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TALLEY ENERGY SYSTEMS, INC.

a **TALLEY INDUSTRIES** Company

7333 East Monterey Way
Scottsdale, Arizona 85251

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OIL SHALE IN-SITU RESEARCH & DEVELOPMENT

DOE Contract No. ET-77-C-03-1791

TALLEY ENERGY SYSTEMS, INC.

Quarterly Report

No. 4

May 1, 1978 through July 31, 1978

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Written by:

Kenneth M. Goldstein

Kenneth M. Goldstein, Systems Engineer

Approved by:

George L. Graf

George L. Graf, Program Manager

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QUARTERLY REPORT NUMBER 4

Introduction

In accordance with the requirements of our contract with the Department of Energy #ET-77-C-03-1791, the TALLEY ENERGY quarterly report for the period 1 May through 31 July 1978 is included.

This period encompassed many of the preparatory operations prior to the explosive fracturing event at Rock Springs Site Section 17 by Talley Energy Systems, Inc. (TALLEY ENERGY) and several consulting and subcontracting firms.

During May, the last two hydraulic fracturing operations were completed, with a final total of four parallel and approximately horizontal hydrofractures successfully created in preparation for the explosive fracturing event. Downhole television logging was initiated in order to locate the fractures; this logging was accomplished in conjunction with well pressurization to force water through the fractures to enhance crack visibility. Posthydrofracture hydrogeological testing was initiated by Science Applications, Inc. (SAI) in observation wells 01 through 06.

In the month of June, the posthydrofracture seismic evaluation of the formation using the High-Resolution Seismic Reflection Survey (HRSRS) and Cross-Hole Seismic Survey (CHSS) systems was performed. Posthydrofrac flow testing and tracer gas studies were conducted by TALLEY ENERGY and Systems, Science and Software (S³) personnel. Downhole television logging was completed, with all hydraulic fracture intersections located and plotted. Gamma-ray logs were completed and evaluated using several different methods of radioisotope tracing. More Sandia instrumentation arrived on-site during this period. TAD TECH completed the detonation system to the point of final qualification testing. Environmental modeling for the Spring season was conducted and the Environmental Plan was presented at Laramie Energy Technology Center (LETC; then LERC).

During July, six instrumentation wells (X, Y, Z, U, V, and W) were completed for Sandia. The Site 17 survey, including well elevations, was completed by Bennett-Carder and Associates. A directional survey of explosive-loading wells S1 through S5 and the above-listed Sandia instrumentation wells was performed by Sperry-Sun during this period. TALLEY ENERGY personnel completed the final qualification system testing for the detonation system in Mesa, Arizona. Sandia brought the majority of their equipment on-site in

preparation for the explosive fracturing event, and also conducted flow testing of the instrumentation wells. TALLEY ENERGY delivered explosive-loading equipment to the site.

More detailed descriptions of selected tasks are presented in the following sections.

May Activities

The third hydrofracture was scheduled for 7 May 1978. Preparations involved the withdrawal of Sandia's instrumentation strings from wells P4, P7, P10, P12, and P13. Explosive-loading well S2 was completed on 4 May to connect with the second hydrofracture. On 5 May, the downhole television logging of the production wells was completed; oozing water was observed from a new fracture at a depth of 399.8 feet, approximately the depth of the second hydrofracture.

The notching for the third hydrofracture was begun in explosive-loading well S5 on 6 May at a target depth of 393.25 feet. Hydrojetting was conducted at a water-to-sand mass ratio of approximately 8 to 1, a pressure of approximately 4,050 PSI, and a flow duration of some two hours. The notching was successfully completed at a depth of 393.3 feet. The notch was subsequently examined using the downhole television system; the notch appeared to be approximately 0.6 inches deep and extended completely through the casing wall into the oil shale formation.

Hydrofrac operations began on 7 May with the pressure testing of the pump equipment and the completion of all instrument checkouts. Breakdown of the formation occurred at approximately 730 PSI. The pressure was then raised to 910 PSI to reach the target flow-rate of three barrels per minute, at which time a constant flow was maintained at a pressure of about 810 PSI. An attempt was made to duplicate the flow phenomenon described in earlier reports. An effort was made to increase the pressure to 1,500 PSI; however, due to pump failure, this pressure was not achieved at a flow rate of 12 BPM.

A subsequent attempt was made with similar results. After communication was established with all wells, and a total of 3,907 gallons of frac fluid were injected, the pumping was discontinued. A one-hour period was observed where no activities were permitted; this allowed a natural subsidence of the pad, and the collapse was monitored on the tiltmeters. Initial downhole television logging confirmed that another approximately horizontal hydraulic fracture had been created.

On 8 May, drilling of explosive-loading well S3 was initiated to connect with the third hydrofracture; this well was completed by 10 May. On 12 May, preparations were completed to allow notching at a depth of 386 feet in hydrofracing well S5. Unlike the previous hydrofractures which were targeted for zones of weakness in the formation, the fourth fracture was to be initiated in an interval of competent oil shale.

The fourth notching operation was conducted in accordance with procedures previously described, with a sand-to-water ratio of about 8 to 1, a hydrojetting pressure of 4,050 PSI, and a flow duration of approximately 90 minutes. The notch was successfully created, but downhole television logging had to be conducted underwater due to drilling rig scheduling problems. The notch could not be seen clearly, but appeared to be adequate. It was determined during the first hydrofracture attempt that frac fluid flow was not increasing despite pressures of up to 2,225 PSI. Several attempts were made to achieve formation breakdown, but with little success.

