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INVESTIGATION OF THE GEOKINETICS HORIZONTAL IN SITU
OIL SHALE RETORTING PROCESS

Fourth Annual Report, 1980

By
David L. Hutchinson

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INVESTIGATION OF THE GEOKINETICS
HORIZONTAL IN SITU OIL SHALE
RETORTING PROCESS

FOURTH ANNUAL REPORT
1980

by
DAVID L. HUTCHINSON
Editor

JAMES M. LEKAS
Project Manager

GEOKINETICS INC.
280 Buchanan Field Road
Concord, CA 94520

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PREPARED FOR THE UNITED STATES DEPARTMENT OF ENERGY

Under Cooperative Agreement #DE-FC20-78LC10787

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SUMMARY

The Geokinetics in situ shale oil project is a cooperative venture between Geokinetics Inc. and the U. S. Department of Energy. The project is governed by DOE Cooperative Agreement #DE-FC20-78LC10787. The objective is to develop a true in situ process for recovering shale oil using a fire front moving in a horizontal direction. The project is being conducted at a field site, Kamp Kerogen, located 70 miles south of Vernal, Utah.

This Fourth Annual Report covers work completed during the calendar year 1980. During 1980 one full-size retort was blasted. Two retorts, blasted the previous year, were burned. A total of 4,891 barrels of oil was produced during the year.

I. INTRODUCTION

The Geokinetics horizontal in situ shale oil recovery project is a cooperative venture between Geokinetics Inc. and the U. S. Department of Energy governed by DOE Agreement #DE-FC20-78LC10787. As the process was developed by private funds for a period of over two years prior to the contract, certain data are proprietary for a limited period of time.

The process is a true in situ process for extracting oil from oil shale. The oil shale is fractured by means of explosives placed in blastholes drilled from the surface. After a specific area has been fractured, thus creating an in situ retort, air injection holes are drilled at one end, the retort is ignited at the air injection wells, and air is continually injected to establish and maintain a burning front. The front is moved in a horizontal direction through the fractured rock. The burning front heats the oil shale ahead of the front, driving out the shale oil, which drains to the bottom of the retort, where it is recovered through oil production wells. As the burn front moves from the air-in to the air-out wells, it burns the residual coke left from the retorted oil shale as fuel. The combustion gases are recovered at the off gas wells. As this gas is combustible, it could be used as fuel for power generation. The process is designed to retort oil shale beds under relatively shallow overburden. However, the basic horizontal burn being developed can be applied to a number of other situations, including secondary recovery of oil from the pillars, floor and roof of a room and pillar mine, and in a modified horizontal in situ process.

The project site, Kamp Kerogen, is located 70 miles south of Vernal, Utah, in the north half of Section 2, R22E, T14S, on land owned by the State of Utah. Oil shale rights are leased by Geokinetics, and 320 acres are dedicated as a test site. Approximately 70 acres are underlain by oil shale. The Mahogany Zone is approximately 30 feet thick and has a grade of 23 gallons per ton. The beds strike in an east-west direction, and dip to the north at about 120 feet per mile. Overburden ranges from zero at places where the shale forms the surface of the ground to a maximum of 110 feet.

Geokinetics holds leases on 30,000 acres of oil shale land in the vicinity of the test site. These leases contain 273,000,000 barrels of shale oil in place with overburden thickness of less than 100 feet.

Prior to 1980, 23 retorts had been blasted and 13 retorts had been burned. This work has established the technical viability of the basic process, as follows:

1. It is possible to drill a pattern of blastholes from the surface into the oil shale and fracture the shale with explosives

to establish a zone of high permeability with a relatively impermeable zone between the fragmented shale and the surface.

2. It is possible to drill through the rubblized material and construct the various wells necessary for the operation, including air-in holes, off gas holes, oil recovery wells and instrument wells.

3. A point ignition can be made in the rubblized shale and expanded into a burn front that covers the cross section of the retort.

4. The burn front can be moved down the length of the retort as a cohesive temperature front, with satisfactory sweep efficiency.

5. Produced oil can be recovered from a well drilled to the bottom of the rubblized zone.

6. Recovery of in place oil of up to 50 percent can be achieved.

In addition, basic retorting parameters such as air injection pressures, air injection rates, rates of fire front advance and recovery factors were established on small retorts. A specific blasting pattern was selected to be scaled up to full size and a patent covering the "Walking W" blast design has been issued.

The environmental impacts of the process upon air, water, land, vegetation and animal life were under investigation. The Environmental Analytical Laboratory has been routinely running analyses of retort gas, stack gas and retort and ground water.

During 1980, Retort #25 was blasted, and Retort #18 was burned. Retorting equipment was fabricated and installed on Retort #24, and the retort was ignited near the end of the year. A number of significant environmental and operating permits were granted. Crude shale oil was sold to a number of refineries and research organizations for refining tests. Two patents were granted covering blasting technology. A number of foreign companies and governments have expressed an interest in the process.

Retort #18, which was ignited during the previous year, was operated until June 18, 1980. A total of 5,500 barrels of oil was produced from this retort. This represents 45 percent of the in place oil. On Retort #24, surface and underground construction was completed, and the retort ignited on November 30, 1980. Retort #24 was a full-size retort (230 feet long by 217 feet wide by 45 feet thick) and represented a major scale-up of all equipment, including the number of air injection and off gas wells (24 total), production wells (6) and observation wells (10). The injection blowers and vacuum blowers were scaled up to 490 horsepower (HP) from a previous maximum of 80 HP. Power generation

facilities were increased from 650 HP to 3000 HP, including standby power. A new evaporation pond covering 1.5 acres was constructed. Air injection and exhaust manifolds, mist eliminators, air pumps, and afterburners were increased proportionately and represented a major construction effort. Start-up of the retort involved ignition of eight ignitor holes in a three day interval. By the end of the year, a stable burn front had been established and air was being injected at the rate of 3000 scfm. Retort #25 was blasted on July 18, 1980. This retort is the same size as #24, with minor modifications in the design to optimize fragmentation. The blast was very successful, and resulted in improved breakage of the oil shale with less damage to the overburden.

