSDP#1 Curation Crew Member(s)____________________ Date(s)____________

Depth or Depth Interval	Amount Recovered (no. of cups and/or bags collected)	Sample Splits Amount, Requestor, Org	Lithology	Comments

Figure 3

FLUIDS LOG

Investigator	Organization	Date	Type of Sample	Volume of Sample	Conditions of Sampling (includes depth)	Preservative	Purpose of Sampling

(Note: No such record as this was made during the flow test of December 28-30. Log will be filled in "after the fact."

F. Sample splits - if the sample is to be split at the site, it should be documented as to the type and the amount of the split, why it is being taken, where it is going and the requestor's name. (Note: No sample splits will be taken at the Salton Sea drill site.)

G. Comments - record anything, from sample handling and operational activities to weather conditions, that may affect the quality of the data. Include core box number here.

Note: All field measurements are to conform to driller's format. In most cases this will mean taking measurements in tenths of feet.

V. CORE HANDLING PROCEDURES - RIG FLOOR

The Drilling Supervisor (Bechtel National, Inc.), the Core Engineer (Norton-Christens~~o~~en), the On-Site Science Manager (USGS), and the UCR curation crew will be present on the rig floor when core barrels are removed from the well. It will be the responsibility of the On-Site Science Manager and staff to supervise the unloading of core barrels into metal trays provided by the Core Engineer.

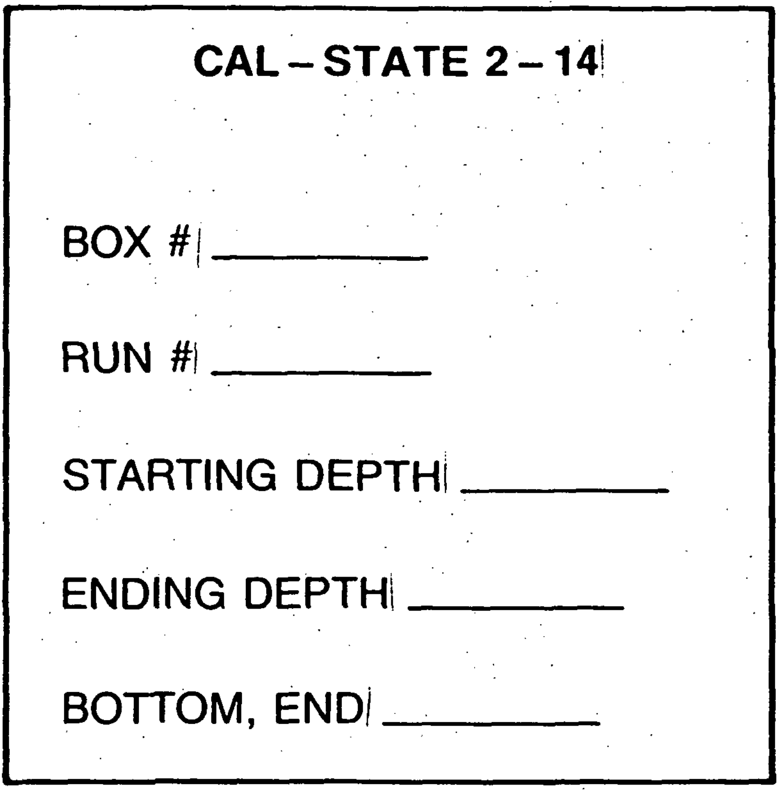
They will be sure that:

- The metal trays are crimped at the downhole end.
- All pieces of core are in the proper sequence.
- All pieces of core are oriented correctly.

The metal trays will be placed in core boxes prepared and sequentially numbered by the UC Riverside On-Site Curation Crew and provided by the Curation Office (Los Alamos). Once the core has been boxed it will be lifted to the Curation Ramada (by the Cleveland Drilling Company rig crew) and become the responsibility of the UC-Riverside Curation Crew.

VI. CURATION HANDLING PROCEDURES - CURATION RAMADA

One end of the core box will be labeled giving the hole designation (Cal-State 2-14), Box #, Run #, and the beginning and ending footages of that particular core box (Fig. 4). If the core needs to be washed this will now be done, unless this is counter-indicated either by a request or by the core being too friable. After the core is washed, it will be pieced back together and properly oriented. Core is then measured in the box to determine percent of recovery. If recovery is less than 100% the unrecovered intervals will always be assumed to be at the bottom. When measuring an individual piece of



CAL – STATE 2 – 14

BOX # ________

RUN # ________

STARTING DEPTH ________

ENDING DEPTH ________

BOTTOM, END ________

Figure 4. Core box label.

core, make the measurement from the center of the ends of that piece of core. This will result i~~s~~n an average length for the core and will eliminate ~~any~~ errors due to angularity of the ends of the core pieces.

The core will now be ready for marking. A continuous line will be drawn the length of the core with a straight edge. Depth will be marked at every foot; hatch marks every tenth of a foot will be marked to the right of the continuous line. Where individual core pieces do not match up, a small closed box will be drawn on each core piece on the continuous line (Fig. 5). The individual pieces of core will then be marked with an uphole arrow, the box number and piece number. The piece numbers should begin with "1" as the first (top) piece and run sequentially to the last (bottom) piece in each box. A photograph of each core box will then be taken.

Core boxes will then be ready to be transported to the UC Riverside Curation Laboratory for detailed descriptions, videotaping, and subsampling.

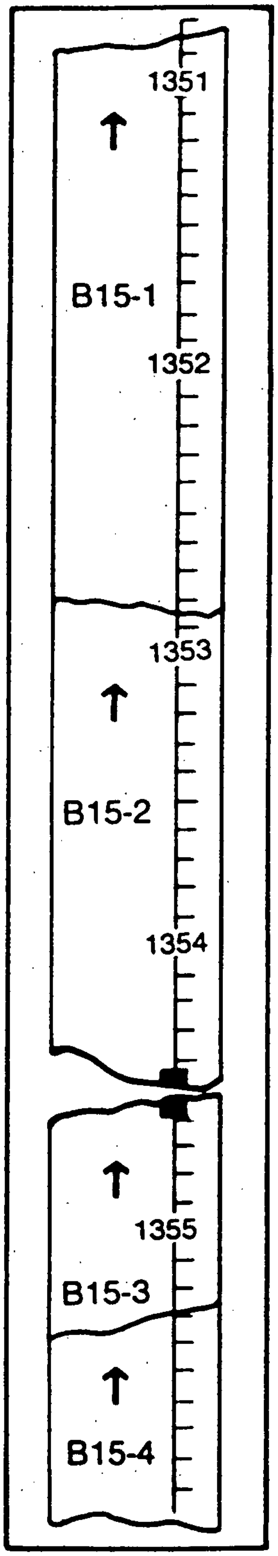


Figure 5.

VII. EXTRA CORE (E-CORE) PROCEDURES

Extra core or E-Core occurs when more core (greater footage) is recovered than was drilled on a particular core run.[3] This is caused by core which was drilled on a previous core run but not removed, being left at the bottom of the hole. This length of core which was left in the hole is then recovered on the next core run. The following procedures should be used when dealing with E-Core.

A. The amount of E-Core should be determined by subtracting the amount drilled from the amount recovered.

B. The E-Core will occur at the top of the core run. It should be marked in the following manner:

  1. Knowing the length of the E-Core, measure down that distance from the top of the run and draw a line circumferentially around the core at that point.
  2. Using a blue felt tip marker make a stripe down the length of the E-Core.
  3. The run number and piece numbers should be marked on the E-Core.
  4. The starting footage of the core should be marked on all pieces of the E-Core.

C. Record information on core log.

VIII. SAMPLE WRAPPING AND WAXING

Immediately after the core has been boxed and marked an appropriate length will be selected for wrapping and waxing if requests for this type of sample have been received. The sample (a 6-12" piece is recommended) should be wrapped in heavy foil and then taped with yellow tape along the seam with the original markings from the piece of core being repeated on the tape (including the arrow and piece number), in addition to the depth internal. They should be legible even after coating the entire package with wax. If not, another strip of tape should be affixed to the outside of the wax for identification. Following wrapping and marking, the sample will then be dipped in melted wax (usually pure beeswax) at least twice. Wrapped and

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[3] This did not happen at the SSSDP. However, core was stuck in the core barrel and not discovered until setting up for the subsequent core run.

waxed samples should be replaced at the proper depth location in the transporting and storage box. Intervals wrapped and waxed should be appropriately documented on the core log as well as the record of waxed samples (Fig. 6).

The following features should be avoided when selecting samples for wrapping and waxing:

A. Never wrap and wax lithologic contacts.
B. Avoid waxing and wrapping two pieces of core in succession.
C. Oriented cores should not be wrapped and waxed.
D. Enough core of each lithology to be left unwrapped and unwaxed to allow for a detailed lithological description.

IX. PROCEDURES FOR HANDLING DRILL CUTTINGS ON SITE

Because the SSSDP is not being continuously cored, it is essential that bit cuttings be collected at designated depth intervals. The mud logger (ExLog Smith) has the responsibility for collecting and processing cuttings (>200 mesh). Samples will be collected according to the following schedule:

- One sample each 60 ft to 3000 ft
- One sample each 30 ft between 3000 and 6000 ft
- One sample each 10 ft from 6000 ft to total depth

A sample will consist of four 16-oz cups filled with cuttings and capped individually. The cups will be supplied by the Curation Office (Los Alamos) to the Curation Crew (UCR). The mudlogger will wash the contents of one of the specimen cups. The three capped cups of unwashed cuttings and one washed cup will be delivered to the UCR Curation Crew. Information about the cuttings samples should be documented on the bit cuttings log (Fig. 2). Containers should be placed in a handling box for on-site storage and transportation to the Curation Laboratory at UC Riverside. One of the unwashed plastic specimen cups will be taken to the curation facility at Grand Junction, Colorado for archiving.

X. CORE AND CUTTINGS SAMPLE DISTRIBUTION PROCEDURES

A. UC Riverside - Core Laboratory

During and after the completion of drilling, core and cuttings sample splits or "subsamples" will be distributed to Collaborating Investigators

Figure 6

RECORD OF WAXED SAMPLES

Core Hole ____________
Run # _____ to _____

Page ___ of ___

Run #	Interval/Piece	Recipient	Run #	Interval/Piece	Recipient

from the UC Riverside Core Laboratory following the DOE General Guidelines (Goff, 1986) and the SSSDP Protocol (Elders, 1985).

Detailed lithologic descriptions of the core (by UCR geoscientists; Fig. 7), cuttings (by the mud logger; Fig. 8), and videotaping of the core must first be completed before subsampling. The amount of subsample that a Collaborating Investigator or other scientist will receive will be consistent with the amount specified in the proposal detailing scientific investigations being performed.

Detailed records on subsampling will be kept by the Core Laboratory staff (Figs. 9 and 10). Core subsamples will be numbered sequentially. For example, the first subsample from piece number B25-4 will be B25-4-1, etc. Pieces of rubble will be numbered with box number, an R, and a depth (for example B25-R-1354.6). Sample splits of cuttings will be detailed in depth interval, weight, and whether they are washed or unwashed splits.

Upon completion of the initial phase of the project (approximately one year), the samples and records will be shipped to the DOE Curation Facility at Grand Junction, Colorado. The curator of the facility will then assume the responsibility of sample distribution and return. Inquiries on the availability of samples can then be addressed to:

Manager's Office
Bendix Field Engineering Corporation
Grand Junction Operations
P.O. Box 1569
Grand Junction, CO 81502-1569
Telephone (303) 242-8621
Attention: R. D. Dayvault or W. A. Girdley

XI. LIQUID AND GAS SAMPLES - ON-SITE HANDLING PROCEDURES

Liquid and gas samples from the SSSDP are also primary sample types. Proper preservation of hypersaline brine samples from the SSSDP site is desirable because many fluid species are unstable. Some unique or unusual measurements can only be made at the SSSDP well site, but other chemical and isotopic parameters can be analyzed months to years afterward if samples are properly preserved. No gas samples will be preserved for the archives.

Liquid and gas samples will be available from attempts to flow the well and from downhole fluid sampling at three different levels, 3000 ft, 6000 ft, and total depth.[4] D. E. Michels, consultant, will coordinate the fluid

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[4] In fact, fluid and gas samples were collected from two flow tests at about 6120 ft and 10,400 ft.

Visual Core Description

Observer______________________

Well Number___________________

Core Run__________ Box #________

Depth Interval_______ to__________

Graphic Representation

Lithologic Unit

Sample Number

LITHOLOGY-PETROGRAPHY

Feet

Figure 7.

EXLOG SMITH
GEOTHERMAL DIVISION

R.F. SMITH CORP.