The fracturing lines were then disconnected and the sand depth in well S5 was measured. The sand was found to be several feet above the newly created notch. The well was then blown out and resanded to just below the fourth notch. On 14 May, hydraulic fracturing operations recommenced.

Formation breakdown occurred at 1,450 PSI. The pressure remained near this value and the target flow-rate of three barrels per minute was reached. Despite high pressures, the hydrofrac continued uneventfully, and pressure and tiltmeter data indicated that communication had been established with all wells. Another attempt was made to reproduce the flow phenomenon observed during the first hydrofrac. The pressure was raised to 2,025 PSI before a flow blockage occurred; the flow rate was immediately reduced to prevent overpressuring. The blockage remained and the hydrofracture was terminated. A total of 3,360 gallons of frac fluid was injected.

Examination of hydrofracing well S5 showed that sand had again accumulated in the well-bore, causing blockage of the notch. It was ultimately found that the gelling agent was not able to keep the frac sand in suspension and thus, whenever sand was introduced with the frac fluid, most would settle out, eventually blocking the notch.

After hydrofrac completion, instrumentation was secured, sand was blown out of the wells, and preparations were made for drilling explosive-loading well S4 to connect with the fourth fracture. All posthydrofrac work went

smoothly except for the S4 completion; S4 suffered damage when the casing jumped during cementing. The known damage occurred at a depth of some 65 feet and consisted of a vertical crack in the well casing approximately 12 inches long and 0.4 inches wide. The repair of the casing took place in July and consisted of extracting the top two sections of well casing, sealing and reinforcing the break, recementing the casing, and pressure-testing.

The explosive-loading wells were then completed by drilling down approximately eight feet below the cement shoe in order to intercept the respective hydraulic fractures. This drilling was done with great care to reduce introduction of drill cuttings into the fracture. It was determined later, however, that these fractures were plugged despite our efforts to prevent blockage. This problem was remedied after the posthydrofracture formation evaluation by flushing water into the explosive-loading wells from well S5, and assured communication between the explosive-loading wells and their respective fractures.

During May, several major components of the retorting instrumentation systems were received. On 18 May, Dr. Robert Hecht-Nielsen, Director of Engineering, and Tom Gould, Senior Engineer, visited York Research in Denver, Colorado (where the equipment was delivered) to verify equipment operation and to define the technical detailing of systems integration. It was confirmed that the major interfacing problems had been solved.

Procurement efforts for retorting equipment was primarily involved with the delineation of possible equipment options. Possible equipment configuration alternatives were also explored in conjunction with retorting plans.

An extensive study of coproduced retort water management was completed in May. This study shall be refined and submitted to fulfill the requirements of Task 2.b. of the TALLEY ENERGY Environmental Research Plan.

A considerable amount of hydrofracture support activity was provided by the TALLEY ENERGY Engineering Department. This support included rock mechanics studies, hydrofrac location microlithology, and hydrostatic elongation calculations for long-tube geometries. Retort and fracture modeling efforts made substantial advances during this period. Fracture modeling work concentrated on the problem of fracture prediction for given stress states in an anisotropic solid. Work on the retort modeling involved detailed examination of several fluid-flow subroutines. The physical chemistry model of oil shale

retorting was also completed. Modeling efforts appear to be progressing well ahead of schedule, and general horizontal retort behavior predictions should be available in advance of retort ignition.

Design of the explosives loading procedures and optimization of the explosive detonation sequence were improved during this period. Two modeling approaches to the explosives loading problem were completed, and work on a third approach was started. A preliminary model has been derived giving crack opening as a function of time; this approach shall be further refined and is expected to yield the exact sequence that will be used during the explosive fracturing event.

June Activities

Activity during the month of June was concentrated on performing the posthydrofracture evaluation studies and preparing for the explosive fracturing event.

Posthydraulic fracture evaluation studies included the following: Downhole television logging of hydrofractures, gamma-ray logging, hydrogeological testing, environmental monitoring, high-resolution and cross-hole seismic reflection surveys, and formation flow and tracer gas studies.

Well-cleaning operations occupied the first week of June; sand and water were removed to below the hydraulically-induced fractures. Downhole television surveying was used to locate, identify, and record the hydrofracs; the results of this logging are shown in Figure 1. The method used to locate the fractures was to pressurize surrounding production wells with water at a pressure of 50 to 100 PSI; the downhole television could then be used to observe where water and/or air entered the well then under examination.

Several of the wells exhibited pre-existing porous layers that had connected with hydrofractures, and these leaked air although they were not true fractures. In well P13, one fracture appeared to be split into two intersecting cracks. Other than this, however, the fracture intersections were observed to be approximately horizontal circles. This preliminary evidence further confirms the analysis that four nearly horizontal hydrofractures were created.

The gamma-ray logging of the production wells was conducted in early June. The wells had been treated with both ^{131}I and ^{46}Sc , but the final

Figure 1 Downhole TV Log of Post Fracture Well Intersection Depths

results were disappointing. The gamma-ray log indicated either a large, but completely smeared-out gamma-ray source in the production zone, or that there was little or no gamma activity difference from the baseline data log.

The posthydrofracture hydrogeological testing was also completed in early June. All six hydrogeological wells (01 through 06) were pump-tested, and the resulting water samples tested for quality. Tables 1 and 2 show the results of this testing. In general, there were no significant changes in either water flow or quality.