A number of significant permits were secured during the year. A PSD permit was granted by the EPA to cover anticipated air emissions for 1981 and 1982. An Underground Injection Control (UIC) permit was granted by the Utah State Department of Oil, Gas and Mining permitting construction of a deep well for underground disposal of retort waters. A geological study of the subsurface formations in the vicinity of the test site indicated excellent conditions for disposal of retort water at a depth of 5000 to 5500 feet below the surface. Additional permits were secured for operation of the camp facilities.

The environment program was very active. In addition to securing the PSD and UIC permits, a new 1.5 acre evaporation pond was designed, permitted and constructed and revegetation studies continued or were initiated on eight spent retorts.

Sandia National Laboratories participated in the blasting of Retort #25 by providing high speed motion picture photography of surface motion at blast time. However, they were not able to field the normal array of blast time instruments due to limitations on their budget. As a result we were unable to gather as much data from this blast as we desired. This represented a serious loss of valuable information. Sandia ran tracer tests in a number of retorts to evaluate rock fragmentation and flow permeability. Sandia also finalized plans for instrumenting the burn of Retort #23. Retort #23, a relatively small retort (100 feet long by 50 feet wide by 24 feet thick) will be heavily instrumented by Sandia and operated to yield the maximum amount of retorting data. Design and acquisition of instrumentation was completed during the year.

An extensive post-burn coring program was completed on Retorts #16 and #17. A total of 28 core holes were drilled, including two core holes drilled outside the retort zone as baseline samples. Extensive chemical and mineralogical tests will be made on the cores. In July 1980, a core showing was held in Vernal, Utah, where representative post-burn cores from this drilling program were displayed to interested parties.

Two patents were granted during the year covering blasting techniques.

At the beginning of the year, we had 6,233 barrels of shale oil in storage. Production during the year was 4,890 barrels and 6,240 barrels were sold to refineries and research organizations for refining tests. On a test for the U. S. Department of Defense, Hydrocarbon Research, Inc. successfully hydrotreated 1,000 barrels. Forty percent of the yield met military specifications for jet fuel, and the remainder was an excellent fluid catalytic cracker feedstock. Western Refining Company, of Salt Lake City, Utah, ran a number of blending tests and marketed a blend as #5 fuel oil to a selected group of industrial users.

Representatives from a number of oil shale companies visited Kamp Kerogen, and indicated an interest in applying the LOFRECO process to their oil shale holdings. Geokinetics participated in the Moroccan Oil Shale Colloquium sponsored by the Kingdom of Morocco, the U. S. Department of State and the DOE. The Moroccan Bureau of Mines indicated a great interest in the application of the LOFRECO process to Moroccan oil shale deposits.

II. DEVELOPING THE LOFRECO PROCESS

Kamp Kerogen, Utah

A Pictorial Story

1974 — 1980

The LOFRECO Process

In the LOFRECO Process, a pattern of blastholes is drilled from the surface, through the overburden, and into the oil shale bed. The holes are loaded with explosives and fired, using a carefully planned blast system. The blast results in a fragmented mass of oil shale with high permeability. The void space in the fragmented zone comes from lifting the overburden, producing a small uplift of the surface.

The fragmented zone constitutes an in situ retort. The bottom of the retort is sloped to provide drainage for the oil to a sump where it is lifted to the surface by a number of oil production wells. Air injection holes are drilled at one end of the retort, and off gas holes are drilled at the other end. The oil shale is ignited at the air injection wells, and air is injected to establish and maintain a burning front that occupies the full thickness of the fragmented zone. The front is moved in a horizontal direction through the fractured shale towards the off gas wells at the far end of the retort. The hot combustion gases from the burning front heat the shale ahead of the front, driving out the oil, which drains to the bottom of the retort, where it flows along the sloping bottom to the oil production wells. As the burn front moves from the air-in to the off gas wells, it burns the residual carbon in the retorted shale as fuel. The combustion gases are recovered at the off gas wells. This gas is combustible and could be used for power generation.

The initial costs involved in starting a production operation using this technique are relatively low and start-up time is short. The process eliminates the need for a mine and relating mining equipment, surface retorts, and all rock moving machinery and their attendant problems, both environmental and financial. The equipment required includes a number of drill rigs to drill the blastholes and subsequent injection wells, off gas wells, and oil production wells. Low pressure blowers are used to provide air to the retort and small oil field type pumps are used to lift the oil to the surface. The off gases from the retort are moved at low pressure through thin walled, large diameter pipe to

scrubbing units to remove the sulfur compounds, and are then burned.

The process so far has been applied to areas where the overburden is relatively thin. At the present time we do not know what the upper limit of overburden thickness will be. We have effectively blasted retorts with 55 feet of overburden, and expect that we can go to thicknesses of 100 feet. How much beyond 100 feet we can go we will learn as testing continues.

There are many locations amenable to the process in the United States and throughout the world. In the United States, there are large areas in Utah and Wyoming where the oil shale beds are within 100 feet of the surface. In Brazil, a significant portion of their widespread oil shale deposits is at relatively shallow depth. In Australia, the Julia Creek deposit in central Queensland includes a very large area with less than 120 feet of overburden. Morocco has extensive deposits of oil shale amenable to the process.

Since the beginning of the testing program in 1975, a total of 24 test retorts have been blasted to develop blasting methods and retorting parameters and procedures. In testing these retorts, 15,000 barrels of shale oil have been produced. Two full-sized retorts have been blasted, measuring 214 feet by 230 feet in area, with a thickness of oil shale of 30 feet. One of these retorts was ignited on November 28, 1980.

A commercial operation would consist of a number of such retorts burning at the same time and each producing from 100 to 200 barrels per day. Each retort would have a life of six to eight months, with an estimated production of 15,000 to 25,000 barrels of oil. A self-contained production unit would produce from 2,000 to 3,000 barrels of oil per day.