GEOTHERMAL DATA LOG

COMPANY BECHTEL NATIONAL, INC.
WELL STATE 2-14
FIELD SALTON SEA
COUNTY IMPERIAL STATE CALIFORNIA
LOCATION SEC 14 T 11S R 13E
ELEVATION -225.2 KB ☐ DF ☐ GL ☒
CONTRACTOR/RIG CLEVELAND DRILLING, INC./ #6
SPUD DATE ______ TD DATE ______
TD ______ TRUE VERT DEPTH ______
BOTTOM HOLE LOCATION ______
WELL STATUS ______
COMPANY REPRESENTATIVE Gerald Reich

LOG INTERVAL

DATE LOGGED 10/26/85 to ______
DEPTH LOGGED 150' to ______
MUD DRILLING ______
AIR DRILLING ______
TEMPERATURE INSTRUMENT TYPE J-Thermocouple
PRESSURE INSTRUMENT TYPE ______
GAS TRAP-AGITATOR ELEC ☐ AIR ☒
LOG SCALE 1:600 UNIT NO. 335
LOG PREPARED BY Ed Zifcheck, Frank Gonzales

HOLE SIZE		CASING RECORD	
40"	to 150'	30"	at 150'
	to		at
	to		at
	to		at
	to		at
	to		at

ENTRIES-WATER/STEAM

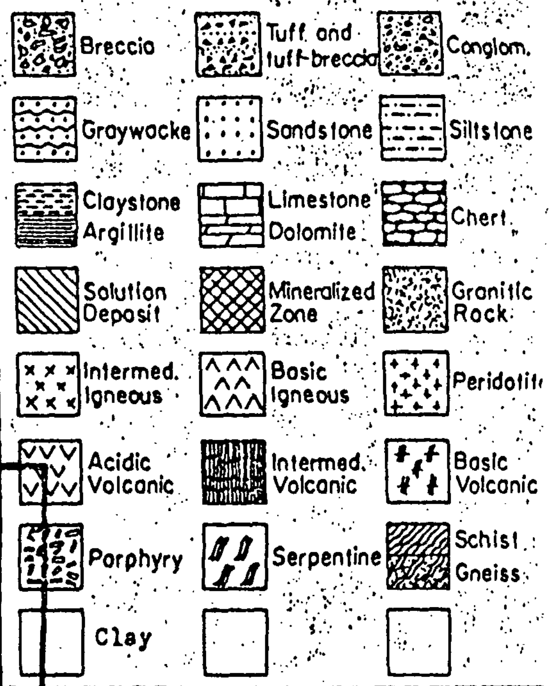
PRELIMINARY SSSDP DATA
NOT FOR REPRODUCTION
OR
PUBLIC INSPECTION

* • TESTED ZONES

LOST CIRCULATION ZONES

MISC. REMARKS

LITHOLOGY SYMBOLS W.a. Elders



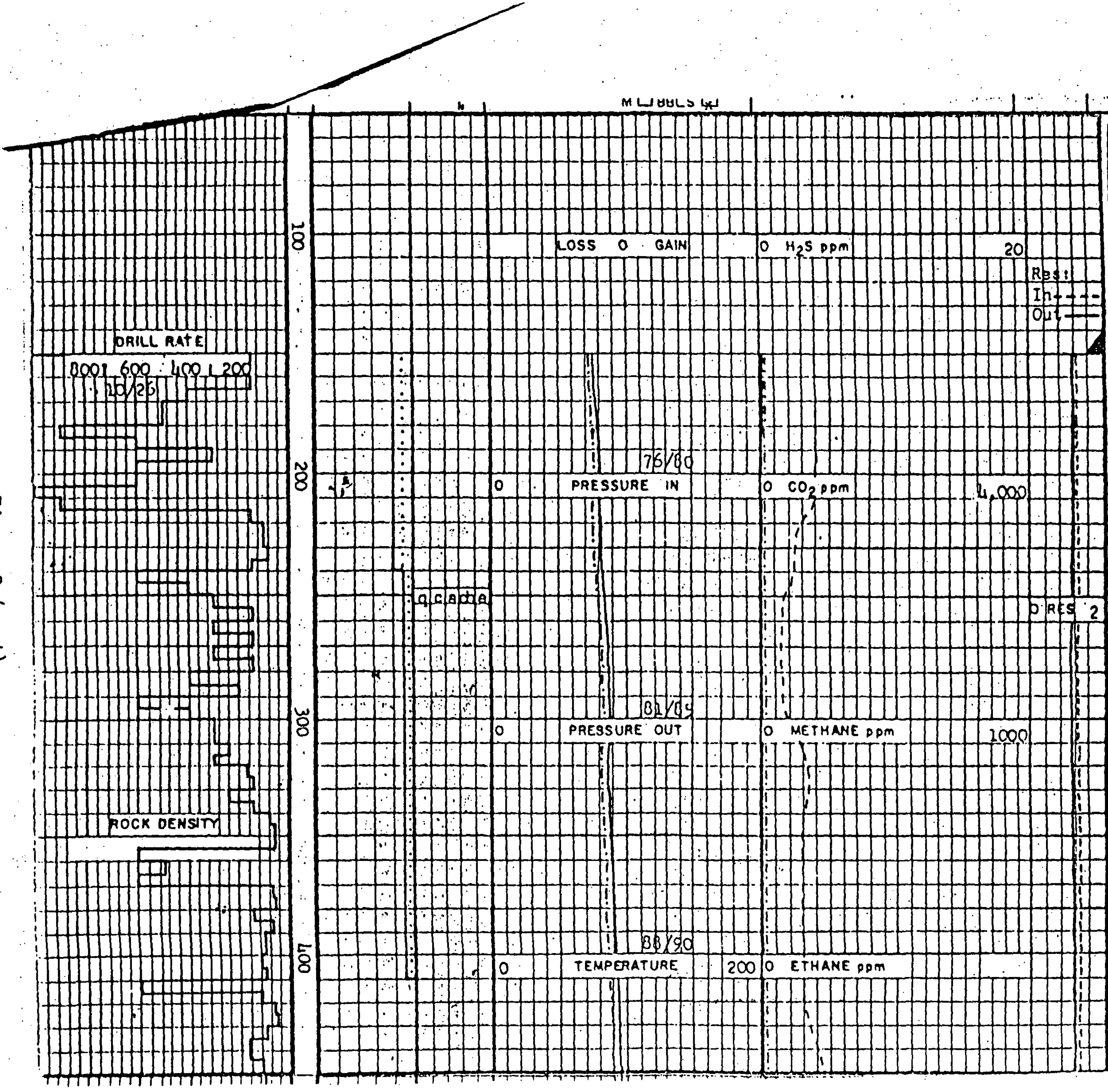
SECONDARY MINERALS

Q • QUARTZ
C • CALCITE
P • PYRITE
E • EPIDOTE
S • sulfide
Cl • chlorite
a • anhydrite

NB	NEW BIT	W	MUD DENSITY ______
RRB	RE-RUN BIT	V	FUNNEL VISCOSITY
CB	CORE BIT	PV	PLASTIC VISCOSITY
WOB	WEIGHT ON BIT	YP	YIELD POINT
RPM	REVS PER MINUTE	F	FILTRATE API
SPM	STROKES PER MINUTE	FC	FILTER CAKE
CFM	CUBIC FT PER MINUTE	SOL	SOLIDS-%
NR	NO RETURNS	SD	SAND CONTENT-%
C	CARBIDE TEST	S	SALINITY-PPM Cl
LAT	LOGGED AFTER TRIP	CA	CALCIUM-PPM Ca
BHT	BOTTOM HOLE TEMPERATURE	RM	MUD RESISTIVITY
TC	TIME SINCE CIRCULATION	⟋	WIRELINE LOG RUN
◢	CASING SHOE	◀	WATER/STEAM ENTRY
▮	CORED INTERVAL	⋈	ORIFICE/FLOW TEST
▯	NO RECOVERY		

DRILL RATE ______ ft/hr ☒ min/ft ☐ m/hr. ☐ min/m ☐ ROCK DENSITY (g/cc) — — —	DEPTH	LITHOLOGY	SECONDARY MINERALIZATION	TEMPERATURE °C ☐ °F ☒ IN —— OUT —— PRESSURE KSC ☐ PSI ☐ IN —— OUT —— LOSS/GAIN ...... M³ ☐ BBLS ☒	H₂S ppm —— CO₂ ppm —— METHANE ppm —— ETHANE ppm ——	SURVEYS RESISTIVITY Ω-M	LITHOLOGY DESCRIPTION AND REMARKS

Figure 8. Cuttings Description



Note:numbers in th
secondary minerals
column denote % of
sample (i.e. 3=3%)
"-" denotes less
than 1%,"+" denote
more than 9%.

Note:opened 40" ho
to 150',set 30" cs
@ 150',begin loggi
@ 150' on 10/26/85
drlg 17½" hole.

Clay:med-choc brn,v
sft,v sol,stky w/fn
interbdd slt/snd.

Sand:wht-clr,fn gr,
well srtd,sbrd-sban
scat slt,mnr-comm d
biot & lithic frags,
mnr coll pyr.

Clay:lt-med gry,v s
v sol,sl calcic,con
stky w/abdt scat sl
mnr det lithic frag

Clay:med gry,sol,stk
comm-abdt scat tan-
slt & snd,approx 90%
clay size particles.

Sand:wht,tan,buff,fn
gr,sbrd-sbang,mod-we
srtd,cln qtz snd w/o
clr grs,mod amts of
lithic frags,mnr col
pyr,tr-mnr det biot.

Clay:med gry,v sft,s
stky w/interbdd slt
snd.

Figure 8 (cont).

Figure 9

CORE SAMPLE SHEET

Core Hole Number SSSDP#1

Sample #	Box #	Run #	Depth Interval (ft)	Type of Sample	Sample Size (length or weight)	Litho. Unit	Requestor/ Organization	Purpose Taken	Date Taken	Date Returned	Comments

Figure 10

Cuttings Sample Sheet

Hole # SSSDP#1

Sample #	Depth Interval (ft)	Washed or Unwashed	Sample Weight/ Quantity	Unit	Requestor/ Organization	Purpose Taken	Date Taken	Date Returned	Comments

sampling effort and will collect and have analyzed reference samples of drilling fluid and additives to provide background information on drilling fluid contamination.

A. Surface Sampling

During each flow test, a capacity production test will be incorporated. At commercial rates (greater than 300,000 pounds per hour), the flow period may be less than 24 hrs of continuous flow because pit capacity (1.1 million gallons) currently limits the total amount of flow. Field optimization is thus a two-fold problem: how thoroughly clean will the fluid be and how much time will be available to accomplish all the sampling before pit fill-up?[5]

Currently, the surface equipment does not include a steam separator. In order to obtain data on steam fraction released and samples of steam-free brine and brine-free steam, a system of orifice plates and in-line sampling separators will be used. A weir will be used to monitor liquid rate out of the silencer. Up to four stages of temperature/pressure conditions may be available in the surface equipment and may be sampled for steam, gases, and brine.

Access to the interior of the flow line will be through gate valves mounted on fixtures at 12 and 6 o'clock positions on pipe spools. Four spools will be separated by three orifice plates to yield steps of temperature/pressure conditions. Steam/gas samples will be collected from at least two spools and brine from one of those. Additional spools will be sampled if time and conditions permit.

& 9:00/
3:00

Samples of steam will be taken from the in-line separator assemblies located on the spools. Separated steam will be passed through a pressure reduction valve and sampled to obtain concentrations of carbon dioxide. Tandem results will be used to compute the steam fractions in the sampling spools. Additional separates from the steam samples will be used to obtain data on hydrogen sulfide, ammonia, additional non-condensable gases, and brine carryover.

Samples of the brine will be taken by inserting 1/4-in. O.D. stainless steel probes through the 1-in. gate valves on the assemblies located at the 6 o'clock positions. The complete sampling assembly permits the brine to be cooled, acidified (dilute nitric), and diluted in 2-3 seconds after entering

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[5] During the second flow test, the pit was filled to capacity yet minor drilling mud additives and lost circulation materials were observed in the brine at the end of the test.

the probe tip. These samples are small. Diluted, they are contained in 50-mℓ polyethylene bottles.

Brine samples will be analyzed by inductively coupled plasma (ICP) to obtain a scan of about 35 elements including boron, silica, other rock-forming elements, and transition metals. Typically, about 16 elements are above detection limits. Additionally, analyses will be made for chloride, bromide, and ammonia. Bicarbonate, fluoride, and sulfate are typically scarce to absent in Salton Sea hypersaline brines. They will not be analyzed for unless the fluid is non-hypersaline or appears to contain non-hypersaline components.

It is expected that sampling needs of other investigators can be met by using the same access ports, but needs may differ in brine treatment/preservation and volume. It is recommended that the project's probe/cooling assembly be used to direct a stream of fresh, cooled brine into other scientists' pre-prepared collection bottles. It is wise to minimize the need to manipulate samples in the field. Additionally, it is recommended to use weight, not volume, in accounting for sample size, dilution, etc. Brine densities may exceed 1.2 g/mℓ.[6] Also, note that the hypersaline brines contain abundant transition elements, some of which can oxidize upon diffusion of air into the sample bottle, yielding precipitates if unacidified. Addition of base or strong nitric acid causes copious precipitation.

B. Downhole Sampling

Downhole (in-situ) liquid and gas samples will be collected at the three depth intervals mentioned above after the flow tests and surface sampling has been completed and the well has been shut in. Downhole samples will be collected using the modified Archuleta-type, 2-ℓ sampler of Los Alamos National Laboratory (Archuleta et al., 1978) and the 1-ℓ sampler of the Gas Research Institute (GRI) built by Lawrence Berkeley Laboratory (Weres et al, 1984).[7] All downhole sampling procedures and sample distribution are to be coordinated by Fraser Goff of Los Alamos. The Archuleta sampler is pre-evacuated before going downhole and inlet valves are operated by temperature hardened motors. The GRI sampler is a flow through type in which valves are closed downhole by solenoids. Because downhole samples will be obtained from discrete fluid entries in the well, it is likely that in-situ

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[6] Densities of flashed brine samples ranged from 1.21 to 1.26 g/mℓ.

[7] Three attempts were made to collect downhole samples with a commerical sampling tool but these attempts failed.

samples will yield analytical results that are different from composite well-head samples, particularly in the lower part of the well.