The on-site environmental monitoring program was conducted during mid-June. A two week seasonal environmental survey was conducted which involved pilot balloon releases, ambient particulate measurements, wildlife surveys, aquatic impact review, and other activities called for in the seasonal monitoring task of the Environmental Research Plan. In addition, the automatic meteorological station continued to collect data throughout June on the following parameters: Wind speed and direction at 10 meters, humidity, insolation, evaporation rate, temperature, and average surface-level wind.

The on-site cross-hole and high-resolution seismic reflection survey studies began during the third week of June. These tests were conducted on a subcontracted basis by Systems, Science and Software (S³). As previously mentioned, there were a number of problems encountered by S³ which prevented the HRSRS system from correctly functioning prior to the hydrofrac operations. In brief, the connection delivering the computer-generated wave-form was hard-wired to the shaker amplifiers. This proved to be a reliable method of providing a precisely generated ground injection signal using an accurate and unvarying time delay.

Once this problem was overcome and another unexpected problem involving shaker wiring was discovered and corrected, the system was subjected to a preliminary test. Three sets of geophones were strung and recordings were made of the signals that were injected from a single shaker. One geophone string was installed in a rectangular pattern near the shaker. The other strings were laid out on the ground approximately 100 feet from the shaker. The computer was instructed to run three sequences of input and geophone data recording.

Table 1

Comparison of Prehydrofracture and Posthydrofracture
Water Quality From the Lower Aquifer (mg/L)

Parameter	Well 01		Well 02		Well 03	
	Pre-	Post-	Pre-	Post-	Pre-	Post-
Sodium	530	530	420	220	640	610
Potassium	10.0	3.6	3.0	2.5	23	12
Magnesium	<0.1	<0.1	0.2	6.1	1.2	1.1
Calcium	6.0	5.6	3.1	35	6.2	6.2
Ammonia	3.5	1.4	1.2	29	1.5	0.3
Chloride	95	90	81	45	270	270
Fluoride	11	9.4	11	3.6	7.3	6.2
Nitrate	0.02	0.01	<0.01	<0.01	0.02	0.02
Sulfate	35	19	1	150	143	156
Carbonate	150	180	135	15	205	130
Bicarbonate	870	830	845	510	845	920
Phosphate	0.05	0.04	0.16	0.07	0.05	0.11
TDS	1,445	1,200	1,235	1,060	1,990	1,750
Total Alkalinity	965	980	910	441	1,035	980
pH	9.05	9.41	8.77	8.45	8.97	9.24

Table 2

Comparisons of Time-Of-Arrival-Data Before and After Hydraulic Fracturing, msec.

Depth of Geophone From Surface (feet) ¹	INNER WELLS			
	Well P12		Well P14	
	Prehydrofrac	Posthydrofrac	Prehydrofrac	Posthydrofrac
432	11.250	11.875	9.875	11.250
416	9.000	-	8.750	10.250
406	8.500	9.250	8.125	9.250
396	8.500	8.750	8.000	9.125
386	8.000	8.375	7.500	8.000
376	8.000	8.500	7.000	7.375

Depth of Geophone From Surface (feet) ¹	OUTER WELLS			
	Well P4		Well P5	
	Prehydrofrac	Posthydrofrac	Prehydrofrac	Posthydrofrac
432	11.125	12.750	14.500	-
416	10.750	12.000	13.375	-
406	10.375	11.250	12.625	11.500
396	-	10.625	12.375	12.250
386	10.375	10.000	11.625	11.500
376	11.000	9.625	11.125	11.000

¹ Not corrected to well S5

The first sequence involved taking 10 successive inputs to each geophone and stacking their outputs. Subsequently, 32 and 64 inputs and stacked outputs were successfully recorded. After the experiment was completed, the stacked responses were cross-correlated with the input wave-form to see if any significant reflections had been obtained. Figure 2 shows results of one of these tests. The output wave-forms of the cross-correlated data show that reflections from some underground feature was obtained.

It must be emphasized that these tests merely establish the capability of the HRSRS to generate, inject, receive, stack, and sort swept seismic signals ranging in frequency from 70 to 300 Hz. Simply stated, the system only proved its ability to detect reflected signals from an unknown reflector. The system's ability to actually operate in a high-resolution mode and resolve small (approximately 20 feet) features has not been established to date. In addition, the above test used only one shaker and was carried out under well-controlled conditions at La Jolla, California and thus does not represent a true field result.

Following the above test, the system was brought to Wyoming to conduct posthydraulic-fracturing formation evaluation. The first tests on-site involved systematic verification of HRSRS component equipment performances. The first of this series of tests involved placing geophones in various production wells and recording their responses to the shaker input. These tests successfully recorded and stacked the shaker inputs at depths of up to 450 feet. Figure 3 illustrates the locations used during this testing.

The next test involved measuring the responses of surface geophones to the shakers as a result of seismic transmission across the earth's surface. These experiments showed an unusually high sonic velocity for the signal traversing the surface from the shakers to the geophones. This has been attributed, however, to a shallow layer of high-sonic-velocity rock near the surface in the vicinity of the pad.