Our objective is to recover fifty percent of the oil in place within the boundary of the retorts. Recent retorts have had recoveries close to this, and we believe we will be able to achieve or exceed fifty percent recovery.

Company Properties

Since March of 1975, Geokinetics has been steadily increasing its holdings of oil shale leases. We currently lease 30,000 acres in the southeastern part of Uintah County, Utah. The company commissioned T.N. Beard, consulting geologist, to make a study of the oil shale resources on these lands. The Beard

report estimates that our leases contain 1,749,000,000 barrels of oil in place. Of this total resource, 273,200,000 barrels are amenable to the LOFRECO process. Assuming 40 percent recovery, the reserves recoverable by the LOFRECO process would be 109,000,000 barrels.

INITIAL DEVELOPMENT OF THE LOFRECO PROCESS WAS CARRIED OUT
IN 1974 AT THE GEOKINETICS FACILITY AT CONCORD, CALIFORNIA.

IN 1975 WE ACQUIRED OUR FIRST OIL SHALE LEASE
IN A REMOTE AREA 70 MILES SOUTH OF VERNAL, UTAH.

A PRIMITIVE FIELD CAMP WAS IMMEDIATELY SET UP AND
CHRISTENED "KAMP KEROGEN."

BLASTHOLES WERE DRILLED TO DEVELOP A BLASTING TECHNIQUE THAT WOULD FRACTURE THE OIL SHALE, AND LEAVE THE OVERBURDEN RELATIVELY UNDISTURBED.

THE FIRST TEST BURN WAS COMPLETED IN MARCH OF 1976, PRODUCING
28 BARRELS OF SHALE OIL - THE FIRST SHALE OIL PRODUCED IN UTAH.

KAMP KEROGEN TODAY.

BLASTHOLES ARE NOW DRILLED WITH A LARGE ROTARY DRILL.

THE BLASTHOLES ARE LOADED WITH IRECO LIQUID EXPLOSIVE
SLURRY PUMPED DIRECTLY FROM SPECIAL TRUCKS.

THE SANDIA NATIONAL LABORATORY ASSISTS OUR BLASTING PROGRAM BY TAKING HIGH SPEED MOTION PICTURES OF THE SURFACE MOVEMENT AT BLAST TIME.

SOPHISTICATED EQUIPMENT IS USED BY SANDIA TO
COLLECT VITAL TECHNICAL INFORMATION AT BLAST TIME.

BLAST OF RETORT #24 - NOVEMBER, 1979

EQUIPMENT EMPLACED ON RETORT #24. PRESSURE BLOWERS FOR INJECTING AIR INTO THE RETORT (ABOVE), AND VACUUM BLOWER FOR REMOVING THE OFF GASES (BELOW).

RETORT #24 AIR INJECTION BLOWERS AND WELLS (ABOVE) AND OFF GAS WELLS, COLLECTOR PIPES, VACUUM BLOWER AND GAS AND OIL HANDLING EQUIPMENT (BELOW).

POWER PLANT FOR GENERATING ON SITE ELECTRICITY.

PIPING FOR HANDLING OFF GASES

OIL PRODUCTION WELLS.

GOVERNOR SCOTT MATHESON OF UTAH VISITS KAMP KEROGEN.

OIL STORAGE TANKS.

LOADING OIL INTO TANKER TRUCK FOR SHIPMENT.

MITCHELL A. LEKAS, PRESIDENT OF GEOKINETICS, SIGNS THE BILL OF LADING FOR THE FIRST SHIPMENT OF UTAH SHALE OIL.

III. DRILLING TECHNIQUES

1. Blast Hole Drilling

Blasthole drilling for Retort #25, our second full-size retort, began in March and was completed in May. All drilling was performed using the company-owned CP-C650 drill rig and Geokinetics personnel. The blasthole diameter was 8-1/2 inches on all of the 211 blastholes, with an average blasthole depth of 84 feet. This blasthole depth exceeded the capability of the drill rig for lifting cuttings out of the hole, and approximately 10 feet of cuttings were left in each hole. These cuttings and any groundwater were removed prior to explosive loading by means of two 750 scfm air compressors attached to air hoses which were lowered down each hole to blow out water and cuttings. The drilling rate averaged 328 feet per day, including moving and setup time between holes.

During August of 1980 a new blasthole drilling technique, utilizing a down-hole vibro-rotary hammer, was tested. This prototype unit was field tested for the first time at Kamp Kerogen. During our test with various bit types, penetration was increased 35 percent over conventional rotary drilling. Further testing is planned which will evaluate the hammer's full potential in oil shale drilling.

2. Re-entry Drilling

Air injection and extraction wells, production wells and instrument wells must be drilled and cased before a retort can be burned. The drilling and casing of these wells present unique problems since the retort zone has been fractured with explosives. All re-entry wells are logged during drilling to obtain indications of the degree of retort fragmentation achieved during blasting. New re-entry drilling techniques, as well as previously tested methods, were used during 1980.

The air injection wells provide air to the retorting zone, sustaining the fire front. Off gas wells are used to remove combustion gases from the retort.

Air Wells

These wells were drilled by Geokinetics personnel using the company-owned Chicago-Pneumatic CP-C650 air rotary drill rig and by an outside contractor using a CP-T650 rig equipped with a casing hammer and an underreamer. Geokinetics usually drilled the cased portion of each hole with an 8-inch diameter bit and cased it with 6-5/8 inch diameter steel pipe. A casing driver was used as needed. In this procedure the casing was set in the hole as deep as possible, a 6-1/8 inch bit was inserted through the casing and drilled a short distance, and the casing then

driven down behind the bit. This procedure was repeated until the casing reached the predetermined depth. An open hole below the casing was then drilled with the 6-1/8 inch bit to the bottom of the retort zone. There is generally about five feet of open hole left between the casing and the bottom of each air well.