The present plan is to make three sampling runs to one fluid horizon at each depth interval. Because of the hypersaline nature of the brine the preservaives used in successive sampling runs will be varied in order to maximize the quality of liquid and gas samples. In Run 1, the sampler will go downhole 3/4 filled with boiled deionized water. In Run 2, the sampler will go downhole 1/4 filled with 0.1N HNO_3. In Run 3, the sampler will go downhole empty. The object of the diluting fluids is to prevent precipitation. In all cases, the exact weight of diluting fluid will be known in order to compute dilution factors. The best gas samples will probably be obtained from Runs 1 and 3, although the most volume will be obtained from run 3.[8]

When the sampler emerges from the well it will be cooled to a temperature below 70°C and the outlet valve attached to a pre-evacuated gas extraction system of known volume. The outlet valve will then be opened and the pressure recorded in the gas extraction system. A 10 cm^3 aliquot of gas will then be extracted for noble gas analysis and the rest of the gas collected into a "Giggenbach" type gas bulb. Once the gases have been collected, the sampler will be opened, the liquid sample will be poured into a container and weighed on a balance. Liquid density will be measured on a 25 mℓ aliquot using a pychometer. This aliquot will also be used to determine pH and Eh. Another small aliquot of 30 mℓ will be used to determine bicarbonate, sulfide, and ammonia in the field. Remaining liquid will then be filtered through 0.45μ paper where appropriate and diluted and/or preserved in various polypropylene and glass bottles and jugs for later analysis. Precipitates and filter papers will also be collected and saved for later analysis. Other on-site investigators may then take aliquots of liquid for specialized preservation and analyses of their own.

Fraser Goff will arrange for major/trace element chemistry of the liquid, stable isotope (D and ^{18}O) analyses of liquid, and tritium analysis of liquid through Los Alamos. Requests from other researchers for in-situ liquid samples should be arranged through him. Because of the limited volume

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[8] Because of the harsh environment in the well only one attempt at downhole sampling acquired a complete sample, although 5 of 9 attempts acquired some sample. Most scientists wanted undiluted sample, thus in most attempts, the sampler went downhole empty.

of sample obtained from each depth interval, researchers should review the chemistry of Salton Sea brines (The Experiments Panel, 1985, p. 27) and request only as much fluid as needed.

XII. BRINE SAMPLES FOR ARCHIVAL

No attempt will be made to archive gas samples. Small volumes of liquid samples from both surface and downhole sampling will be archived in order to provide liquid for unforseen non-routine analytical work that future researchers may request. D. E. Michels will be responsible for archival of surface samples while Fraser Goff will be responsible for downhole samples. All archived liquid samples will be sent to the curatorial facility in Grand Junction, Colorado one year after the SSSDP project is completed.

A. Surface Samples

From each depth interval it is recommended that 3 types of archival samples be collected in the bottles rinsed with dilue nitric acid:

1) Filtered, diluted sample: 1-ℓ of 0.45μ filtered brine diluted with 3-ℓ of deionized water stored in polypropylene bottles of various sizes.[9].
2) Filtered, acidified sample: 3-ℓ of 0.45μ filtered brine diluted with 1-ℓ of 0.1N HNO_3 stored in polypropylene bottles.
3) Raw sample: 4-ℓ of raw sample stored in polypropylene and glass bottles.

B. Downhole Samples

Similar types of downhole samples will be collected as outlined above although the volumes will be much smaller by virtue of the limited capacity of the samplers. All samples remaining with Fraser Goff after 1 year of completion of the project will be sent to Grand Junction.

C. Sample Accounting

All researchers receiving liquid and gas samples will be required to submit to D. E. Michels a completed Fluids Log Form (Fig. 3) describing the type of sample, conditions of sampling, volume of sample, and purpose of sampling.

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[9] Samples diluted in the fashion will invariably precipitate.

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APPENDIX

SSSDP FLUID SAMPLING DURING FLOW TESTS

by

Don Michels

I. EQUIPMENT AND PROCEDURES

A. Sampling Hardware

Geothermal well State 2-14 was fitted with a flowline system made mainly from 10-inch pipe, schedule 60. The complete system, approximately in sequence from the wellhead, included:

- multiple control valves,
- supports for accomodating growth of the wellhead due to thermal expansion of the casing,
- diversion line to the mud pit,
- test line of flanged spools that comprised the sampling section,
- by-pass for the sampling section,
- an expansion loop to accomodate thermal expansion of the surface piping,
- second diversion line (blooie line) to the main brine pit,
- metering orifice on the main line,
- James tube assembly
- cylindrical shroud entry to a silencer,
- vertical cylindrical silencer,
- twin discharge lines from the silencer to a stilling tank,
- metering weir at the end of the stilling tank (Figure 1).

The following description concerns the taking of steam and brine samples from the sampling section made of flanged spools.

The axis of the sampling section was colinear with the main flow line beyond the diversion point for the bypass. All the sampling section and the nearby piping were at the same elevation. Fluid could be throttled by a valve located at the head of the sample section (below the bypass connection). That valve constituted the major flow control point when the sampling section was operational.

All spools were constructed in the same way. Each was approximately ten feet long and all ends were flanged. Taps for pressure and temperature indicators were located about 4 feet upflow from the downstream ends, at the 9- and 12-o'clock positions.

The first spool of the test section was located about 15 feet down the flow direction from the throttle valve and was numbered S-3. The three subsequent spools were numbered sequentially through S-6. Those four spools and their accoutrements comprised the sampling section.

Three orifice plates were located, respectively, between S-3 and S-4, S-4 and S-5, and S-5 and S-6. Their purpose was to establish a 4-step cascade of temperature-pressure conditions in the sampling section. Each step would be characterized by pressure and temperature indictors. The sampling environments in the spools would be different also, reflecting sequential increases in the steam/brine ratios. Having a series of steam/brine ratios was a principal objective in the design of the sample section.

B. Sample Collection

1. Gas Samples

Each spool was equipped with an in-line separator (Figure 2). Essentially, this is a short pipe mounted radially inside a small chamber appended to the spool at the 12-o'clock position, beneath and connected to an access valve. As two-phase fluid moves through the short pipe toward the valve, brine droplets tend to deposit to the walls so that enriched steam exits the valve.

In some situations, steam from the access valve is brine-free and can be sampled directly. Otherwise, an additional separation effort is needed. In the case of good quality steam, a pressure reduction apparatus (Figure 3) was used to lead steam from the in-line separator to a low-pressure discharge tubing connected to a condensing coil. Condensate could be collected into sample containers open to the atmosphere. Non-condensable gases, with condensate, could then be collected by sampling trains, evacuated bulbs, syringes, etc.

Alternatively, a portable centrifugal separator was connected to the in-line separator. The steam discharge from the portable separator could be directed through any of various cooling coil assemblies to condense the steam fraction. Collection of condensate could be made into containers open to the atmosphere. Non-condensable gases, with accompanying steam condensate, were collected in pre-evacuated bulbs or in syringes.

2. Brine Samples

The objectives in brine sampling relate to obtaining a parcel of liquid that can be characterized in regard to its status in the flow line at the point of sampling, then preserving it for transport and analysis. Major factors to consider are the pressure in the flow line, two-phase conditions in the flowline, and chemical instabilities of the sample due to cooling. The cooling instabilities arise from the in-flowline cooling by steam release prior to sampling and from the in-sampler cooling.

Techniques of sample collection are aimed mainly at avoiding two kinds of problems. The first is incorporation of vapor into the sampling stream which, in the cooling coil, condenses, diluting the sample by an unknown amount. The second is to avoid plugging in the sample tubing that occurs due to particulates carried in the brine, deposition of silica scale in the mid-temperature areas, or deposition of sodium chloride in the cooler zones.

Each flowline spool was equipped with a 4-inch diameter downcomer about 16 inches long, mounted at 6 o'clock positions about three feet up from the downstream flanges. These served as liquid traps so that a probe inserted into them would be below a liquid level, thereby avoiding the collection of steam or a two-phase mixture.

Two valves were on these downcomers. One permitted insertion of a hollow steel probe into the space of the downcomer, the other allowed blowdown so that fresh fluid could be assured in the sampling zone.

The steel probe was inserted through a fitting equipped with an elastomer gland to control blowout of brine. It served as the leading part of an external assembly that included a cooling coil followed by a flow control valve (Figure 4).

Cooled brine exits the flow control valve as a stream that can be directed into sample containers. For many components collections are made into containers pre-loaded with dilutant water or a dilutant-preservative, such as acid. Exact dilutions can be determined by weighings made before and after the sample collections.

II. SAMPLES

A. Brine

1. Analysis of Chloride On-site

Samples of chilled brine from the 6-o'clock downcomers were collected into weighed amounts of distilled water, diluted into the sea water range of chloride concentrations as determined by weighing, and the chloride was titrated by [illegible] methods. The analyses were later verified in the laboratory. The increasing concentrations of chloride in the set of samples can be used to compute the incremental steam releases between the orifice plates.

2. Basic Composition

Chilled brine from the cooling coil out of the 6-

o'clock downcomers was collected into about 2.5 volumes of 0.1N nitric acid to make the field samples. These samples served as stock from which analytical aliquots were prepared later, in the laboratory.

Composition of the lab aliquots was scanned for 37 elements by the method of ICP (inductively coupled plasma) and 15 components were typically above limits of detection. Additionally, analyses were made for chloride and ammonia.

The set of samples from the sequence of flowline spools also provides a redundant check on the steam releases identified in part 1.

3. Collection of Archival Samples

Because the purposes of archival samples are not clearly defined, different preservative methods were employed. All collections were into polyethylene bottles with polypropylene caps. Bottles and caps had been pre-rinsed with nitric acid, flushed with distilled water, and air dried.

The brine samples will undergo several changes during storage. Some are due to uncompensated reactivity of the brine. Others are due to in-diffusion of oxygen through the container walls and seals.

Three methods of sample preservation were used, none are perfect, but collectively, they will permit a variety of analytical investigations aimed at either brine or precipitates. Methods a and b yield abundant precipitates. Method c yields a true solution, although it is supersaturated in silica.

a. No preservative -- Brine was collected directly into polyethylene bottles, which were filled to the top, and the caps seated after squeezing the bottle slightly to expel air. Sixteen 1/4-liter bottles were used.

b. Distilled water -- Bottles were pre-loaded with distilled water and fillings were made to marks so as to yield a dilution of about 6:1. Exact dilutions were determined later by weighing. Air remained inside the bottles while the caps were being seated. Two 1-liter and four 1/4-liter bottles were used.

c. Dilute nitric acid -- Bottles were preloaded with the 0.1 N nitric acid and fillings were made to marks so as to yield dilutions of about 3.5 to 1. Remaining treatment was as in part b. Two 1-liter and four 1/4-liter bottles were used.

B. Gases

The suite of non-condensable gases is dominated by carbon dioxide with the other prominent gases being methane, nitrogen, and hydrogen sulfide. Several other gases can be found in trace amounts. Gases were sampled from the in-line separators and from the portable centrifugal separator attached, in series, to the in-line separator. Different investigators had their own methods of trapping and preserving selected gas species. There was no attempt to collect gas for archive samples.

The basic characterization seeks only the carbon dioxide, hydrogen sulfide and the collective amount of other gases without regard to their identity. The following description applies to the samples taken for basic characterization of the gas contents.

1. Field Analysis

The sampling method used is a field assay based on pressure-volume-temperature relationships and the solubility of gases in water (condensate). A closed syringe (50 ml) is attached to the discharging cooling coil after flow through it is stabilized. The discharge pressure extends the syringe plunger while the mixture of condensate and gases fill the syringe body. A clamp limits the plunger motion, after which the syringe body continues to fill at constant volume as the syringe approaches system pressure. Care is taken to assure that the collection continues at ice temperature. When flow into the syringe ceases, readings are taken of the system pressure, liquid volume and total volume in the syringe. The condensates were subsequently collected into tared bottles for later weighing to obtain more accurate results.

Because the geothermal gases are a mixture, each assay involves two collections, one beginning with an empty syringe, as described. The other collection is similar, except for beginning with a syringe pre-loaded with a hydroxide solution. In the second collection, carbon dioxide and hydrogen sulfide are totally solubilized into the liquid. Temperature, volumes and pressure are treated as before, although considerably more condensate enters the syringe upon pressurization.

The two sets of PVT data permit computation of (i) weight percent of carbon dioxide in the steam and (ii) mole fraction of carbon dioxide in the non-condensable suite.

2. Lab Analysis

The hydroxide-condensate mixtures were saved into bottles and preserved with a solution of zinc acetate. Analysis for sulfide was made later in a laboratory by standard methods.

3. Carbon Dioxide as a Steam Tracer

The results of the above methods are all based on the steam (condensate) as a carrier and concentrations refer to the steam available at the specific sampling point. By collecting samples at all four of the sampling spools, the increments in apparent gas contents are measures of the incremental steam yields.

Because the gases are essentially all exsolved at the first sampling point, algebraic manipulations can be made, yielding computations of the total steam fraction. Thereupon, the gas contents can be referenced to a basis of total fluid flow. The brine components are then similarly reported on a basis of total flow.