Beyond these tests, much time was spent attempting to diagnose a problem that had arisen in the incoming geophone signals. Interference signals connected with the injection wave-form were found to be disrupting the first portions of each geophone signal. It was thus impossible to use these signals. Although this problem was at least partially resolved in the field, the fact that no reflections had been seen on the downhole geophone responses

Figure 2 Typical HRSRS Stacked Response (La Jolla, California)

Figure 3 Location of Shakers During HRSRS Tests

during the initial component test (prehydrofracture) led to the conclusion that further system refinement would be necessary before a reflection survey could be successfully accomplished. Testing of the HRSRS ended once this conclusion had been reached. The net result of this HRSRS test was that no usable formation data were obtained.

The posthydrofracture testing of the CHSS occurred in mid-June, 1978. The CHSS system was run in a very similar manner to the prehydrofracture tests. The few changes in the tests involved the fact that well S5 was now cased, whereas in the prehydrofracture it had been uncased. There were also different amounts of water in the wells.

As before hydrofracture, the geophones were clamped in production wells and the explosive line-charge seismic source was again detonated at various depths in well S5. Figure 4 (A,B,& C) presents examples of geophone response traces.

Each geophone contained three orthogonal, single-axis accelerometers as sensing components. Typically, the vertical component represents the most unequivocal data in that this response is in a known direction. The results of these tests were essentially the same as those done prior to hydrofracture. It would not be expected that any but the largest interface features would be detected; thus, the primary useful information obtained relates to the sonic velocity in the rock (time-of-arrival data). Figure 5 presents a comparison of the time-of-arrival data as a function of source depth for both the prehydrofracture and posthydrofracture test runs.

In some instances the transient time increased and in others it decreased; thus, no clear interpretation of these data can be made. Except for time-of-arrival data for wave formation, the geophone responses contained no usable information other than a reflection feature from a reflector located at a depth of approximately 490 feet. This unidentified reflector had been detected on most of the prehydrofracture output traces; however, during the posthydrofracture testing, only the traces from well P8 show this feature. No conclusions have been drawn from these data.

In light of the demonstrated lack of spacial resolution and the inability to interpret the time-of-arrival data, the CHSS system has not demonstrated the capability to provide useful information on our formation.

The formation flow testing and tracer gas studies were also conducted by S³ beginning in mid-June in two stages. The first stage involved determination of air flows using pressurized air from wells S2 and P16 to other wells. The

Figure 4A Typical CHSS Geophone Response (Vertical Component)

Figure 4B Typical CHSS Geophone Response (Longitudinal Component)

WELL P4

Figure 4C Typical CHSS Geophone Response (Tangential Component)

Figure 5
Comparisons of Time-Of-Arrival-Data Before and After Hydraulic Fracturing, msec.

Depth of Geophone From Surface (feet) ¹	INNER WELLS			
	Well P12		Well P14	
	Prehydrofrac	Posthydrofrac	Prehydrofrac	Posthydrofrac
432	11.250	11.875	9.875	11.250
416	9.000	-	8.750	10.250
406	8.500	9.250	8.125	9.250
396	8.500	8.750	8.000	9.125
386	8.000	8.375	7.500	8.000
376	8.000	8.500	7.000	7.375

Depth of Geophone From Surface (feet) ¹	OUTER WELLS			
	Well P4		Well P5	
	Prehydrofrac	Posthydrofrac	Prehydrofrac	Posthydrofrac
432	11.125	12.750	14.500	-
416	10.750	12.000	13.375	-
406	10.375	11.250	12.625	11.500
396	-	10.625	12.375	12.250
386	10.375	10.000	11.625	11.500
376	11.000	9.625	11.125	11.000

¹ Not corrected to well S5

second stage involved determining air flows using tracer gases from well P16 to other wells. The original plan called for the use of wells S1 through S4 for injecting air and tracers but, due to borehole damage, the lack of well communication prevented this initial procedure and, after the first week, well P16 was used.

The pressurized air flow testing was accomplished in three separate experiments. The first used well S2 to pressurize the formation in an open-hole manner, the second used well P16 in a like fashion, and the third used well packers to make flow tests from well P16 to selected sections in other wells.

Tracer gas flow tests were used to provide a direct measure of gas penetration from well P16 through the field both in the horizontal and vertical directions. A semiquantitative determination of the horizontal penetrations evidenced by these tests support the conclusion that the hydrofractures were more open in the north and northwest sections of the field than they were in the south and southeast sections of the field. Figure 6 shows the air flow through the fracture system resulting from application of 44 PSI air pressure on well P16; the tracer gas studies showed similar results.

The tracer gas data were also used to give an estimate of the penetration of the tracers from fracture 1 to fractures 2, 3, and 4, and from fracture 3 to fractures 1, 2, and 4. Many conclusions are allowed by examination of the tracer gas data. A summary of these conclusions is that the data do indeed show vertical penetration between the hydraulic fractures. The vertical flow is shown to be greater from fracture 3 than the flow along hydrofracture 3; this cannot occur unless vertical fractures are present.

System pressurization rates, sustained differential pressures, and tracer gas velocities among the 16 production wells are all consistent with fracture widths in the range of 0.001 to 0.006 inches. Unfortunately, there are no such flow data available for the S1 through S5 wells in the center of the field. If the average fracture thickness for the entire field is 0.01 inches, as indicated for some of the inner P-wells, then the average fracture thickness within the 50-foot radius is calculated to be 0.05 inches.

All test data indicate that the fractures within the retort are nonhomogeneous and that some fractures do not penetrate all 16 production wells. These indications are not surprising when the complexity of the formation is considered as well as the fact that the formation attempted to return to its

Figure 6 Schematic showing air pressure throughout fracture system 18 hours after well S2 had been shut in at a pressure of 100 PSI.

original configuration following each hydrofracture. The lack of homogeneity of each resulting fracture is the product of the failure of the formation to complete this transition.