Production Wells

Production wells are used to recover the oil and water produced during a burn. The bottom of the retort is shaped during blasting so that it slopes downward toward the air-out end, with troughs or channels running the length of the retort. Low points, or sumps, are located along these troughs, and the production wells are located in these sump areas.

Generally, the CP-C650 drill rig was used to drill 8-inch diameter wells. The wells were cased with 6-5/8 inch diameter steel pipe which was perforated at the bottom 30 to 60 feet. Packers were placed in the well annulus above the perforations. The well annulus was then stemmed using gravel in the rubble zone with cuttings and soil used nearer the surface. Production wells were drilled 10 to 15 feet deeper than the rubblized trough; this open hole serves as a sediment trap.

Instrument Wells

Instrument wells are used to monitor the temperatures and pressures within a retort. Thermocouples and other measuring devices are located in the instrument wells.

Instrument wells were drilled with a Gardner-Denver 3200 air trac and a 750 scfm compressor, using a 3-inch bit and foam circulation. The holes were cased with 1-inch steel pipe. The wells near the center axis of a retort were used as both pressure and temperature monitoring wells, which required two separate 1-inch pipes in the hole. The pressure monitoring pipes had 10 to 15 feet of perforations at the bottom of the well. Instrument wells adjacent to air-in wells were also equipped with double pipes to monitor temperature and provide gas samples.

Observation wells are used to monitor fluid levels in a retort and to collect gas samples. The observation wells were drilled with the CP-C650 drill rig.

New Drilling Techniques

Re-entry drilling into a rubble pile has unique problems. A hole must be drilled and cased into the rubble zone without reducing the permeability of the zone surrounding the well bore. In an effort to improve our re-entry drilling techniques, we have been investigating various drilling tools and machines. The end result is hoped to be a machine with the proper equipment to improve re-entry operations.

The process for drilling re-entry holes has been to drill the hole to a total depth using foam to keep the hole open. The casing is then rotated and driven into the hole to the desired depth. With this technique, most of the cuttings are lost to the formation, decreasing the well bore permeability. Also, substantial delays are encountered when the hole caves before the casing can be positioned.

In December of 1980, we tested a method used for water well drilling in cobble formations. The method utilizes a hollow casing driver that allows the drill string to pass through its center so that the casing can be driven behind the bit down the hole while the hole is being drilled. This provides a solid conduit for the cuttings to escape to the surface, and the casing operation is completed while the hole is being drilled. This method has encountered a few problems in its application to oil shale; however, the method promises to produce a significantly better well bore.

IV. RETORT FRAGMENTATION

Since the initiation of field test operations in 1975, a number of blasting patterns have been developed, tested, and the resulting retorts have been burned. From this work, a specific pattern has been developed, that we consider to be a viable blasting scheme that can be used for a commercial operation. Although this is a viable blasting system, we expect that it can be improved substantially as we gain experience in its use.

This system, designated the "Walking W", is described in U. S. Patents #4,205,610 and #4,223,734. Vertical blast holes are drilled from the surface, through the overburden and the oil shale bed. A pattern of holes at one end of the retort, designated the "initiation round" is fired first. The force of this blast is directed upward towards the surface, breaks the oil shale, and lifts the overburden. Before the uplifted formations at the initiation round settle back, successive rows of adjacent holes are fired using appropriate delays. The energy from these detonations is directed sideways, into the void created by the uplifted initiation round. The entire blast with all its delays is over in less than a second, and results in a surface uplift at one end of the retort, and a flat, uplifted zone over the remainder.

Two full-sized retorts have been fired to test this blasting pattern, #24 was fired in 1979, and #25 was fired in 1980. Retort #25 is 229 feet long by 217 feet wide, with an average overburden of 55 feet, which was an increase of 10 feet over Retort #24. The other dimensions were the same in both retorts.

Although Retort #25 is the same size and basic design as #24, a number of changes were made in the design that resulted in significantly better fragmentation.

1. The delay between the initiation round and the first row of W's was increased.
2. The powder column length in certain key holes was changed.
3. Bottom priming was used on most blastholes.
4. The powder factor was increased in the initiation round and decreased in the "W's." The overall powder factor was slightly reduced.

Retort #25 was blasted on July 18, 1980, using 79.4 tons of IRECO explosive slurry. Maximum post-blast surface uplift was 13.1 feet. The blast went as planned, with good lateral movement along the "W" rows, indicating the likelihood of good breakage

within the retort. There was some surface breakage above the initiation round.

In comparing the results of #25 with #24, the following improvements were noted:

1. In the venting of the explosive gases after the blast, no brown smoke was noted, indicating more efficient burning of the explosive.

2. From an operational standpoint, the loading, stemming and firing was much faster than with #24. This was largely due to dry summer weather. that enabled the loading trucks to maneuver easily over the round, and the use of bottom primers, which simplified the loading procedure.

3. The uplift over the initiation round was broader and flatter.

4. Post-blast core drilling indicated better breakage in the "W" section of the round.

The Sandia National Laboratories monitored the blast with high speed photography of the surface motion. Optical time of arrival devices (TOA's) were employed to designate the firing times of certain charges. There was one TOA gauge in each row of the W's, and some TOA's were placed on charges in the initiation round. These devices consisted of lengths of Ensign Bickford Nonel shock tube leading up out of the explosive column and positioned on the surface for optical (camera) data collection.

The complete suite of instrumentation that is normally fielded by Sandia at blast time was not available due to limitations in the Sandia budget. The understanding of blasting phenomenology provided by the Sandia instrumentation has been of great value in developing an effective blast design, and it is unfortunate that the full instrumentation program was not available for the #25 blast.

V. RETORTING EQUIPMENT

Retorts #18 and #24 were burned during 1980. The retorting equipment for those retorts is described here.

Retort #18

The surface facilities layout on Retort #18 is illustrated in Figure 10.

1. Power System - Electrical power for the operation of Retort #18 equipment was supplied from the Kamp Kerogen power grid. The primary source was a 200 kilowatt (KW) diesel-powered generator, with a 150 KW backup unit.