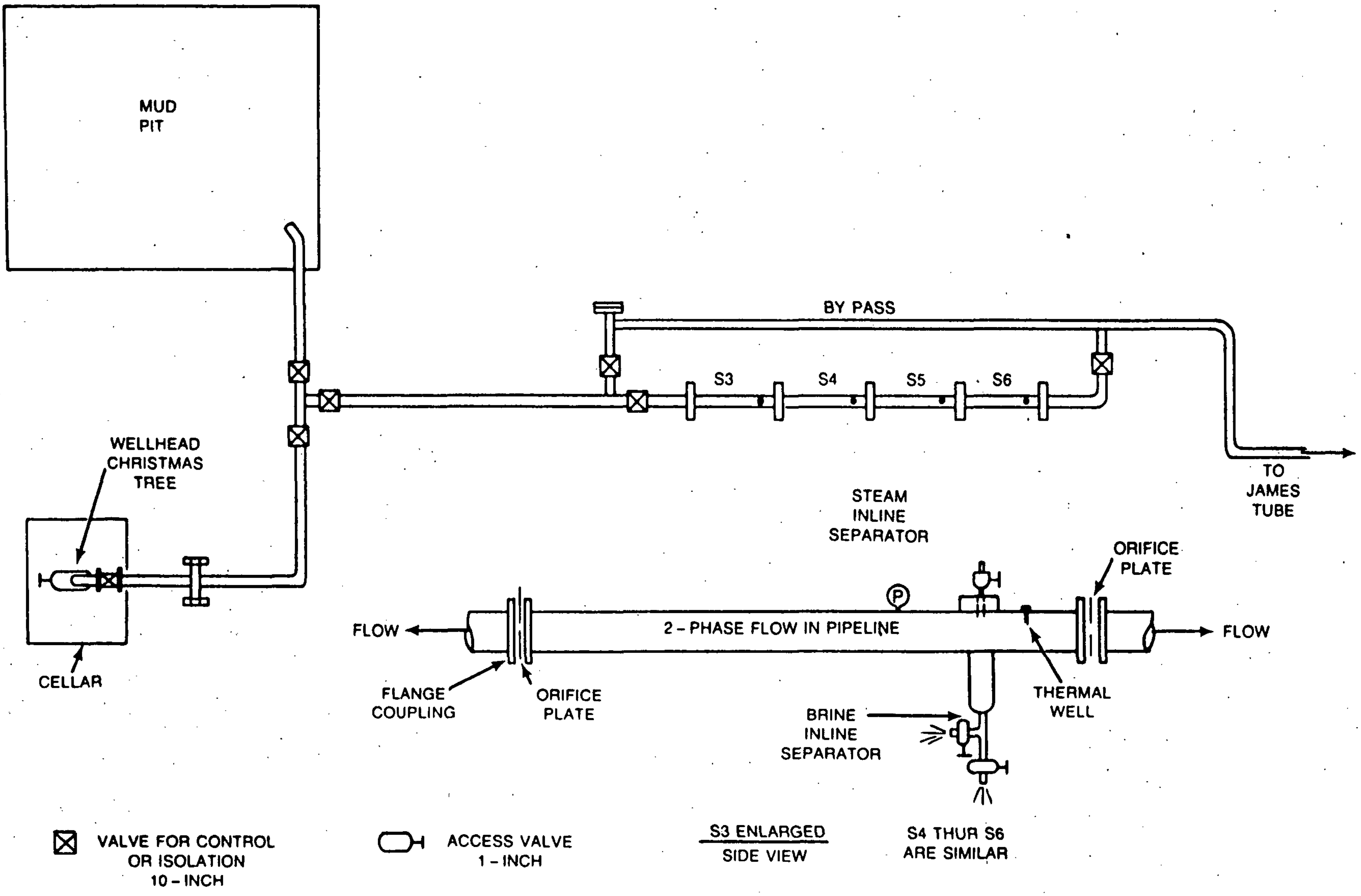

Figure A-1.
State 2-14--SSSDP Flowline and Fluid Sampling Spools (plan view not to scale).

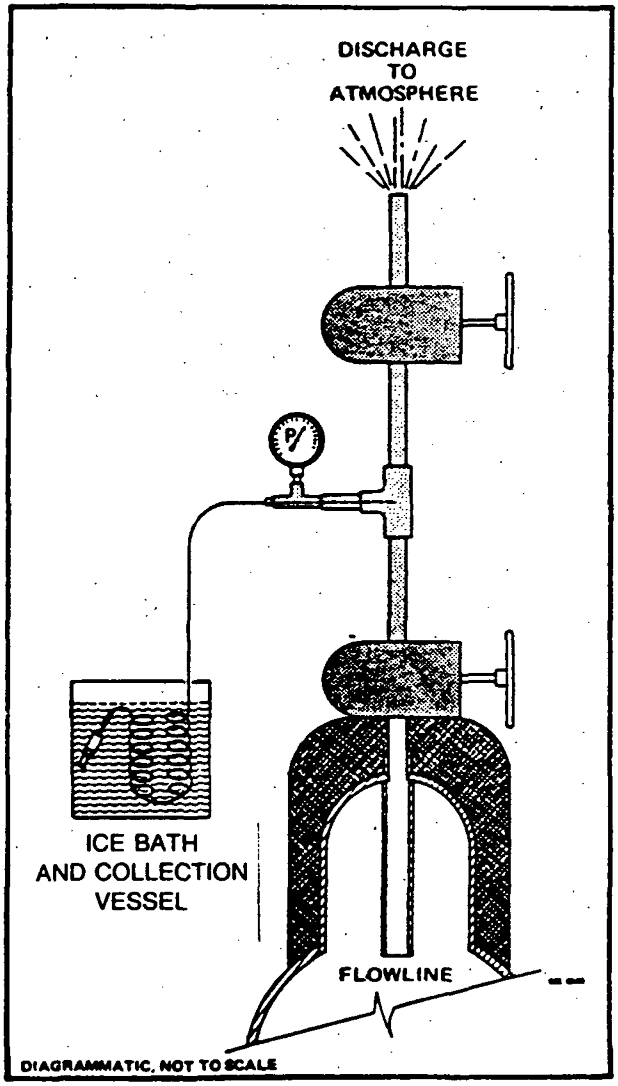

Figure A-2.
Pressure Reduction Setup for Steam and Non-Condensable Sampling.

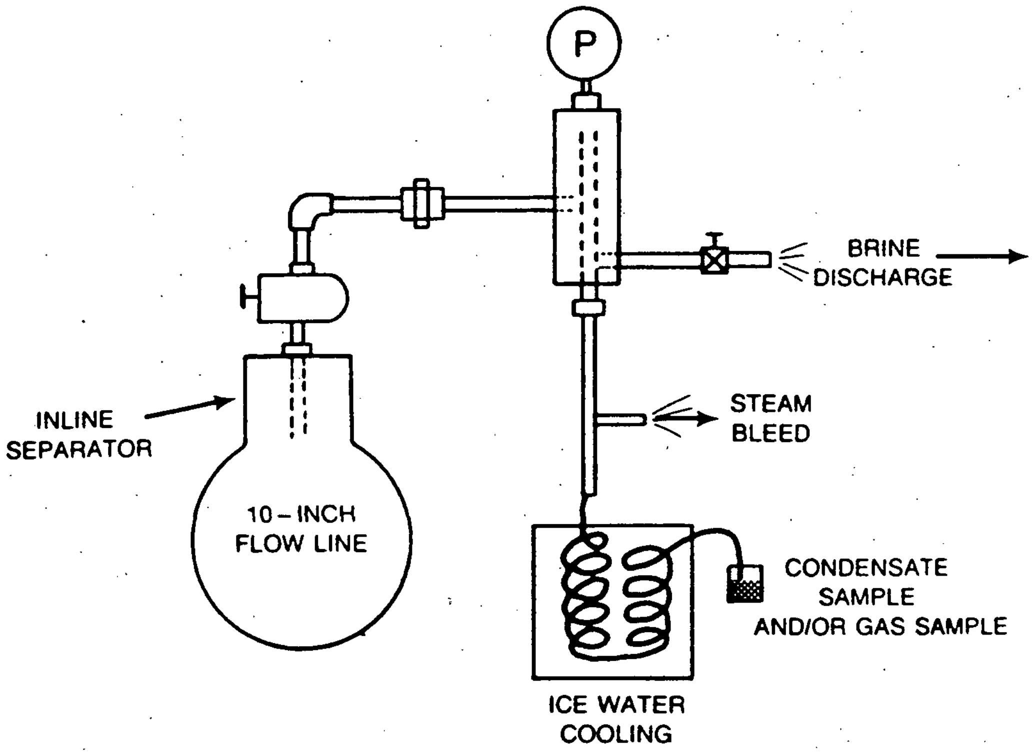

Figure A-3.
Alternate Steam Sampling with Portable Weber Separator.

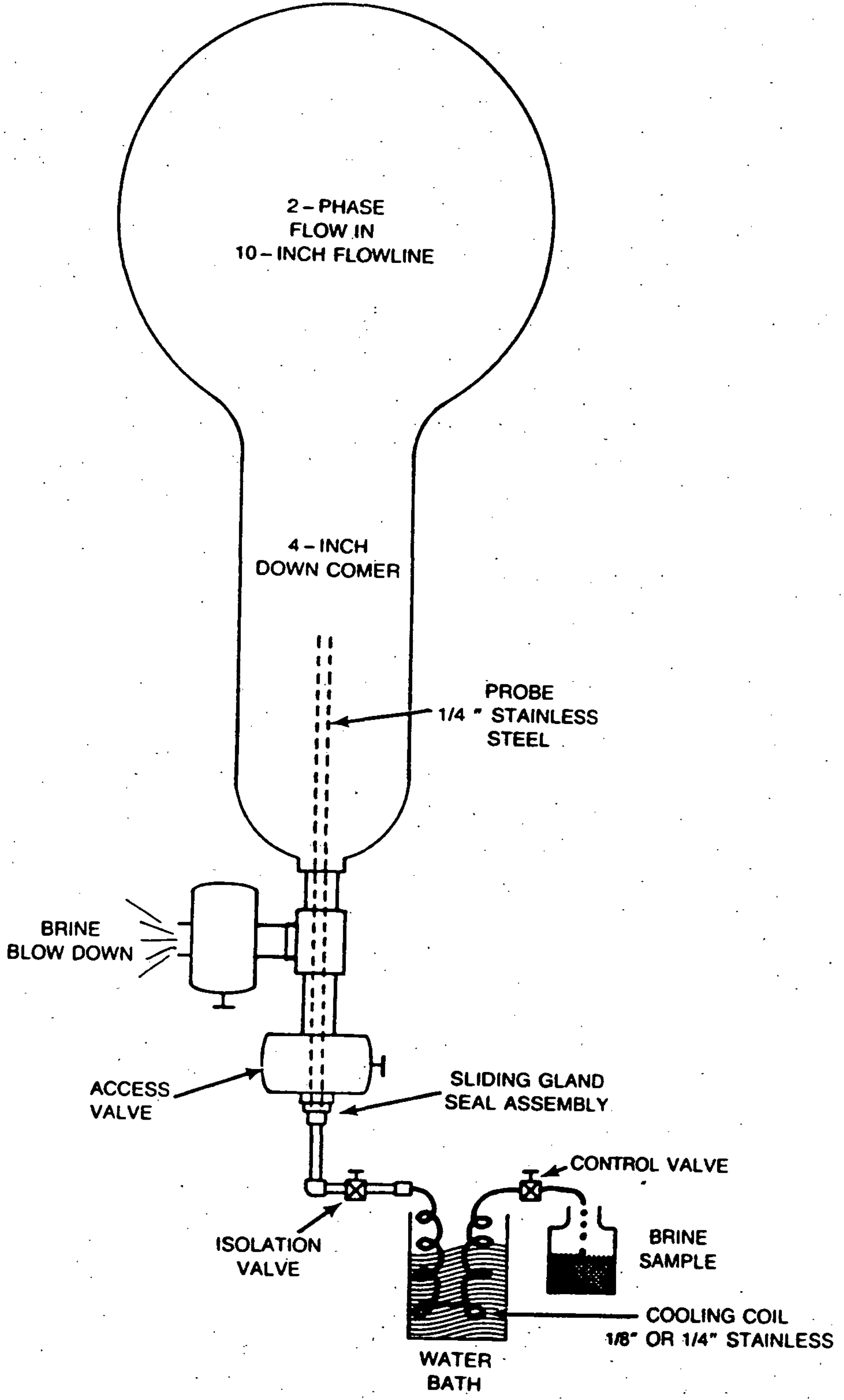

Figure A-4.
Brine Sampling Arrangement.

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June 14, 1985

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BECHTEL GROUP
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50 Beale Street
San Francisco, California 94118

Subject: SALTON SEA SCIENTIFIC DRILLING PROJECT -- Use of continuous silm hole wireline coring systems in deep geothermal wells

Dear Mr. Harper:

I am enclosing my report covering earlier conversations with you and your people while in San Francisco and have directed my efforts to reviewing the use and performance of slim hole wireline tools as applied to the Salton Sea Drilling Project which embodies a very deep hole drilled under very high (400°C temperatures).

Sincerely,

Jack D. Powers

JDPowers:bsp/aps

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USE OF CONTINUOUS SLIM HOLE WIRELINE CORING SYSTEMS ON THE SALTON SEA SCIENTIFIC DRILLING PROGRAM (SSSDP)

The following topics are the subject of discussion in this report.

1. SUMMARY COMPARISON OF CONVENTIONAL VERSUS CONTINUOUS WIRELINE CORING
2. ENGINEERING AND CONCEPTUAL DESIGN BASIS FOR THE EVALUATION
3. WHAT ARE THE DESIGN AND OPERATING FEATURES OF CONTINUOUS WIRELINE CORING?
4. WHAT TECHNICAL OR PRACTICAL LIMITATIONS ARE INVOLVED FOR SAFE COMPLETION OF A HOLE SUCH AS THE SSSDP?
5. WHAT ADAPTATIONS OR BREAKTHROUGHS WOULD BE REQUIRED?
6. WHAT SORT OF DEVELOPMENT PROGRAM WOULD BE REQUIRED, WHAT ARE ITS ESTIMATED COSTS, AND DEVELOPMENT TIMETABLE?
7. A SHORT REVIEW OF U.S. CONTINUOUS WIRELINE CORE DRILLING CONTRACTORS THAT HAVE PARTICIPATED IN CORING IN GEOTHERMAL ENVIRONMENTS
8. A REVIEW OF LONGYEAR'S NEW 10,000 FOOT DRILL RIG
9. COMPARATIVE COST OF DRILLING AND CORING FROM 6,000 TO 10,000 FEET USING THE CONVENTIONAL OIL FIELD ROTARY METHOD AND CONTINUOUS WIRELINE CORING METHOD
10. CONCLUSIONS

1. SUMMARY COMPARISON OF CONVENTIONAL VERSUS CONTINUOUS WIRELINE CORING

A. Core Versus Cost

	Conventional Rotary	Continuous Wireline
Probability of reaching 10,000 ft	Very high (95%+)	Low (50%)
Potential core recovery (30 ft cores/60 ft cores)	800/1,600	4,000
Core diameter	4 in.	2.5/1.7 in.
Estimated time to drill from 6,000 to 10,000 ft	65 days	64 days
Estimated cost*	$576,000	$810,400

*Includes rig, fuel, mud, drilling tools, casing and cement.