In general, the posthydrofracture air and tracer-gas pressurization studies indicate that the retort region is fractured. However, the fracture widths are small and, thus, air flow within the system is generally restricted. In the region of the production wells, typical fracture widths are on the order of 0.001 inches. If, as indicated by pressure data, the average fracture width for the entire retort is 0.01 inches, then the corresponding increased void space most likely occurs in the center of the field. If this void space is contained within a 50-foot radius of well S5, then the fracture width in this region may be on the order of 0.05 inches.

These tests were carried out using air at driving pressures much lower than the overburden lithostatic pressure. Given this driving pressure, a moderate to high-viscosity liquid will not readily flow through the narrow fractures. The ease of reopening the fractures as necessary to obtain the required liquid flow depends not only on the initial fracture widths measured during these tests but also on the material strengths, overburden, fluid viscosity, and fluid pressure. As a result, it cannot be expected that the slurried-explosive flow patterns will necessarily be identical with the open-flow patterns obtained during these low-pressure air tests.

Sufficient data were obtained during these tests to characterize the hydrofracture flow properties of the TALLEY ENERGY retort, particularly in the region of the 16 production wells. These data may be used as a base for evaluation of the results of the next series of tracer gas pressurization tests scheduled to occur after the retort is explosively fractured.

After completion of the four hydrofractures, the sand and water were blown out of the production wells and the formation was pumped dry. The downhole television was then used to survey all of the production wells for the purpose of locating changes (fractures) that had occurred since the pre-hydrofracture baseline survey had been taken. To allow visualization of the hydrofractures, the following procedure was used.

A production well was chosen and air at 125 PSI was injected into it. As the air was being injected, the downhole television camera was lowered into nearby production wells to observe water or bubbles issuing from the cracks where the hydrofractures intersected the wells. Although this method was limited by the fact that the injected air followed the path of least resistance, it was possible to see a great many fracture intersections. Figure 1 presents the data obtained by this means.

Observed downhole fractures took the forms of either clearly discernable fractures issuing water and/or bubbles, or of porous zones exuding water and/or bubbles. Other than the fractures observed using the above-listed procedure, the only changes from the prehydrofracture baseline survey were that the formation in the open-hole segments of the wells seemed to have undergone some probable oxidation (based on their slightly darker appearance) and that the quantity of natural gas issuing from the M-bed seemed to be somewhat reduced.

Evaluation of the downhole television data indicates that four approximately parallel hydrofractures were created. If the parallel fractures traverse planes of weakness, then this is evidence that in the area of the retort the formation dips approximately two to four degrees to the WNW and strikes to the SE.

Gamma-ray logs were obtained shortly after each hydrofracture and also three weeks after the fourth and final hydrofracture. Radioactive iodine (^{131}I) was added to the frac fluid for the first hydrofracture. Ideally then, the gamma-ray log taken immediately after the first fracturing step would show a ^{131}I "spike" at the location of that fracture in each production well. Figure 7 is the gamma-ray log of wells P1, P5, P8, P10, and P11. These logs do not show the intersection of the hydrofracture with the wells. However, they do show that wells P8 and P11 had large amounts of radioactivity below 385 feet, that wells P5 and P10 had a slight increase below 385 feet, and that well P1 remained unchanged from the prehydrofracture log shown in Figure 8.

These data then show that the fracturing fluid reached wells P8 and P11 in quantity, that it reached wells P5 and P10 to a lesser degree, and did not reach well P1. The conclusions are not entirely supportive of the pressure, resistivity, tiltmeter, TV, and flow tests which unanimously indicate that hydrofracture number one progressed mostly to the north and northwest and less to the south and southeast.

On the other hand, the gamma logs shown in Figure 9 do not completely deny the above conclusion. That is, they show the largest communication to the north and west (P8 and P1) with none reaching the far north-northwest well (P2) and a lesser communication to the northwest (P10) and to the southeast (P5).

For the second hydrofracture, radioactive scandium (^{46}Sc) was added to the Oklahoma Fines sand to see if the fracture intersections could be discerned

by a gamma-ray log following the hydrofracturing. Figure 9 shows the gamma-ray logs of the same five P-wells as Figure 7 showed for the first hydrofracture. For this test, well P1 remained unchanged from prehydrofracture and well P5 had returned nearly to the prehydrofracture level; well P10 showed a major accumulation of radioactive material below 385 feet; and wells P8 and P11 showed additional major accumulations below 375 feet. Thus, the interpretation of the gamma-ray log data from the second hydrofracture are not significantly different than the first one. The labelled sand penetrated northwesterly to a line between wells P8 and P11 but not as far as well P1. Southeasterly, the sand did not penetrate to well P5.

Figure 10 shows the gamma-ray logs of the same five production wells taken three weeks after the fourth and final hydraulic fracture. Before the logs were obtained, the sand and water were blown out of the production wells and the formation was pumped dry. The noteworthy thing that is evident from these logs is that the gamma activity in each well had returned to its prehydrofracture level (Figure 8).

During each of the hydrofracture operations, two arrays of instrumentation were installed by Sandia Laboratories into selected wells. Sandia also provided an array of pressure transducers and resistivity stakes placed on the surface. This real-time data collection was managed by a computer-directed data signal-conditioning system housed in Sandia's B49 instrumentation trailer. This instrumentation provided for pressure measurements, resistivity measurements, hydrophone data, and crack-opening measurements.