2. Blowers - Air was injected through three air-in wells using two Peerless centrifugal blowers rated at 2100 scfm at 1.25 pounds of static pressure and one Sutorbuilt positive displacement blower rated at 1000 scfm at four pounds pressure. Vacuum to the air-out wells was supplied by two Peerless blowers of the same type.

3. Surface Piping - The air-in blowers were connected to the air-in wells via a "Y" connection constructed of 10-inch diameter steel pipe. Retort off gas passed from the air-out wells to the mist elimination system and the afterburner through a similar manifold built from 10-inch diameter steel pipe.

4. Mist Elimination - Retort off gas was recovered at the air-out wells and passed through an Austin-Western type "T" mist eliminator to remove oil and water mist entrained in the gas stream. A secondary mist collection system was located downstream from the blowers. This system consisted of a five gallon tank welded in-line with a drain line to the mist sump. This tank functioned to remove the fluid which passed through the Wright-Austin mist eliminator and flowed along the bottom of the air-out manifold. The entire system was drained continually to the main separator tank by a Teel pump which drew a vacuum on the mist sump and the two drain lines. It was concluded that the Wright-Austin type "T" mist eliminator would function more efficiently on the pressure side of the air-out blower. This should allow for better drainage of fluids from the eliminator. Pressure in the type "T" unit would also aid in moving the fluids from the drain in the bottom of the mist eliminator to the sump. Another equipment modification suggested is the installation of a larger particulate screen between the mist sump and Teel pump. This would allow unrestricted flow for a longer period of time.

5. Afterburner - The afterburner was designed to combust retort off gas. The cylindrical steel structure stood 20 feet

high with a diameter of eight feet, and was lined with refractory. Two blowers were installed at the base of the afterburner to inject combustion air into the unit.

6. Production Wells - Retort #18 was equipped with four production wells. Two-inch diameter sucker rod pumps with an 18-inch stroke were hung on two-inch pipes. Recovered fluids were pumped to a 32-barrel capacity separator tank for gauging and transfer to the tank battery.

7. Instrumentation

a. Gas Flow - Nine orifice runs were used to measure gas flow into and out of the retort. Pressure differential was determined using U-tube manometers.

b. Retort Temperatures - A total of 56 thermocouple wells were drilled to the bottom of the retort zone and cased with one-inch steel pipe. Three of the wells were used only to monitor ignition temperatures. In each of the other 53 wells, four 1/16-inch chromel-alumel thermocouples were placed so that temperatures at four levels within the retort zone could be monitored. Thermocouple data was recorded with an automatic data recording system built by WestAq Corporation. Retort #18 was the first retort where such a system has been utilized.

The four stationary thermocouples in each thermocouple well were wired into a central panel in the retort instrument shed. A data processor accessed each thermocouple individually and recorded the date, time, retort number, thermocouple location and temperature in degrees Fahrenheit. The data was recorded on magnetic tape and on paper tape, and could be displayed digitally. The processor was programmed to record data automatically at prescribed intervals and could be manually accessed to look at data from any or all thermocouples. Prior to Retort #18, retort bed temperatures were measured by manually sliding thermocouples through the well casing to specified locations within the retort zone. This method had the disadvantage that the casing pipe would plug when the fire burned through a thermocouple well. When that happened, the thermocouples would no longer slide and temperatures below the plug could not be measured. Retort bed temperatures behind the fire front were thus not accessible. The stationary thermocouple system enabled data collection to continue after thermocouple wells plugged and would have prevented the use of sliding thermocouples.

c. Retort Pressures and Wellhead Static Pressures - Retort pressures were measured at four points along the length of the retort. One-inch diameter steel pipes extended into the retort zone, with the bottom 15 feet perforated. Retort pressures as well as air-in and air-out wellhead pressures were read using U-tube manometers.

d. Oil and Water Recovery - Oil and water recovery was measured by a Hydril model NOC 200 Net Oil Computer. The device determined the BS&W (bottom sediment and water) content of the shale oil emulsion without physical separation. The Net Oil Computer incorporates an enclosed computing unit, a capacitance probe and a turbine meter. The device accepts volumetric data from the in-line turbine meter and a qualitative signal from the capacitance probe indicating the BS&W of the emulsion. The computer correlates the volumetric data and BS&W level, and displays the results on counters on a front panel. Readouts are given for oil, free water and total water.

Retort #24

Surface equipment for Retort #24 was fabricated and installed during the summer and early autumn of 1980. The layout of surface facilities is shown in Figure 11.

1. Power System - Electrical power was supplied from the Kamp Kerogen power grid. The primary source was a 600 kilowatt generator powered by a natural gas burning Caterpillar engine. Two 700 KW diesel powered generators were on standby. The distribution system provided 440 volt three-phase, 220 volt single-phase and 110 volt single-phase electrical power to the retort through buried conductor cables.

2. Blowers - Air to the retort was injected through eight air-in wells by three blowers. This included a 3000 scfm, 1.5 pound Peerless centrifugal blower powered by a 40 horsepower (HP) motor, and two Roots positive displacement blowers rated for 3000 scfm at four pounds of operating pressure driven by 75 HP electric motors.

3. Surface Piping - The air-in blowers were connected to well heads with a manifold constructed of 10-inch steel pipe. The air-out manifold incorporated 8-inch, 12-inch, 16-inch and 20-inch steel pipe.

4. Mist Elimination - Retort off gas is laden with entrained mist when recovered at the air-out wells. Three mist elimination devices were installed on Retort #24 to remove the mist prior to off gas incineration. The first of these devices, located upstream of the air-out blower, consisted of a large, baffled cooling chamber. The chamber was cooled with forced air from a 10 HP blower. Two Wright-Austin type T mist eliminators were located downstream of the air-out blower.