B. Additional Requirements for Continuous Wireline Coring

1. Extra mobilization and demobilization
2. 25 to 30 ft high substructure lease required
3. 5 in. casing (6,000 ft) and cement (250 ft minimum)
4. 4 in. casing (7,500 ft) and cement (2,750 ft minimum)
5. 3,750 ft of 101 mm drill rod expended
6. 5,000 ft of 76 mm drill rod expended

C. Dimensional Limitation of Continuous Wireline Cored Well

1. 2.98 in. diameter wellbore is inadequate for Kennecott flow test (5 in. minimum is required).

2. Sandia's temperature, pressure, and flow logging tool (3 in. diameter, 8 ft length) can be lowered only to 7,500 ft

3. Los Alamos' fluid sampler (3.5 in. diameter, approximately 10 ft length) can be lowered only to 7,500 ft before 4 in. casing (3.476 in. ID, 3.351 in. drift) is set and can not be put down the hole at all after the casing is set.

4. Placing the 5 in. and 4 in. casing strings in the well, especially if they must be cemented to the surface, seriously limits any options Kennecott might wish to exercise for latter commercialization of the well or for the science groups to test drilling or logging tools.

D. Technical Features of Continuous Wireline Coring Creating Engineering Concern and Requiring Further Study

Small flow rates (small flow annuli) and no flow during core retrieval could have the following effects:

- Limit cooling effectiveness and encourage metal corrosion and fatigue failure. (Frequent inspection of drill rods will be required to identify and remove damaged or cracked rods. Half of the 101 mm and 76 mm drill rod strings are expected to be scrapped at the completion of the job. The core retrieval cable may have to be replaced during the job.)
- Wellbore temperatures near the surface may get high enough during extended periods of no circulation to create a high potential for flashing, requiring the use of a core unloading chamber at the surface. Core retrieval rates might have to be reduced as well.
- Cuttings removal could be ineffective, resulting in frequent sticking of the drill string
- Relatively small zones where the formation took fluid could result in lost circulation. The typical materials pumped down the drill stem bore to block off the formation and reestablish circulation could clog the annuli in the continuous wireline coring system instead.

2. ENGINEERING AND CONCEPTUAL DESIGN BASIS FOR THE EVALUATION

The base case used in the analysis is that the well would be completed to 6,000 ft by conventional rotary drilling and coring. Bechtel estimates that this point would be reached in early November. Continuous wireline coring would then ensure using the Longyear HD600 system. One of these rigs has been built for export to South Africa. Longyear has indicated that they would build a second of these rigs were they to receive an award for the job and believe they could have it operational in about 2 months. The mast is 80 ft, enabling the rig to handle triple stands (60 ft) of drill rod. Core length would be 20 ft. The substructure is only 8 ft high. The hoist capacity is 85,000 lb, but the limiting load handling capacity is that of the drill string feed control system which is 60,000 lb.

The specifications of the drill rods and core barrels are shown in Table I, reproduced from the most recent Longyear brochure. These are the "standard" sizes used in the industry.

Table I

Specifications

	Metric			English		
	CHD 76	CHD 101	CHD 134	CHD 76	CHD 101	CHD 134
Hole Diameter (Regular)	75.7 mm	101.3 mm	134.0 mm	2.980 in	3.990 in	5.250 in
Core Diameter	43.5 mm	63.5 mm	85.0 mm	1.713 in	2.500 in	3.344 in
Drill Rod						
Rod OD	70.0 mm	94.0 mm	127.0 mm	2.754 in	3.701 in	5.000 in
Rod Joint ID	55.0 mm	78.5 mm	104.8 mm	2.165 in	3.091 in	4.125 in
Rod Midbody ID	60.3 mm	83.0 mm	114.3 mm	2.375 in	3.268 in	4.500 in
Rod Weight/3 m	25.2 kg	40.6 kg	69.7 kg	55.6 lb	89.5 lb	153.9 lb
Rod Joint Pre-Torque	2034 Nm	3390 Nm	4070 Nm	1500 lbf ft	2500 lbf ft	3000 lbf ft
Thread Length	50.8 mm	50.8 mm	73.0 mm	2.0 in	2.0 in	2.875 in
Depth Rating	2750 m	3050 m	3050 m	9000 ft	10,000 ft	10,000 ft
Core Barrel						
Outer Tube OD	73.0 mm	98.4 mm	127.0 mm	2.875 in	3.875 in	5.000 in
Outer Tube ID	57.2 mm	79.4 mm	104.8 mm	2.250 in	3.125 in	4.125 in
Inner Tube OD	50.8 mm	73.0 mm	95.3 mm	2.0 in	2.875 in	3.750 in
Inner Tube ID	45.3 mm	66.9 mm	88.9 mm	1.781 in	2.635 in	3.500 in

CHD rods are available in 1.5 m, 3 m, 4.5 m and 6 m lengths, or 10 ft and 20 ft lengths.
Standard core barrel lengths are 3 m and 6 m. Special length on request.
Note: 1. Specifications are subject to tolerances and are therefore approximate.
2. Depth ratings are based on straight, vertical, clean, fluid-filled holes.

(A special 6-3/4 in. drill rod was fabricated for Norton-Christensen several years ago for use on a hazardous waste injection well in Nevada. The project was cancelled and the 3,000 ft of rods were never used. The small quantity available and high weight of approximately 25 lb/ft makes it unusable for the SSSDP).

The weight of the drill rods, the maximum length of drill string that could be used on the Longyear rig, and the associated costs are shown in Table II.

Table II

Drill Rod Type	Lb/ft for 20 Ft. Rods	Maximum string length at 60,000 lb*	Cost per Foot	Cost for String
CHD 134	13.10	4,800	$27.50	$132,000
CHD 101	8.53	7,400	$20.10	$149,000
CHD 76	5.56	11,300	$14.20	$142,000**

* Bouyancy factor = 0.859 for 9.2 lb/gal mud; Drag = 10%
** To 10,000 ft

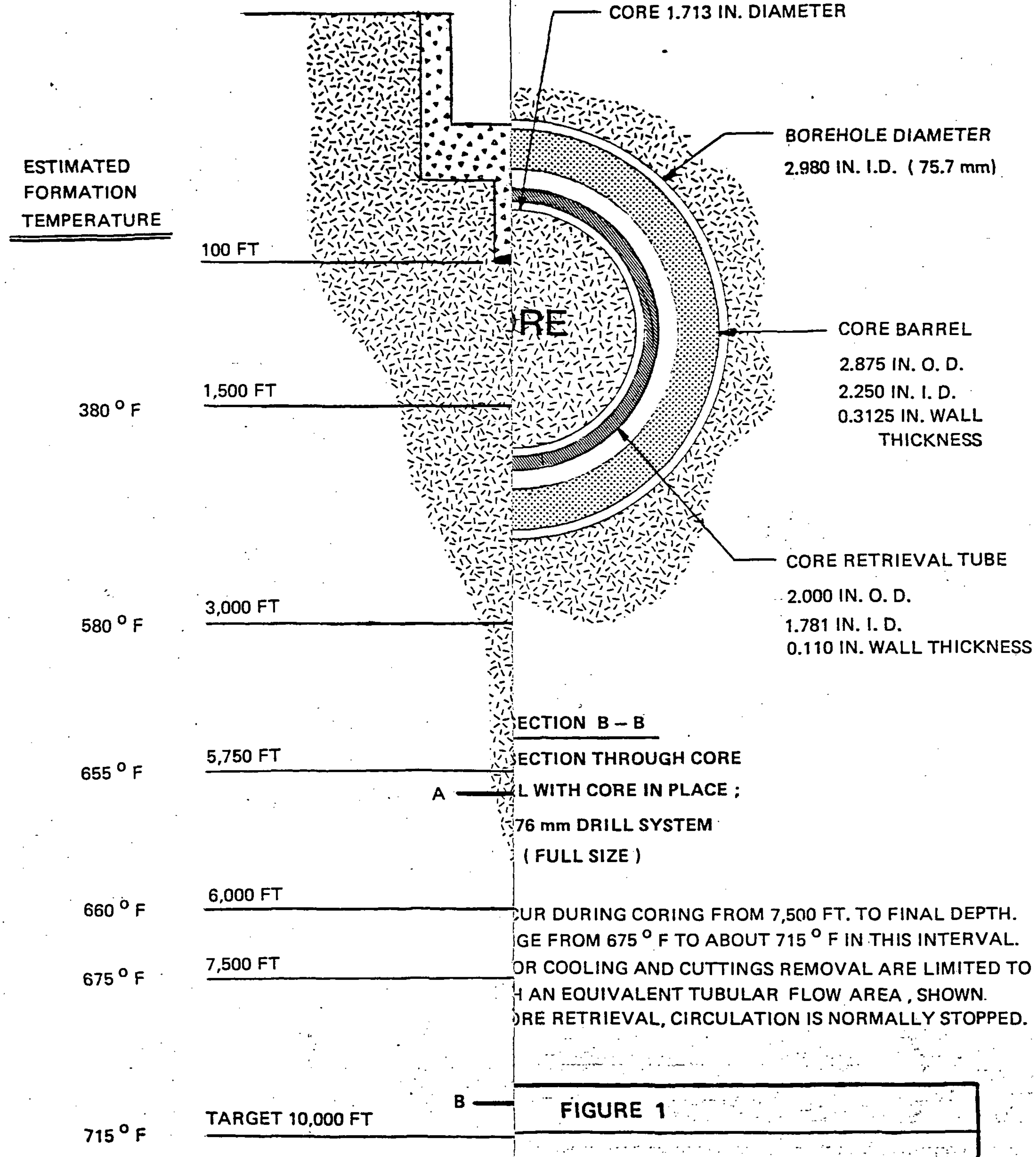
The 60,000 lb weight limit precludes use of the 134 mm (5 in.) drill rods in the SSSDP well. Coring would have to be started at the 6,000 ft casing point to about 7,500 ft with the 101 mm (3.875 in.) drill rods, switching to the 76 mm (2.875 in.) drill rods from there to total depth. If the 101 mm string got permanently stuck before reaching the 7,500 ft limit, the 76 mm string would be inserted through the 101 mm string, the 101 mm drill head reamed out, and coring continued on until the 76 mm string reached total depth or got stuck. Using the Longyear rig, and the 101 mm and 76 mm strings, the driller could only get permanently stuck twice before operations would have to be discontinued or side tracking the hole attempted.

Other coring rigs with weight capacities suitable for using the 134 mm (5 in.) drill rods from 6,000 ft to total depth exist in the United States and could be outfitted for use on the SSSDP if suitable time were available. Tonto Drilling, one of the leading independent wireline coring contractors, expressed interest in this alternative. It would take them about four months to locate, overhaul, and be ready to mobilize such a rig. If Bechtel could award a contract for continuous wireline coring by September, the larger rig would not be ready until January, two months later than required. Being able to start coring with the 134 mm and to run both that and the 101 mm string to total depth would have been a much preferable position to be starting from on this first-of-a-kind application for continuous wireline coring.

The conceptual design for a coring program using the Longyear rig is shown in Figure 1. In summary, a 5 in. casing would be installed from the surface to 6,000 ft to guide and support the 101 mm string. At a minimum, the bottom 250 ft (5,780 ft well depth) would have to be cemented in to provide blow out protection. Ideally, it would be cemented to the surface. With only 250 ft cemented, the 9-5/8 in. BOP stack would be kept in place as a precaution during the continuous wireline coring operation. The 5 in. casing would be set by the rotary drilling contractor just prior to demobilization and move out. At 7,500 ft, a 4 in. casing would be cemented back to 5,750 ft to guide and support the 76 mm string. The 4 in. casing string would be set using the coring rig. If the 10,000 ft target depth were reached, the final well configuration would have 7,500 ft of 4 in. (3.476 in. ID, 3.351 in. drift) cased hole and 2,500 ft of 2.980 in. open hole.

The combination of the 9-5/8 in. BOP stack and the BOP for the coring strings would be about 30 ft tall. The Longyear rig would have to be mounted on a substructure at least 25 ft high. This would require that a suitable substructure be fabricated or leased from a rotary drilling contractor willing to idle his rig during the coring period.

During coring, the annuli between the drill string and the borehole and the core barrel and the core retrieval tube are quite small. As shown in Figure 1, Section A-A' and B-B', the downflow annulus on the 76 mm system



UR DURING CORING FROM 7,500 FT. TO FINAL DEPTH.
GE FROM 675 ° F TO ABOUT 715 ° F IN THIS INTERVAL.
OR COOLING AND CUTTINGS REMOVAL ARE LIMITED TO
H AN EQUIVALENT TUBULAR FLOW AREA , SHOWN.
RE RETRIEVAL, CIRCULATION IS NORMALLY STOPPED.

FIGURE 1

CIENTIFIC DRILLING PROGRAM

ON IF CONTINUOUS WIRE LINE CORING

SCHEMATIC W ,000 FT. TO 10,000 FT. INTERVAL

(NOT TO SC

KEY :

▨ CEMENT

▨ FORMATION

is 0.125 in. (total areas for flow = 0.83 $in.^2$) and the return annulus is 0.05 in. (total area for flow = 0.45 $in.^2$) until entering the final 6,000 ft where it increases to 0.72 in. (total area for flow).