During each hydrofracture, pressures were recorded from transducers located at the well-head on each production well and downhole as shown in Figure 11. In addition, the pump truck had pressure and flow transducers attached to the hydrofracturing flow line. Pressure data was displayed in graphical form during the hydrofrac for use in diagnosing and controlling hydrofracture progress and was also stored on magnetic tape for later processing and evaluation.

Pressure data was reduced to two presentation formats following the hydrofractures. One format was a graphical display plotting the pressure of a given transducer as a function of time (See Figure 12). The other presentation was a polar-coordinate plot of fracture growth as a function of total injected fluid volume (produced by Mr. R. R. Beasley of Sandia) (See Figure 13). This polar plot uses the time-of-pressure-rise in the outer production wells

DOWNHOLE DEPTH (APPROX-NOT ADJ TO S5)

Figure 11 Downhole Hydrofracture Instrumentation

Figure 12 Hydrophone Level and Wellhead Pressure VS Time (Typical)

Figure 13 Hydrofracture Geometry as a Function of Injected Volume for Hydrofracture No. 1

to establish an average fluid velocity in each of the eight radial directions determined by the outer production wells. The plot shows the assumed shape of the first fracture (based on the assumption of constant radial fluid velocity in each of the eight directions NNW (P1), WNW (P2), etc.) at times corresponding to injected fluid volumes equal to $\frac{1}{4}$, $\frac{1}{2}$, and total fluid volume injected. Figure 14 shows the composite final fluid configurations of all four hydrofractures based on these calculations for each of the four hydrofractures.

An array of resistivity stakes were monitored to determine changes from the baseline pattern of resistivity. These were recorded during each hydrofracture for analysis at a later time. The analysis of these data involves the use of a computer model that relates changes in surface resistivity to the movement of the conductive frac fluid at depth. The results of this analysis are presented as a series of contours giving the fracture shape at various times during the hydrofracture. Figure 15 shows the location of the 52 measuring points and the fluid contour derived from resistivity data for the first hydrofracture.

The resistivity experiment was difficult to perform because of the need to insulate the blender, pump-truck, and flow line from the ground. As a result of the difficulties encountered in actually making this system work in a field environment, reliable data were not collected for all of the hydrofractures.

Wells P2, P4, P7, P10, P13, and P16 were equipped with hydrophones during the hydrofracturing operations (See Figure 11). The hydrophones were expected to record any noise associated with the interception of the production well by the fracture. For example, this noise might be associated with the cracking of the rock, the influx of water, or the turbulent movement of material within the well. Hydrophone data were recorded as audio signals during each hydrofracture. Reduction of these data involved a determination of overall level and frequency as a function of time. Figure 16A presents a typical hydrophone response. While there is some correlation between the hydrophone audio signal and the rise of pressure within the well, it has not been determined what caused each component of the recorded audio signal.

An attempt was made to measure crack opening of the hydrofracture during each hydrofracture operation. An LVDT string was installed in each of wells P10 and P13 (See Figure 11) with the intention of measuring the change in distance between the magnet and foot as the fracture intersected the well.

Figure 14 Composite of Final Hydrofracture Geometry Based on Well Pressures
Using Wells P1 Thru P8

MEASURING POINTS		RADIUS
RING 1	RESISTIVITY 1001-1012	48'
RING 2	WELLS P9-P16	71'
RING 3	RESISTIVITY 2001-2012	92'
RING 4	WELLS P1-P8	113'
RING 5	RESISTIVITY 3001-3012	262.5'

CODE:

- ⊙ INJECTION WELL S5
- ⊗ PRODUCTION WELLS P1-P26
- △ RESISTIVITY
- FRACTURE LINE

Figure 15 Resistivity Measurement Points and Calculated Hydrofrac Boundary for Hydrofracture No. 1

Figure 16A Typical Hydrophone Response

Figure 16B Typical LVDT Response

Figure 16B presents a typical response from an LVDT during hydrofracture operations. While the first movement of the LVDT certainly correlates with the rise of pressure in the well, the subsequent behavior is not easily explained and clearly does not give a true indication of fracture width.

During each hydrofracture, an array of 10 tiltmeters was used to monitor the fracture-growth pattern. The locations of the tiltmeters are shown in Figure 17. The tiltmeters were sensitive in the 10^{-9} radian range, and the radial and tangential tilt components of the fracture were monitored for each tiltmeter. The tiltmeter data were used in two ways: (1) real-time graphical displays of the radial extent of each tiltmeter were used to give a dynamic estimate of the fracture growth pattern, and (2) both the radial and tangential tiltmeter responses were recorded for later use in determining the final, theoretical boundaries of each hydrofracture. An estimate of the boundaries of each fracture was input into a tiltmeter fracture model and the radial and tangential responses that were predicted from that input were compared to the responses actually obtained. This curve-fitting process was repeated until a satisfactory fit of the data was obtained. Figure 17 presents the derived boundaries for all four fractures.

July Operations

Instrumentation wells X, Y, Z, U, V, and W were started on 12 July and were completed 24 July 1978. The initial plans called for the completion of only three wells; however, calculations indicated three additional wells on a larger radius (50 feet versus 25 feet) were required in order to yield the data that were required. These additional wells allow the monitoring of time-of-arrival as well as the downhole pressures and crack-opening measurements that were initially planned for the explosive fracturing event.