5. Afterburner - The function of the afterburner is to incinerate the retort off gas. The afterburner was a cylindrical steel vessel measuring 10 feet in diameter by 30 feet in height. On the inside, the lower one-third of the vessel was insulated with a refractory cement lining. The rest of the interior of the

vessel was lined with Kaowool thermal blankets. Performance of the Kaowool lining was not satisfactory. Plans are to build a new afterburner completely lined with refractory cement.

6. Production Facilities - The production wells were equipped with 2-inch diameter sucker rod pumps having an 18-inch stroke, activated by Jensen walking-beam pump jacks. Fluid recovered from the retort was pumped into a 50-barrel separator tank. The fluid was then pumped through a measurement device and stored in two 200-barrel capacity tanks. Production fluids were transferred to the tank battery by a 100-barrel tanker truck.

7. Instrumentation -

a. Gas Flow - Air flows in and out of the retort were measured using orifice runs and manometers. An orifice run was used at each of the eight air-in wells. Two orifice runs were used to measure total air-out flow, individual air-out well flows were measured using a pitot tube.

b. Retort Temperatures - Temperatures were monitored by means of 204 thermocouples placed in 57 thermocouple wells. Eight of the wells were used only to monitor the retort ignition. The remaining thermocouple wells contain four 1/16-inch type K thermocouples each. The thermocouples were wired into the WestAq automatic data recording system which was used successfully on Retort #18. A multiplexer was added to the system prior to the burn of Retort #24. The data acquisition system accessed each thermocouple on an hourly basis and recorded the data, time, retort number, thermocouple location and temperature in degrees Fahrenheit. The data was compiled on magnetic tape and printed on paper tape.

c. Retort Pressures and Gas Samples - In 29 of the thermocouple wells, gas sampling and pressure monitoring pipes were installed. Eight of these were used only to monitor retort ignition. The half-inch diameter pipes were perforated at the bottom 10 feet, and installed alongside the 1-inch thermocouple pipes. The pressures are read using U-tube manometers, and periodic gas samples were drawn from the pipe with a vacuum pump.

d. Oil and Water Recovery - Retort #24 oil and water recovery was measured by the Hydril Net Oil Computer that was used previously on Retort #18.

VI. RETORT EXPERIMENTS

Retorts #18 and #24 were operated during 1980. Retort #18 was ignited in 1979 and burned into 1980. Retort #24 was ignited late in 1980 and continued burning into 1981.

Table 1

Summary of Parameters of Retorts Burned in 1980

	<u>Retort 18</u>	<u>Retort 24</u>
Ignition Date	11-12-79	11-30-80 and 12-1-80
End of Burn	5-11-80	Burn in progress
Thickness of Shale Blasted	17 feet	28 feet
Overburden Thickness	27 feet	45 feet
Cross-Section Area (ft ²)	1,836	6,100
Tons of Broken Shale	19,000	94,000
Barrels of Oil Recovered	5,547	531*

*Oil production as of December 31, 1980.

Retort #18

Retort #18 was blasted on July 27, 1978, utilizing the "Walking W" blast design. The burn was ignited on November 12, 1979. Retorting took place for 181 days, ending on May 11, 1980. A total of 5,547 barrels of oil were recovered from the retort; 4,498 barrels of oil were recovered in 1980. Retort #18 data is summarized below in Table 2.

Table 2

Retort #18 Data Summary

Retort Dimensions:

Thickness (after blasting)	18.6 feet
Width	108 feet
Length	156 feet
Overburden	27 feet
Cross-Section (after blasting)	2,009 feet ²

Blasting Parameters

Date Blasted	July 27, 1978
Total Explosive	16,291 pounds IRECO explosive slurry
Average Surface Uplift	4.2 feet

Retorting Parameters:

Began Burn	November 13, 1979
Ended Burn	May 11, 1980
Duration of Burn	181 Days
Average Grade of Oil Shale	28.4 gallons per ton
Oil in Place	12,175 barrels
Retort Volume (Between air-in and air-out hole)	267,262 feet ³

Production, Oil and Water:

Emulsion	12,130 barrels (54.3% water)
Oil	5,547 barrels
Water	6,583 barrels (1,021 barrels free/water and 5,562 barrels from emulsion)
Recovery	45.6% oil in place
Average Rate of Oil Production	30.6 barrels/day
Average Rate of Oil Per 100 ft ² of Cross-Section	1.5 bbls/100 ft ² day
Peak Rate of Oil Production	51.0 barrels/day

Production, Gas:

Air Injection Rate	1,252 scfm average
Total Air Injected	321 MSCF
Air Injection Rate per square foot of Cross- section:	

Before Blasting	0.62 scfm/ft ²
After Blasting	0.50 scfm/ft ²
Total Air Injected Per Barrel Recovered	61,000 cf/bbl
Combustible Gas Production	338,000,000 cubic feet
Average Rate of Fire Front Advance	0.8 ft/day
Average Retort Pressure	5.9 inches of water

Pre-Burn Pumpdown

At 4 p.m. on October 10, 1979, the pre-burn groundwater pumpdown was initiated. Fluid levels and individual pumping rates were measured at the six available observation wells and four production wells.

The primary purpose of the pre-burn pumpdown was to dewater the retort. However, the data collected can also be used to determine void volume within the retort and net water influx.

Since there was no appreciable precipitation during the pumpdown period, the groundwater influx was assumed to be negligible; and the volume of water pumped from the retort can be directly related to the void volume. The pumpdown data also revealed that the rate at which fluid levels dropped increased with time. The water level dropped 0.6 feet per day during the first five days of pumping and increased to 1.5 feet per day during the final three days. Since pumping rates remained fairly constant throughout the duration of the pumpdown, the increase in rate of fluid level drop indicated less breakage and less void volume at the bottom of the retort.

Retort #18 Ignition Procedures

Retort #18 was ignited on November 12, 1979, utilizing the charcoal point ignition procedure. Individual ignitions were executed for each of the three air-in wells.