Typical circulation rates used by Longyear while coring are 7 to 10 gpm, with a practical maximum of about 15 gpm. A calculated pump pressure of approximately 600 psi would be required for 15 gpm flow in the well as shown. Theoretically increasing the flow to 25 gpm would require a pump pressure of about 1,500 psi. At 50 gpm, the pressure requirement would increase to about 6,500 psi. The maximum rating on the standard Longyear pump is 35 gpm @ 1,000 psi. During core retrieval, circulation is normally stopped. Round trip time at 9,000 ft., for example, is estimated at 130 minutes, under normal circumstances. During this period, the drill string would be exposed to formation temperatures and any brines which entered the well bore.

The average expected coring rate from 6,000 to 10,000 ft is estimated at about 2.6 ft/hr, based on total time from mobilization to demobilization, and about 3.25 ft/hr when coring. If the core retrieval rate must be reduced to control downhole flashing, the average coring rate would have to be adjusted downward.

3. WHAT ARE THE DESIGN AND OPERATING FEATURES OF CONTINUOUS WIRELINE CORING?

A. Potentially 100 percent of the hole is cored.

B. A relatively large core is taken compared to hole size, generally resulting in a very good percentage of core recovery in most rock formations. For example, with 101 mm system holes size (3.895 in.) core size is 2.500 in. or for 76 mm system holes size (2.980 in.) the core size is 1.713 in.

C. In harder formations, much faster core penetration rates result because of the narrow kerf of the diamond bit.

D. Very accurate feed control and high rotator speeds (500 - 750 rpm) increase core recovery and penetration rates while coring.

E. Core is extracted by pulling the inner barrel laden with core through the string of pipe to the surface with a wireline. This allows for almost immediate review of the recently cored material, and since the rods do not have to be removed each core trip, there is less chance of hole deterioration. Because it is easy to pull and check core in the inner tube, a core blockage or short run can be easily tripped to the surface and checked rather than continuing the run and losing core. Continued grinding of a broken core decreases bit life, core penetration rates, and most important reduces core recovery.

F. Because of the system's small size and weight, it requires much less rig horsepower, both in hoisting and rotating, and has smaller fluid systems requirements. Hence, rigs are generally much smaller in physical size, and in most cases the rigs are run with much smaller crews. However, in the case of the SSSDP, the crew size could be almost as large as on a conventional oil rig.

G. The thin walled drill rods (0.25, 0.129, and 0.19 in.) and small annuli (0.125, 0.145, and 0.113 in.) reflect a design optimization for coring in crystalline rock for minerals explortation. Under these circumstances, the borehole supports the drill string and provides stability. The smooth, nonpermeable borehole wall efficiently conducts the cuttings to the surface with little or no fluids loss to the formation.

4. WHAT TECHNICAL OR PRACTICAL LIMITATIONS ARE INVOLVED FOR SAFE COMPLETION OF A WELL SUCH AS THE SSSDP?

A. One-Way Valves. A wireline drill rod string is open from the coring bit to the circulation swivel; there are no one-way fluid valves in the pipe string as would be used in conventional systems. This eliminates one of the normal safety features. Careful planning and management of well control would be required.

B. Pipe Wear and Corrosion. The continuous wireline coring system relies on high alloy (4130 heat treated tool joint, tensile strength 125,000 psi and 1035 or 4130 mid body, 90,000 psi) for high strength with low weight. Thin wall tubing with thicknesses from 0.188 to 0.219 in., do not lend themselves to exterior wear, stress cracking, and corrosion that will likely occur in the high temperature, saline environment. Drill rod failure may be considerably more frequent then in non-geothermal wells, in spite of best efforts to inspect frequently.

C. Poor Well Cooling. While retrieving core, circulation is normally stopped, allowing the stagnant wellbore fluids to heat up and cuttings to settle out. As the hole gets deeper, you will be spending more time retrieving the inner tube laden with core than will be spent coring a 20 ft run. Continuous fluid circulation while extracting core through the string is highly desirable, but may not be physically possible. At 9,000 ft, circulation could be interrupted 130 minutes or more. Table III is an estimate of time required for making a complete core cycle in a 9,000 ft hole. At temperatures approaching 700°F, the strength of the drill rods decreases about 10 percent. Some additional development and planning must be worked out to accommodate this condition.

Table III

a.	Insert core retrieving overshot	
	0 - 9,000 ft	30 min
b.	Retrieving inner tube with core	
	9,000 - 0 ft	40 min*
c.	Inserting new inner tube and circulating to aid drop time	
	0 - 9,000 ft	40 min
d.	Adding pipe connections and disconnecting extras	20 min
	Total Time =	130 min
	Time spent pumping inner tube	-40 min
	Time when hole is not being circulated	90 min
	Estimated Core Time per 20 ft core run	60 min

The 90 minute period where there is no circulation could present hole problems due to not moving the fine cuttings to surface plus not continuing to cool with circulating fluid.

* Assumes approximately 200 ft/min retrieval rate.

D. Mud Cleanup System. Because of the very small annulus between hole and drill pipe, low fluid volumes are used (about 15 gpm maximum for the 76 mm string). Additional fluid volume at depth only increases fluid pressure and could direct fluid into the formation, rather than up the hole. Reverse circulation may have the same effect. When circulation is stopped during core retrieval, cuttings may settle out of the mud column and accumulate in the bottom of the hole. It becomes very important to get these cutting out of hole and that the mud and fluid systems do not break down at the temperatures and pressures expected. The use of desilters and deslimers plus large return mud tanks would be a must to minimize the chances of differential sticking of the drill pipe.

E. Supplementary Cooling Options. It may be necessary to supercool all fluids entering the hole, plus use larger return tank-system, cooling tower or heat exchanger to aid in cooling before reentry to the hole. These large tanks might also be used to reduce solids in the return fluid.

F. H_2S Embrittlement. There is a possibility of hydrogen (H_2S) embrittlement, which could adversely affect the wireline and drill rod. They are already at a lower factor of safety at total depth of 2 to 1, whereas conventional API pipe has a 3 to 1 factor of safety. H_2S may not be encountered, however, because of the amount of free metal ions in the brine. But since this type of drill pipe has never been used in this environment, at this depth, H_2S should be carefully monitored.

G. Small Retrieval Cable. The continuous wireline coring system relies on a small diameter cable (3/16 in., 0 to 3,000 ft, 1/4 in., 0 to 5,000 ft, 3/8 in., 0 to 10,000 ft) to retrieve core-laden inner barrel from the bottom of the core hole. This means that the wireline cable is subjected to the effect of brine as well as very high temperature. It may not be a major problem, but it is another consideration that must be planned for and constantly watched, in an effort to reduce rope failure that could shut down the core drilling process.

H. Core Barrel Life. Continuous wireline core barrels and associated parts do not seem to present any additional problems that would not exist with the conventional or field core barrels. There are however, more mechanical working parts to be considered, even though these barrels have functioned well in the shallow geothermal holes. Corrosion and abrasion could present the major problems with these systems and would require the operator to replace parts more often or set specific maximum footage or rotating time limits for each complete core barrel.

I. Bit Life. Diamond bits used in continuous wireline coring systems at the temperatures in question appear to be state of the art. All diamond bit manufactures questioned do not view 400°C as a major problem.

J. Logging Tool Diameters. Fluid sampling, wireline logging, temperature measurements and flow information can be gathered through the 134 mm and 101 mm boreholes. The 76 mm (2.98 in.) borehole may restrict the use of larger tools. However, through the drill string logging has not been done at the depths or temperatures in question by a continuous wireline core contractor to date.

K. Blow-out Preventors. Continuous wireline contractors have used blow-out preventors (BOPs) in the past, and their use is not envisioned as a problem. However, the availability of smaller specialty BOP's may be limited.

L. Directional Control. The core-drilling industry over the years has been able to maintain hole straightness through the use of packed-hole core barrels (core barrels that have been fitted with special stabilizers that are very close to hole gauge), by increasing or decreasing rotational speeds, and by carefully watching the weight on the diamond bit. Traditionally, deviation hasn't been a major problem in crystalline rock. There may be a tendency to drift in the sedimintary formation in the Imperial Valley. Typically, hole correction has been done with similar tools as those used in the oil field, such as Nave Drill, Dyna Drill or whip-stock methods. There has never been any directional or corrective drilling done at temperatures or depths that are remotely near the ones that maybe encountered in the SSSDP.

M. Hole Flashing Problems. Initially hole flashing problems were of concern due to high downhole temperatures. After consideration it seems to be more of a problem near the surface than at the bottom of the well. There is still some concern that the very low fluid circulation rate of the wireline system may allow the well to get hot enough near the surface that flashing could be induced during core retrieval and perhaps even during rotary core tripping. This needs more extensive analysis.

ANALYSIS OF FLASHING POTENTIAL IN THE LOWER PORTION OF THE SSSDP WELL

	Estimated Temperature °F	Hydrostatic Head @ 0.4775 psi/ft. (Mud weight 9.2 /gal)	Flash Point of Water	Pressure Drop Required for Flashing
6,000 ft	660	2,865	2,340	525
7,000 ft	670	3,342.5	2,520	823
8,000 ft	680	3,820	2,700	1,120
9,000 ft	690	4,297.5	2,880	1,417
10,000 ft	715	4,775	3,240 (vapor)	-

5. WHAT ADAPTATIONS OR BREAKTHROUGHS WOULD BE REQUIRED?

A. Develop a loading chamber system atop the drill string so that the core laden tubes can be isolated from the heat and pressure of the hole during core removal. The operation method used at present subjects personnel to some potential safety problems if flashing occurs.

B. Conduct a complete test of continuous wireline core retrieving cables under Salton Sea brine conditions. The main concern is the effect of corrosion on cable performance.

C. Subject continuous wireline core drilling pipe and core barrels to some simulated wear and corrosion tests to indicate rotating hour life for safe operation.

D. Develop a system to continue to circulate sufficient volumes of fluid while coring and retrieving core to help keep the hole temperature down and to keep the solids moving to the surface for hole cleaning.

E. Previous drilled rotary holes in the Salton Sea area indicate very high drag forces in both torsional and tension, in some cases as much as 100,000 lb above the string weight. Continuous wireline core pipe could be subjected to proportional testing to simulate these conditions.

F. In the long run, develop larger diameter drill rods and rigs to reach greater depths.

6. WHAT DEVELOPMENT PROGRAM WOULD BE REQUIRED, WHAT ARE ITS ESTIMATED COSTS AND DEVELOPMENT TIMETABLE?

A. Suggested development program:

1. It appears that the interest is very high toward the continuous wire line coring methods. Demands on existing systems that were designed for the mineral industry have expanded to geothermal, gas, oil and scientific programs, many of which demand special disciplines. With this in mind, it is suggested that a committee be established consisting of core drill manufacturers, core drilling contractors, interested rotary manufacturers and contractors, oil and mineral companies, plus those companies and individuals who need, use, or have expertise in these disciplines. This should include government agencies.

2. Suggest the above committee or group start by working on problems that are outlined in No. 3 listed earlier.

3. Perhaps a government grant through a research or engineering group could provide funds to actually set up a field testing program.

B. Estimate costs of development type of program:

Any estimate at this point is speculation, but a $500,000 program should get the existing drilling system up to speed in all areas.

C. Timetable that must be required:

A timetable that would cover those conditions as tests in No. 3 might be accomplished in as short as 9 months to as long as 15 months.

7. A REVIEW OF U.S. CONTINUOUS WIRELINE CORE-DRILLING CONTRACTORS THAT HAVE PERFORMED DRILLING SERVICES IN GEOTHERMAL ENVIRONMENT

The experience of U.S. contractors is summarized below:

	Geothermal Wells			Deepest Hole Under Mineral Conditions
Contractor	No. Holes	Max Depth	Max Temp	
Tonto Drilling Services Size	30	4,000 ft	350°F	6,900 ft - 'H'
Longyear	18	3,000 ft	390°F	7,100 ft 101 MM
		3,000 ft	490°F	7,400 ft 'B' Size
Boyle Bros Drilling	2	2,800 ft	-	6,100 ft 'N' Size
Himes Drilling Co. Inc.	2	2,800 ft+	-	- - - - - - - - -

This review reveals that two (2) contractors have done, by far, the majority of the drilling. Tonto Drilling Services has drilled the deepest hole, 4,000 ft, while Longyear has drilled in the hottest environment (reportedly 390°F). Mr. Dick Swayne, Manager of Longyear's Contract Drilling Division, has reported that 490°F was encountered in China Lake Well No. 5. The above table also shows the maximum depths that each contractor has drilled under normal mineral drilling conditions.

A review of the work done to date reveals that these U.S. contractors have not had any drilling experience in super-high temperature geosolution, nor have any reached the 10,000 ft depth requirements that are planned in the SSSDP.

The majority of continuous wireline core drilling contractors have been very successful drilling geothermal holes 3,000 ft to 4,000 ft deep that have a loose circulation condition (no return circulation). Under this condition the core drillers using the continuous wireline method were able to advance the hole in the blind condition plus recover the core. Wireline core systems allow these holes to be continued and bottomed, whereas the conventional rotary equipment made hole advancement extremely difficult and very expensive.

8. A REVIEW OF LONGYEAR'S NEW 10,000 DRILL RIG

Derrick - 80 ft extended
43 ft retracted
60 ft (triple) stands
API Rated at 100,000 lb
Crown sheaves rated at 100,000 lb

Draw Works - Hydrostatically driven with automatic release on drum while coring. Built-in spring loaded brake system for static holding only. Drum 24 in. OD with rope grooving. Load handling through 6 part line using 7/8 in. rope, giving maximum hook load of 85,000 lb.

Line Speed Bare Drum - 6 part line
High 1,356 ft/min - 226 ft/min hook speed
Low 498 ft/min - 83 ft/min hook speed

Top Drive Head and Feed System
60,000 lb hold back load while coring
Head can chuck 3-15/16 in. when drilling over 5,000 ft a Hex Ring Kelly System is used through the top drive head to handle maximum weight condition.