Downhole television surveys were then made of the instrumentation wells to determine the intersection with the fractures and aquifers. These surveys presented a problem in that the wells were filled with water that was extremely turbid, with small suspended particles that prevented adequate visual observation. A concurrent problem was that the instrumentation wells also had borehole damage which prevented the water pumped under pressure from the explosive-loading wells, S1 through S4, from flowing through the fractures that had been previously created.

CODE:

⊗ PRODUCTION WELLS

⊙ TILTMETER SITES

— FRACTURE BOUNDARIES

Figure 17 Tiltmeter Locations and Composite Fracture Boundaries

TALLEY ENERGY personnel, in conjunction with a flow-logging expert from Sandia, decided to pressure-up the S-wells to between 400 and 600 PSI to attempt to stimulate flow. It was found, however, that the water primarily sought the paths of least resistance, and very little flow was observed through the fractures in the S-wells. This method was attempted until a total of some 800 barrels of water had been pumped in, filling the production wells; pumping was discontinued at that time as there was a possibility that several of the hydraulic fractures might be extended. It was determined that four wells had communication through three fractures, and that two wells had communication through one fracture before the flow logging procedure was terminated.

Mathematical calculations were derived to determine the remainder of the fracture intersections in order to locate the instrumentation in the six wells. These calculations were completed on 5 August, and the instrumentation installation began at that time.

A complete survey of all well elevations was conducted by Bennett-Carder beginning on 25 July and was completed on 15 August. Table 3 shows the surveyed well elevations.

A directional survey of the explosive-loading wells (S1 through S5) and the instrumentation wells (X, Y, Z, U, V, and W) was conducted by Sperry-Sun from 24-26 July and the results are included as Figure 18. Deviation from the vertical was found in several wells, primarily due to the drilling problems encountered during the rainy season.

The detonation system final qualification testing was conducted in mid-July by TALLEY ENERGY personnel in Mesa, Arizona. Two tests were run to determine whether the detonator system would function normally and would withstand the shock.

The first test utilized an annular ring of TAL-1005E slurried explosive which was assembled 10 inches above the detonator on the outside of a piece of 10-inch well casing (See Figure 19). An unactivated detonator was used for this first test; after the test shot, it was discovered that the detonator housing was intact, with no water leakage. The detonator was manually tested and fired normally; it was noted, however, that the reed switches appeared to have suffered some damage.

The second test was conducted exactly the same as the first test except that this detonator was activated before the explosive test, with its internal

Table 3. Well Elevations⁽¹⁾

WELL #	ELEVATION (FT ABOVE MSL)	REFERENCE POINT
P1	6354.28	Bracket Top ↓ Bracket Top Collar Top ↓ Collar Top Scribe Mark Collar Top ↓ Collar Top
P2	6351.76	
P3	6351.71	
P4	6354.20	
P5	6357.07	
P6	6358.37	
P7	6357.29	
P8	6355.13	
P9	6354.12	
P10	6352.76	
P11	6351.61	
P12	6353.16	
P13	6356.51	
P14	6354.18	
P15	6356.93	
P16	6355.35	
O1	6353.45	Collar Top ↓ Collar Top Scribe Mark Collar Top ↓ Collar Top
O2	6357.00	
O3	6351.61	
O4	6354.73	
O5	6351.47	
O6	6354.55	
S1	6354.98	
S2	6355.96	
S3	6356.10	
S4	6356.15	
S5	6355.10	Collar Top ↓ Collar Top
U	6356.76	
V	6355.53	
W	6353.99	
X	6355.61	
Y	6355.04	
Z	6354.49	

⁽¹⁾ Per Bennett-Carder Survey, dated 8/15/78

HORIZONTAL DEVIATION (FT) AT MAXIMUM SURVEY DEPTH												
WELL	S1	S2	S3	S4	S5	U	V	W	X	Y	Z	WELL
N	-	-	-	17.515	-	-	-	2.85	1.03	-	-	N
S	2.073	22.906	30.111	-	4.874	0.44	1.67	-	-	1.52	10.80	S
E	1.231	1.634	12.006	5.027	0.748	0.83	4.25	2.59	4.28	0.49	8.09	E
W	-	-	-	-	-	-	-	-	-	-	-	W

Figure 18 Results of Sperry-Sun Directional Survey

Figure 19 Detonator Final Qualification Test System Assembly

timer operational. The test indicated that all of the reed switches were destroyed and shorted open; thus, all of the flashbulbs simulating the detonating caps had not fired. When the reed switches were shortened manually, however, the detonating caps all fired, indicating a functional detonator.

It was decided to encapsulate the reed switches in epoxy to cushion them from the shock and to prevent mechanical deformation. A detonator was then tested by dropping it 40 feet to check the reed switches; there was no damage found either internally or externally. The tests were then concluded and the detonators qualified for the explosive shot.

Sandia stationed their instrumentation trailers on-site 21 July, and the field personnel arrived on the 24th. Shot monitoring equipment was assembled and wired to the trailers approximately one-half mile from the pad (See Figure 20)(A&B).

During this period, assembly of all of the downhole instrumentation was accomplished. The computers used to record and monitor the explosive event were programmed and used to make initial checks of downhole instrumentation. These procedures continued up through the time of the explosive shot in August.