Ignition commenced in the center air-in well; a total of 120 pounds of charcoal were used to establish ignition. The second well was ignited four hours later with 40 pounds of charcoal. The third well was ignited one and one-half hours later with 140 pounds of charcoal.

Post-Ignition Fracture Sealing Program

After ignition, some surface leakage was detected on the retort. Carbon monoxide measurements were taken at 32 locations daily

using a portable carbon monoxide analyzer. On the average, CO emissions were low except in the immediate vicinity of a surface leak. When such leaks were detected, they were quickly sealed.

Several methods were used to deal with the problem of surface leakage.

The most widely used was running a tamper over the leaking zone. This technique was most successful when a crack was new and the soil was not too dry due to heat or too wet due to moisture in the retort gas. The best results were attained on small cracks. On larger cracks, other methods were utilized.

One method used involved moving of soil over the crack with a bulldozer. The soil was then "walked on" with a D-7 bulldozer. This compacted the soil and created an effective seal lasting up to four weeks.

Another method involved removing the soil immediately above a leaking zone and exposing the fracture. A layer of fresh soil was then distributed over the exhumed zone and compacted. This process was repeated until the fracture was completely filled. The result was a seal which did not require any further work.

Post-Ignition Fluid Elevation Monitoring

During the burn, fluid elevations were gauged daily at six observation wells. A capacitance probe was used to determine the top of the fluid column and the oil-water interface within the retort. A steel tape was used to gauge the top of the fluid column when the capacitance probe was not operating properly. Monitoring of fluid elevations was discontinued when retort temperature at the observation well exceeded a maximum for accurate gauging.

Maximum fluid levels were 8 to 10 feet above the bottom of the retort. The fluid column consisted of water, with a layer of oil 1/2 to 2 feet thick floating on the water. When the fluid levels were high, there was a common fluid elevation in the observation wells. When the levels were pulled down, the two oil collection troughs had different levels. At times when the oil well pumps were inoperative, the fluid level would rise, indicating oil and water storage in the retort.

Retort #18 Burn

The average air-injection rate was 1.251 scfm. This included several major air flow fluctuations corresponding to different air-injection experiments.

On elapsed day four, air-in flow was approximately 900 scfm. The flow was increased about 125 scfm every eight days to 1,400 scfm on elapsed day 37 and remained at this rate for the next 20 days. Over the following 25 days, the air-in rate was gradually in-

creased, averaging 1,690 scfm. During the next 82 days no significant changes in air-flow rate occurred. The air-in flow over the last 17 days of the burn decreased steadily to a low of 190 scfm. The average flow of combustion gases out of the retort for the duration of the burn was 1,298 scfm.

Retort Pressure

Retort pressures were measured at four points along the axis of Retort #18. The average retort pressure was 5.9 inches of water; retort pressures ranged from -0.1 to 12.0 inches of water.

Air Flow Rates Versus Oil Production

The oil production and air flow data from Retort #18 was averaged over eight intervals covering 144 days of the burn. Days in which production pumps malfunctioned, electrical power failed, or unusual process conditions existed were excluded. These included the first fourteen days and last six days of the burn. The intervals considered and corresponding oil production and air flow rates are listed below.

Table 3

Retort #18 Air-In Flow Rates Versus Oil Production

<u>Average Air-In Flow (scfm)</u>	<u>Average Oil Production (bbls/day)</u>	<u>Interval (Elapsed Days)</u>
793	17.3	167 - 175
894	25.3	15 - 17
1185	26.0	19 - 39
1285	26.9	141 - 164
1317	34.6	53 - 57
1362	37.2	83 - 139
1617	42.0	58 - 76
1845	42.8	77 - 82

The above data indicates a correlation between oil production and air injected. An increase in air flow rate corresponds to an increase in oil production.

Table 4
Retort #18 Average SGV Versus Oil Recovery Per
100 Square Feet of Retort Cross-Section

<u>Average</u> <u>SGV*</u>	<u>Average Oil Production</u> <u>(bbls/day/</u> <u>100 sq. ft of Cross-Section)</u>	<u>Interval</u> <u>(Elapsed Days)</u>
.31	.67	167 - 175
.50	1.40	15 - 17
.59	1.30	19 - 39
.51	1.10	141 - 164
.58	1.50	53 - 57
.54	1.50	83 - 139
.70	1.80	58 - 76
.79	1.80	77 - 82

* SGV = scfm/sq. ft. of Cross-Section

Sweep Analysis and Isotherm Interpretation

Throughout the burn of Retort #18 temperatures were measured daily at four levels within the intended retort zone. The 800° isotherm contours were plotted from the temperature data every four days. The 800° isotherm contours were analyzed and the elapsed day the retorting front reached each thermocouple row was determined. The quantity of oil actually produced between successive thermocouple rows and the oil in place within these intervals was also calculated.

Table 5
Retort #18 Sweep Analysis Summary

<u>Thermo-</u> <u>couple</u> <u>row</u>	<u>Average</u> <u>air flow</u> <u>(scfm)</u>	<u>Oil in</u> <u>place</u> <u>(bbl)</u>	<u>Actual oil</u> <u>production</u> <u>(bbl)</u>	<u>Percent</u> <u>recovery</u> ²
2	875	904	288.5	35.1
3	1235	1329	636.3	52.6
4	1363	1663	539.8	35.7
5	1631	1663	1140.5	75.5
6	1338	1663	737.5	48.7
7	1358	1663	658.4	43.5
8	1352	1663	949.8	62.7
9	1060	1115	402.7	39.7

Actual production refers to oil recovered between thermo-couple rows. (i.e., Row 3 actual production refers to oil recovered between TC Row 2 and Row 3.) The percent recovery refers to fraction oil recovered of oil in place for volume affected based on a 91% sweep efficiency.