Rated Capacity of the Drill Unit in a Fluid Filled Hole
CHD - 134 mm = 5,000 ft
CHD - 101 mm = 7,500 ft
CHD - 76 mm = 11,500 ft

A quick review of the above specifications reveals that the 60,000 lb maximum hold back feed system is the limiting depth factor of this drill rig. Though the hoist has more capacity, 85,000 lb, it cannot be used in the feed or rotating mode, hence the drill's capacity is limited to 60,000 lb. You can theoretically drill a 10,000 ft hole, but this hole must be done with 76 mm size 2-3/4 in. OD pipe in a 3 in. OD hole. In the case of the Salton Sea hole, you would seriously limit your alternatives because you do not have the option of starting the coring with the larger 134 mm system. From a hole engineering point of view, you should maintain the largest size system until required to reduce due to in-hole conditions. This allows you the safety of continuing the hole with 101 mm, leaving you the option of an additional reduction to 76 mm to assure completion to 10,000 ft total depth. (Detailed drill rod specifications are presented on the following page.)

DRILL ROD SPECIFICATIONS

	76 mm	101 mm	134 mm
Rod OD	2.75" (69.8mm)	3.701" (84.0mm)	57 (137mm)
Midbody OD	2.375" (60.3mm)	3.268" (83.0mm)	4.5" (114.3mm)
Midbody Wall	.187" (4.7mm)	.2165" (5.5mm)	.2500" (6.35mm)
Threads Inch	2.5	2.5	2.5
Coeff. Friction (Lubrication)	.2	.2	.2
Tensile Strength Box Material	125,000 psi	125,000 psi	125,000 psi
Tensile Strength Pin Material	125,000 psi	125,000 psi	125,000 psi
Tensile Strength Midbody Material	90,000 psi	90,000 psi	90,000 psi
Weight of Rod	5.56 lb/ft	8.53 lb/ft	13.1 lb/ft
Area of Box (Min.)	1.137 sq. in.	1.519 sq. in.	
Area of Pin (Min.)	.751 sq. in.	1.244 sq. in.	
Midbody Area	1.509 sq. in.	2.37 sq. in.	
Burst Pressure	9, 545 psi	8,189 psi	9,000 psi
Collapse Pressure	7,479 pis	6,025 psi	4,380 psi
Kerf Area	4.67 sq. in.	7.6 sq. in.	
Yield of Box in Tension	113,713 lbs.	151,963 lbs.	257,000 lbs.
Yield of Pin in Tension	75,114 lbs.	124,379 lbs.	257,000 lbs.
Yield of Midbody in Tension	120,755 lbs.	189,600 lbs.	
Failure of Box in Tension	142,141 lbs.	189,954 lbs.	
Failure of Midbody in Tension	135,849 lbs.	213,300 lbs.	
Yield of Joint in Torsion	8,773 ft/lbs	17,201 ft/lbs	
Failure of Joint in Torsion	10,967 ft/lbs	21,501 ft/lbs	
Pre Torque of Joints	1,550 ft/lbs	2,500 ft/lbs	3,000 ft/lbs
Max. Rated Torque	2,000 ft/lbs	3,400 ft/lbs	5,000 ft/lbs
Thread Length	2"	2"	2.975"
Depth Rating (2-1 Safety Factor)	2,900 metres	3,000 metres	3,000 metres
Weight of 6 metre Rod	110 lbs.	165 lbs.	262 lbs.
Standard Core Size	1.713"	2.5" (HQ)	2.244" (PQ)
Standard Hole Size	2.98"	3.99"	5.250"
Midbody Material	Grade 1035 or 4130	Heat Treated UTS - All CHD the same	
Joint Material	Grade 4130	Heat Treated UTS - All CHD the same	

It is understood this drilling unit was designed for South Africa, which has a requirement of drilling to 10,000 ft, and the maximum hole size in that part of the world is 2.98 in. OD using the 76 mm system. So while the drill meets the depth requirements, it does not allow the additional hole size and depth alternatives that may be needed to meet hole conditions that could be present on the SSSDP.

Per Mr. Dick Swayne of Longyear Co. the following is a typical hole that was recently drilled in New Mexico on an Oil Gas exploration well.

Rotary 0 - 900 ft, 9 7/8 in. bit
900 - 2,500 ft, 7 7/8 in. bit

Casing 0 - 2,800 ft, 6 5/8 in. Casing

Coring 2,500 - 4,000 ft, 134 mm - 5 1/2 to 6 in. bit

Casing 0 - 4,000 ft, 5 in.
4,000 - 7,000 ft + 101 mm - 4-3/8 in. Bit

Rotary Pump - GD - 5-1/2 in. x 8 in.

Core Pump Bean Twine Model 835
Hydrostatically Driven
10 to 70 GPM @ 850 PSI

Ideal Core Rig Capacity. From a continuous wireline coring point of view the drill rig should have the capacity to handle both hoisting, rotating and feeding of the 134 mm string to the maximum depth of 10,000 ft. If in hole conditions didn't demand casing, it would be to the advantage of the program not to case and change hole size. However if the hole condition required casing and size reduction, we have that alternative available, plus an addition size smaller as a last resort.

0 - 10,000 ft	134 mm System	131,000 lb
0 - 10,000 ft	101 mm System	85,300 lb
0 - 10,000 ft	76 mm System	55,600 lb

It would appear the drill rig with a hook load capacity of 225,000 lb would be more desirable plus have feed and rotating capacity of 150,000 lb to handle the 134 mm system to the 10,000 ft depth.

9. THE COMPARATIVE COST OF DRILLING AND CORING FROM 6,000 TO 10,000 FT USING THE CONVENTIONAL OIL FIELD ROTARY METHOD AND CONTINOUS WIRELINE CORING METHOD.

The proposed approach would have the first 6,000 ft drilled conventionally and cased. The rotary unit would drill through the high pressure gas zone and set the 9 5/8 in. casing to 6,000 ft. After completion, this same rig could set the 5 in. casing string for use with the 101 mm system.

The following are some of the cost considerations:

A. There are move-in move-out costs for the rotary drill, as well as the core drill. For the coring part of the hole, Longyear estimates these costs to be approximately $100,000.

B. The rotary drill substructure should be left in place to accommodate all of the BOPs needed. A review of the hole casing plan for the rotary indicates 9-5/8 in. production casing with its normal BOP stack plus wireline coring 5-1/2 in. casing to accommodate CHD-101 mm wireline coring system plus 4 in. casing string to accommodate CHD 76 mm wireline coring system. These casing <u>and</u> drilling strings will require a BOP stack.

   The substructure of oil rotary rig has sufficient clearance, 25 to 30 ft, to accommodate these BOP stacks, but the Longyear coring rig only has about 8 ft clearance. The Longyear drilling rig is of modular design, so it can be easily mounted on the deck of the substructure without its subbase but would require a rental crane to mob and demob. Additional arrangement must be made with the rotary contractor to lease his substructure during the coring operation. The cost of the substructure has not been included in the wireline coring estimate.

C. Coring costs will increase as a result of only drilling the lower part of the hole for the following reasons:

1. Mob and demob would be the same as if started from 0 to 10,000 ft, but you can only write off this cost against 4,000 ft of drilling.

2. Under this scenario the contractor will be required to have two (2) strings of pipe 101 mm 0 to 7,500 ft and 76 mm 0 to 10,000 ft and must write off wear and cost over only 4,000 ft of drilling, though he is required to invest a very large amount for the entire string of pipe.

3. This method requires a very large core drilling rig because of depth and size, and all the related costs of the large rig must be written off against a small amount of footage drilled.

4. If this hole is planned to be used for production, there is a good chance that these small strings of casing or stuck rods could not be removed, or if so it might be done at a substantial cost. The small core drill does not have hoist capacities to remove the 5 in. casing string that was set by the rotary. In order to rework the hole for production, a remob of the rotary drill may be required.

The following pages show a rough cost estimate for continuously wireline coring the SSSDP from 6,000 to 10,000 ft and a comparable Bechtel estimate for conventional rotary drilling and coring. The continuous wireline coring estimate is about 30 percent higher.

Continuous Wireline Coring	$810,365
Conventional Rotary Coring and Drilling	$576,050

BID CALCULATION FORM

DATE: 6/11/85
CUSTOMER: Bechtel
LOCATION: STATE: California
COUNTY: ______ TOWN: ______
FOOTAGE FOR CALCULATION: CORE: 6000-10000 ROTARY: ______

1. CORE	SIZE 101mm-76mm	HOURS	2. ROTARY	HOURS	TOTAL
0-500	EST. FTS. F.P.D.H.				
500-1000	EST. FTS. F.P.D.H.				
6000-6500	EST. FTS. F.P.D.H. 4.5	111			
6500-7000	EST. FTS. F.P.D.H. 4.5	111			
7000-7500	EST. FTS. F.P.D.H. 3.5	143			
7500-8000	EST. FTS. F.P.D.H. 3.5	143			
8000-8500	EST. FTS. F.P.D.H. 3	167			
8500-9000	EST. FTS. F.P.D.H. 3	167			
9000-9500	EST. FTS. F.P.D.H. 2.5	200			
9500-10000	EST. FTS. F.P.D.H. 2	200			
500-500	EST. FTS. F.P.D.H.				
500-500	EST. FTS. F.P.D.H.				

	HOURS		
3. REAMING EST. FOOTAGE ______ F.P.D.H.			
4. CASING	30		
5. CEMENTING	30		
6. SURVEY, PAID DELAY, LOST CIRCULATION	40		
7. MOB. & DEMOB.	60	SERVICE HOURS	160
8. MOVING, SET-UP, TEAR DOWN MOVE ______ HRS. EA. ______			______ %
9. EQUIPMENT BREAKDOWN	60		
10. WEATHER DELAY			
11. HOLE PROBLEMS	40	DELAY HOURS	120
12. OTHER DELAYS	20		______ %

TOTAL DRILLING HOURS 1242 % OF DRILL TIME 78%
TOTAL NON-DRILLING HOURS 280
TOTAL HOURS 1522 SHIFTS PER DAY ______
63 ft/day 2.65 ft/hr
HOURS PER DAY ______ JOB DAYS 64 DURATION MOS. ______

LABOR COST 13.	PER HR.	PER DAY	TOTAL
FOREMAN (1)	15.00	168.00	
F. DRILLER (1)	13.50	151.20	
DRILLER (3)	12.00	403.20	
HELPER (6)	8.00	537.60	
DRIVER (1)			
TRAVEL TIME			
SUB-TOTAL		1260	
PAYROLL BURDEN STATE %	32	403	
SUBSISTENCE		205	
FRINGE			
		1868	

TOTAL LABOR COST $ 119565.00

SUPPLIES 14.	PER DAY	TOTAL
BULK FUEL	300.00	19,000
CREDIT CARD GAS	45.00	2,880
CORE BBLS.	3.5 ft	14,000
DRILL TOOLS	2.25	9,000
CASING & cement		101,800
SPECIAL SUPPLIES	2.00	8,000
MISCELLANEOUS		10,000
STATE TAXES 6%		7,478
mud $6.00/ft FREIGHT &		24,000
LINE TRUCK Well head tools	30.00	1,920
ROTARY BITS F ______ C/F ______	→	4,000
DIA. BITS F ______ C/F 9.00		36,000
SALES TAX % 6%		2,160
TOTAL		240,418

RENTALS 15.	PER DAY	TOTAL
MOB. & DEMOB.		100,000
R. DRILL ( )		
D. DRILL (XX)	150.00	11,000
PUMPS (XX)	50.00	3,200
W. TRKS (x)	25.00	1,600
MILES 30x1.00	30.00	1,920
PICKUPS (X)	40.00	2,560
MILES 100x25		
RODS 76mm 10,000'		145,937
TRAILERS 101mm 7,500'	-	
COMPRESSOR	-	
OTHER RENTALS B.O.P.	100.00	6,400
TOTAL		272,617

CONTRACT EXPENSES 13, 14, 15

TOTAL		632,600
CONTRIBUTION TO OVERHEAD	15 %	
PROFIT	15 % 30 %	177,765
REQUIRED CONTRACT INCOME		810,365
LESS SERVICE REVENUE		149,500
INCOME REQUIRED FOR DRILLING		660,865

$$\frac{810,365}{4,000\text{ft}} = \$202.59/\text{ft}$$

SOURCE OF SERVICE REVENUE

#3. Mud $6.00	______ x ______	24,000
#4. HOURLY RATE	(225.00) 30	6,750
#5. HOURLY RATE	(225.00) 30	6,750
#6. HOURLY RATE	(225.00) 40	9,000
#8. HOURLY RATE	( )	
MOBILIZATION & DEMOB. COLLECTED		100,000
WATER HAUL CHARGES (TRUCK DRIVER, MILES, ETC.)		2,000
Core Boxes 4000'x50/ft OTHER CHARGES, STATE TAXES, BITS, ETC.		1,000
TOTAL SERVICE REVENUE		149,500

THIS SECTION FOR BID ON FOOTAGE BASIS:

INCOME REQUIRED OF DRILLING ( )
DRILLING CREW HOURS ITEM 1 & 2 ( )
REQUIRED INCOME PER DRILLING CREW HOUR $ ______
2.63ft/hr

THIS SECTION FOR BID ON HOURLY BASIS:

INCOME REQUIRED FROM DRILLING ( )
TOTAL CREW HOURS-NON PAID TIME ( )
PER HOUR $ ______

INCOME REQUIRED FROM SERVICES ( )
TOTAL CREW HOURS ( )
CALCULATED PRICE PER HOUR $ ______
BID PER HOUR $ ______

	CALCULATED PRICES				BID PRICES			
	NC	NX	BX	ROTARY	NC	NX	BX	ROTARY
0-500								
500-1000								
1000-1500								
1500-2000								
2000-2500								
2500-3000								
3000-3500								
3500-4000								
4000-4500								
4500-5000								
5000-5500								
5500-6000								

80-170

BECHTEL ESTIMATE FOR ROTARY DRILLING AND CORING FROM 6,000 TO 10,000

Component	Daily Rate	Approximate Days in Use	Subtotal Daily Cost
Rig rental (includes crew and drill pipe)	$5,600	65	$364,000
Rotating head rental	55	65	3,575
Drill bits	235	20	4,700
Drill tools	765	20	15,300
Mud and chemicals	1,685	65	109,525
Core barrels and bits	1,150	45	51,750
Coring supervisor	525	45	23,625
Trucks, crane, welding and other misc.	55	65	3,575
TOTAL			$576,050
Cost per ft.			$144.01

10. CONCLUSIONS

From an engineering point of view there is no question in my mind that if hole completion is important, the rotary oil rig with all its proven systems and its excess capacities would assure one of successfully completing this hole to 10,000 ft. However, from a scientific point of view one could certainly obtain additional scientific information by continuous wireline coring in areas where presently there is limited information.