TALLEY ENERGY explosive-loading equipment arrived on-site early in July. The remaining explosive fracturing equipment such as the loading heads arrived later in July and were assembled. The compressors and tools used in the explosives loading were transported from our explosives manufacturing plant in Pryor, Oklahoma, and were pressure-tested. Equipment associated with the TAD-Tech detonation system also began to arrive on-site in late July.

TALLEY ENERGY personnel worked continually at repairing the borehole damage to explosive-loading wells S1 through S5 in preparation for the explosive event scheduled for 15 August. The casing damage to well S4 was completed during this period as previously described. The posthydrofrac report and the explosive fracturing plan were presented to Norm Merriam of LETC in late July and were later approved.

Projected Activities For The Fifth Quarter

The explosive fracturing event is currently scheduled for 15 August 1978. It will involve the rubblization of 40,000 ft² of oil shale formation to a depth of 40 feet by the injection of 68,000 pounds of TAL-1005E slurried explosive into four hydraulic fractures and the subsequent sequential detonation.

Figure 20A View of Site Showing Location of Trailers

Figure 20B View of Site From Inside Trailer
Showing Instrumentation Line

Immediately after the explosive shot, a preliminary analysis of the results will be conducted. Additional activities will include cleanup of the site, disassembly of the explosive fracturing equipment and transportation back to Pryor, Oklahoma, and cleaning out of the debris from the wells. Sand, water, and instrumentation strings will be removed from the wells, and the downhole television survey system used to determine extent of rubblization, borehole damage, and other formation characteristics. Well S4 will also be cleaned out completely through the oil shale formation so that it can be used as the air injection well during the retorting operations.

TALLEY ENERGY will submit for TPO approval a postexplosive fracturing plan. The postexplosive fracturing formation evaluation will then be conducted. This includes air flow tests using Sandia's flow logging apparatus; well logging utilizing LETC's caliper logs, and tracer gas studies with LETC's tracer gas equipment. In addition, directional surveys will be conducted on all 16 production wells.

Concurrently with the formation evaluation, the retort and production equipment and instrumentation will be set up. The pad configuration will be changed somewhat in that the field office will be relocated to the west side of the pad and will be used for an instrumentation trailer during retorting. In addition, a new road will be constructed to service several heated tanks which will be used for collection of retorted shale oil. Assembly and installation of process piping, pumps, and instrumentation (including the computer data logger) will continue into mid-November.

The final scheduled field operation during the fifth quarter is the autumn environmental monitoring. This will include pilot balloon launchings as well as continuing hydrogeological monitoring and evaluations.

Computer modeling for retort design and evaluation will be completed during this period. This modeling will be used to compare field test results to the parameters calculated as optimal for the retort system. The computer model will provide for the control, monitoring, and recording of at least the following data:

- (1) Temperature, pressure, and flowrate for each injection and production well;
- (2) Quality and quantity of water produced;
- (3) Quantity, quality, and composition of the oil produced;
- (4) Environmental data as required by the Environmental Research Plan;

- (5) Quantity and composition of the gas produced;
- (6) Measurement of the vertical temperature profile in the retort;
- (7) Seismic technique for monitoring the reaction front; and
- (8) Quantity and composition of air mixture injected.

TALLEY ENERGY's Engineering Department will also design and submit to the TPO for review and approval the optimal conditions for operating the retort to achieve the objectives set forth in Section I, Appendix A of Contract Number ET-77-C-03-1791.

APPENDIX A

Downhole TV Shot of Notch for Second Hydrofracture

BEFORE

AFTER

Downhole TV Shot of Fracture No.3 in Well P14

Flow Testing Straddle Packers and Control Panel

HRSRS Shakers

Downhole TV Equipment

[illegible]

TASK	1977					1978												1979			
	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
3.2 Pre-Hydraulic Fracture Cross-Hole Seismic Survey (S ³ Task 11.1)						==	==														
3.3 Pre-Hydraulic Fracture Tracer Gas Flow Survey (S ³ Task 12.1)						==	==														
3.4 Submit Pre-Hydraulic Fracture Evaluation Report (TESI)						△	△														
4 INSTRUMENTATION																					
4.1 Thermocouple Array																					
4.2 Crack Measuring Instrumentation																					
4.2.1 Obtain Production Prints From SANDIA							◇														
4.2.2 Manufacture Twenty Down-Hole Devices and Associated Materials																					
4.3 Resistivity Measurements to Determine Explosive Arrival (SANDIA)																					
4.4 Tilt Meter Measurements (SANDIA)																					
4.5 Acoustics																					
4.6 Impression Packers (TESI)																					
4.7 Air Flow Measurements (TESI)																					
4.8 Water Flow Measurements (TESI)																					
4.9 High-Speed Moving Pictures of Site Surface (SANDIA)																					
5 ENVIRONMENTAL IMPACT ASSESSMENT REPORT (SAI ONGOING)																					
5.1 Environmental Research Plan (SAI)																					
5.2 Hydrology and Water Resources																					
5.3 Meteorology and Air Quality																					
5.4 Biological and Health Effects																					
5.5 Effects on the Land and Reclamation																					
5.6 Societal Influences																					

2

[illegible]

[illegible]

TASK	1977					1978												1979			
	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
20.2 Restore Site Per Approved Plan																					
20.2.1 Plug and Abandon Wells																					
21 MONTHLY PROGRESS REPORTS		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
22 QUARTERLY REPORTS				□			□			□			□			□			□		□
23 DRAFT AND SUBMIT FINAL REPORT (TESI)																					△

3 a

3 b

14