One must weigh using the continuous wireline method against the following facts.

A. The 10,000 ft core drilling rig presently being built by Longyear has never attained that depth.

B. No continuous wireline coring contractor in the United States has personnel that have drilled to 10,000 ft nor at temperatures close to those that will be encountered at the Salton Sea Project.

C. Wireline core drilling tools have been subjected to geothermal environments but none have been subjected to such high temperatures or possibly as corrosive and abrasive geothermal solutions as will be encountered in the 10,000 ft Salton Sea hole.

D. Because of the very close tolerances between hole size and casing used, cementing holes could present real problems. Add to this condition 400°C hole temperatures plus brine solutions, and cementing may be impossible. At any rate, as of now, it is an unknown for the wireline core driller.

E. I have a serious concern with the continuous wireline core method in the following areas:

a. Corrosion

b. High drag forces (torsional and tension)

c. Wear

d. Temperature

e. Very low fluid volumes used in drilling present some safety questions

f. Hole deviation because of in-hole conditions that are different (sedimentary formation versus granitic formation) where most of wireline work has been done using the continuous wireline core method

The task of deep wireline core drilling is not impossible. However, there are certainly many unknown conditions in the Salton Sea project, that the wireline core drilling contractors would be eager to start solving. To do so in a timeframe that would assure completing the hole to 10,000 ft may take from 9 to 15 months of development work prior to beginning drilling.

There are two things that tend to assure hole completion:

1. Seasoned personnel that have drilled in these conditions to the proposed depths with support people they are familiar with

2. Proven rigs, tools and support systems

In view of the task at hand, it would appear that the continuous wireline coring system needs the support of a separate research program.

RESUME

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EXPERIENCE

1982 - Present Consulting Engineer. Have maintained a drilling consulting business servicing with mining and oil companies. Have successfully completed projects for Amoco Minerals, Getty Oil and Minerals, World Bank, Dresser Industries, Denison Mines, Bureau of Reclamation, Rio Colorado, Prodrill, Exxon, Noranda Mining, Hanna, Roberts Union Corp., and Irish Base Metals. Have traveled much of the world as consultant to the above and have recently helped RUC, South Africa reach 5,000 meters with wireline core drilling systems.

1982 - present Acquired part ownership in Matrix Drilling Products Co., which manufactures wireline core drilling rod by plasma welding system. Have worked with Matrix to develop special super deep DH5000 wireline rods to set world wireline core depth record. Matrix group has several developments to its credit.
1. Small, lightweight, reverse circulation string and system.
2. Lite Pipe, high strength, light rotary rods for Water Well and Oil industries.
3. Ultra-lite high speed rods for underground drill.

1972-1982 Longyear Co.
925 Delaware St. S.E.
Minneapolis, Minn. 55414
Duties and Responsibilities

1974-1982 Manager of Operation of the contract drilling division. Managed seven (7) operating zones stategically located throughout the United States and serving the mineral and geotechnical industries with gross sales of more than $32,000,000 annually.

1976-1982 Vice President, Longyear Americas INc. Responsible for all exploration drilling outside of North America in the Western Hemisphere; coordinated management and all field requirements.

1968-1972 Boyles Bros. Drilling Co.
P.O. Box 25068
Salt Lake City, Utah 84125
Utah District Manager. As manager was responsible for a 20 drill operation which includes shop and district office.

Before becoming manager, set up complete company maintenance program, wrote maintenance manual and computerized equipment and maintenance.

1964-1968 Joy Manufacturing Co.
Salt Lake City, Utah
Area manager

1960-1964 Nichols Drilling Co.
(Morrison-Knudsen Co.)
Selby Drilling Co.
Boise, Idaho
Chief Engineer -chief estimator.

1954-1960 E.J. Longyear Co.
Salt Lake City, Utah
Western Zone Manager
Set up the first operating zone for Longyear Co.

EDUCATION

1951- Michigan Technological University
B.S. Mech. Engr.
Registered Professional Engineer
1949- University of Minnesota
Business & Accounting B.A.
1945- Duluth Central High School diploma

Also obtained certificates from Baroid Mud School, Halliburton Cement School, plus management seminars at University of Minnesota, University of Utah, and University of Idaho.

Conducted Drilling Management and Information classes at University of Minnesota, Colorado School of Mines.

PROFESSIONAL MEMBERSHIPS

AIME, American Society of Mechanical Engineers, Canadian Diamond Drilling Assoc., Colorado Mining Assoc., National Drilling Contractors Assoc., Northwest Mining Assoc., Southwest Mining Assoc.

REFERENCES

R.I. Peters, Pres.
Matrix Drilling Products
P.O. Box 36
Lewisburg, Tenn. 37091
1-615-359-6564

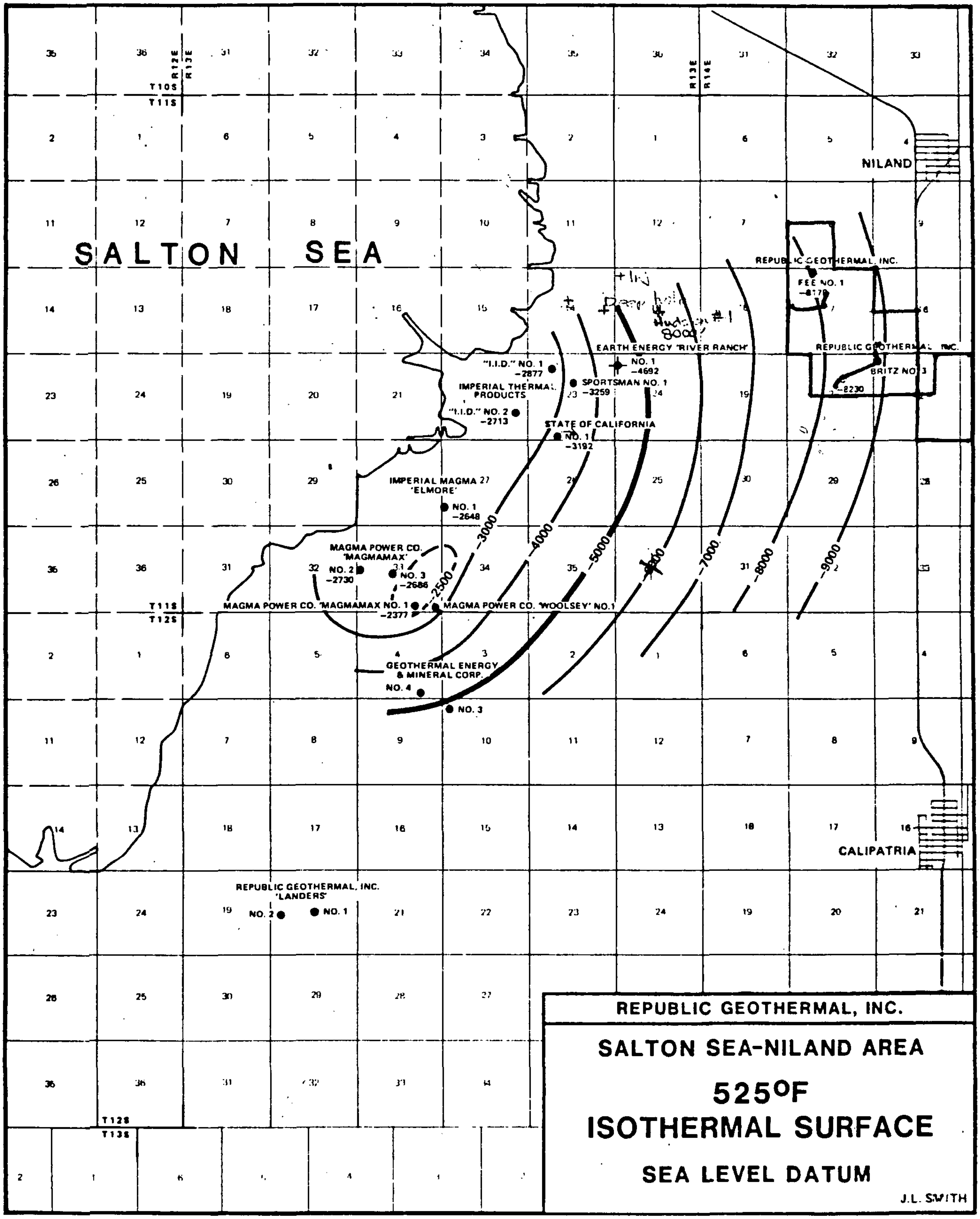
Siegfried Muessig, V.P.
Getty Oil Co.
3810 Wilshire Blvd.
Los Angeles, Calif. 90010
1-213-739-2100

Mr. Robert H. Ruggari, Pres.
Utah-Wyoming Consolidated Oil Co.
P.O. Box 1045
Moab, Utah 84532

1-801-259-5611

PERSONAL

Date of birth: 11/11/25
Place of birth: Duluth, Minnesota
Marital status: married (Susan)
Ages of children: two sons, 22 and 25.



REPUBLIC GEOTHERMAL, INC.

SALTON SEA-NILAND AREA

525°F ISOTHERMAL SURFACE

SEA LEVEL DATUM

J.L. SMITH

EGI C1073

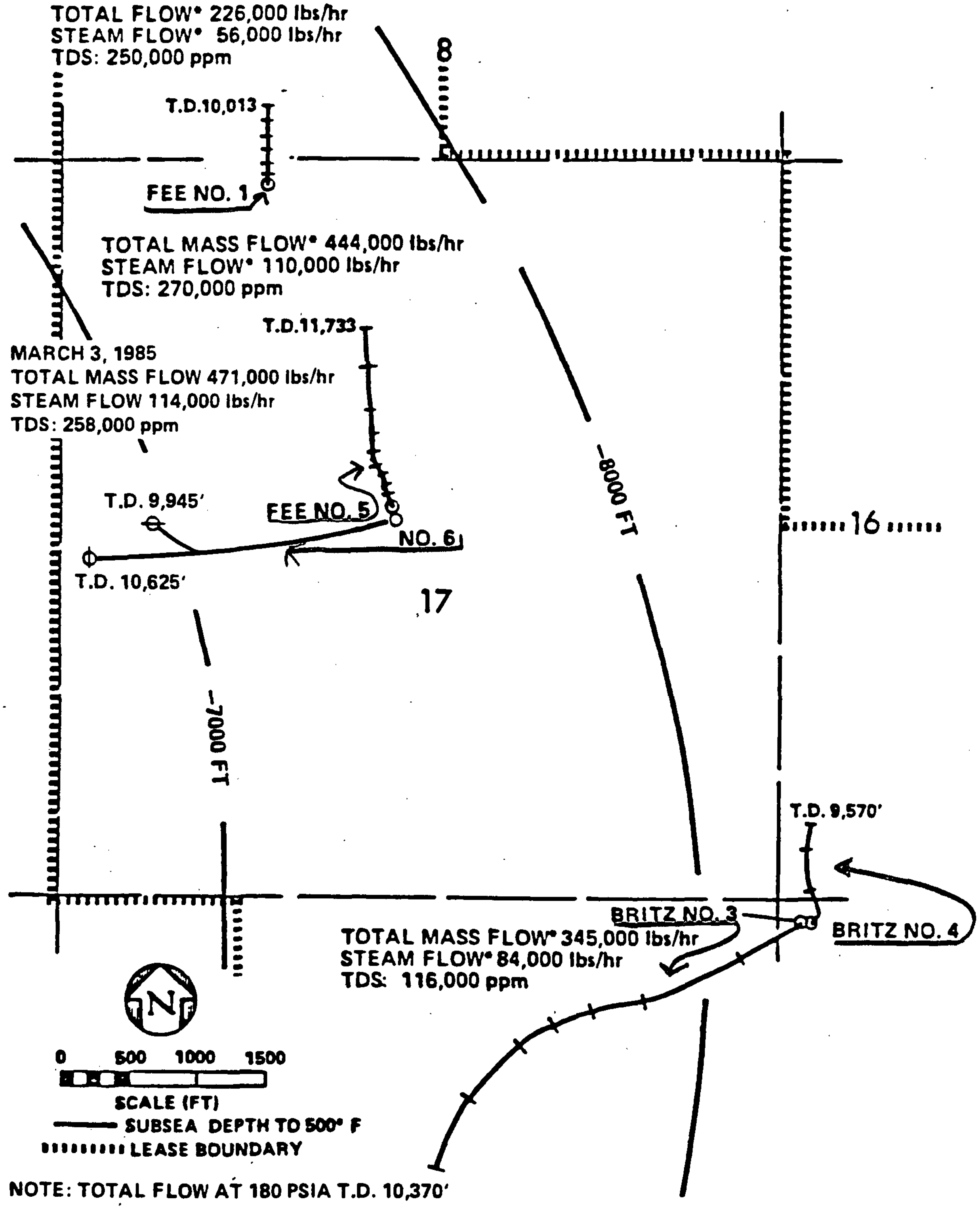


Figure 4-2 - Well Location Map
T 11 S, R 14 E, SBB & M