Table 6
Retort #18 Gas Analysis Data Summary - By Volume

<u>Constituent</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>No. Sam- ples</u>	<u>"Typical"</u>	<u>High</u>
Hydrogen (H ₂)	6.514	1.432	96	6.618	9.904
Carbon Monoxide (CO)	6.597	1.583	96	7.954	9.206
Oxygen (O ₂)	2.282	1.100	96	1.214	2.078
Carbon Dioxide (CO ₂)	22.979	3.436	95	21.415	25.778
Nitrogen (N ₂)	59.541	4.419	96	59.054	49.169
Methane (CH ₄)	1.564	0.500	95	3.032	2.681
Ethane (C ₂ H ₆)	0.295	0.075	94	0.211	0.465
Ethene (C ₂ H ₄)	0.082	0.045	92	0.060	0.092
Propane (C ₃ H ₈)	0.141	0.041	94	0.620	0.244
Propene (C ₃ H ₆)	0.096	0.040	93	0.096	0.134
Butanes (C ₄ H ₁₀)	0.078	0.057	96	0.074	0.115
Butenes (C ₄ H ₈)	0.058	0.031	95	0.054	0.080
C ₅	0.058	0.021	80	0.049	0.069
Hydrogen Sulfide (H ₂ S)	0.193	0.061	51	0.255	-
Ammonia (NH ₃)	0.045	0.034	45	0.032	-

Accuracy of measurement for all the gases listed in Table 6 is good, except for ammonia which varies widely. Ammonia analysis will be watched very carefully on future retorts to determine whether the variability is an analysis problem or is reflective of retort operation.

Retort #24 Burn

Retort #24 is the first prototype full-sized horizontal in situ retort, measuring 217 feet by 230 feet with an average of 45 feet of overburden. The oil shale averages 22 gallons per ton.

With the burn of Retort #24, the following milestones will be achieved:

1. A 30-foot thick section of oil shale will be burned for the first time.

2. The largest retort cross-section to date will be burned.
3. First ignition in low grade shale (10 - 15 gallons per ton).
4. Ignition at eight air injection wells.
5. Increased automatic data collection.
6. Extensive intra-retort gas analysis.
7. Availability of a computer for data reduction and possibly retort modeling.
8. First attempt to operate a retort at a SGV (superficial gas volume) of greater than 0.8.

The objectives of the Retort #24 burn include:

1. Determine the feasibility of burning a 30-foot section of oil shale using existing LOFRECO technology.
2. Determine the effects of increased cross-section on process control (e.g., burn front tonguing and override).
3. Develop ignition procedures in low grade shale.
4. Correlate air flow and production at greater than 0.8 SGV.
5. Run krypton (Kr^{85}) downhole tracer studies before ignition to determine void distribution within the retort.
6. Determine the effect of burning a 30-foot section of oil shale on retort sweep efficiency by correlating thermocouple data with blast data and tracer results.
7. Analyze extensive intra-retort gas analysis data to develop an algorithm relating gas chromatograph data with thermocouple data and distance from the retorting front.
8. Carefully monitor sulfur (S_2) emissions and correlate with SGV and air-in flow:air-out flow.
9. Determine the percentage of mist in off gas and to what extent the gas is saturated.
10. Observe during the burn the effects of an extensive "standard method" preburn sealing program.
11. Study the compositional changes in the water during the burn.

Pre-Ignition Sealing of Surface Fractures

Prior to the ignition of Retort #24, a large surface fracture at the initiating round (air-out) end of the retort was sealed. A trench was dug through the overburden down to the bedrock, exposing the fractured bedrock, and a mud slurry was injected into the crack. A grout plug was placed on top of the crack above the bedrock, and the soil was replaced and tamped to complete the sealing procedure.

Retort #24 Ignition

The ignition was accomplished over a two-day period beginning November 30, 1980. The charcoal ignition technique was used at each of the eight air injection wells. An average of 200 pounds of charcoal was used in each well. Air-in flows were increased gradually from a level of 43 scfm per well at ignition time to approximately 410 scfm per well over a three-day period. Down-hole temperatures at the ignition monitoring wells measured in excess of 1,000° Fahrenheit, and oxygen and combustible levels of gas samples substantiated that oil shale combustion was underway.

Retort #24 Burn to Date

By elapsed day 7, retorting temperatures had reached several locations at the first row of thermocouples. The rate of fire front advance for three locations was approximately 2.85 feet per day to elapsed day 7. On elapsed day 27, retorting temperatures were reached in one location at the second row of thermocouples. The rate of fire front advance between thermocouple rows one and two had slowed to 1.65 feet per day. These figures reflect the rate of fire front advance for a few locations only; the actual overall advance rate is probably lower.

During this period of time the air-in flow rate remained at 3,000 scfm with minor fluctuations. Generally, by the time the fire front reached the first thermocouple row, it had expanded to yield a uniform configuration across the whole retort cross-section.

The calculation of the efficiency of the burn to date has been impaired due to production well difficulties. Problems were identified in pump check valves and pumping the high viscosity fluid from the retort. Cool temperatures at the bottom of the retort near production wells is believed to cause the oil/water emulsion to be too viscous for efficient pumping. In order to prevent the problem of oil cooling on future retorts, production wells will be drilled closer to the air-in wells.

Gas Analysis

Retort #24 gas samples were taken daily from a sampling port downstream of the demisters on the air-out line. The samples were analyzed at the Analytical Laboratory using a Hewlett-Packard 5830A gas chromatograph. The results of daily gas sampling from Retort #24 are summarized on Table 6.

Other Retort Experiments

A new technique for sealing retort surface fractures was designed and implemented on Retort #25. The procedure calls for the removal of at least one foot of topsoil from the area to be sealed. A special grade of bentonite (GSR-60) with gas and steam retention properties is applied to the retort surface at a concentration of one pound per square foot. The bentonite is then mixed with the top two inches of soil remaining on the surface, which should contain approximately 10 percent moisture. The bentonite/soil mixture is compacted to 90 percent, and the original topsoil is replaced over the compacted bentonite. This procedure is aimed at containing both wet and dry fugitive emissions.

In Situ Retort Simulator

The purpose of the simulator is to simulate horizontal insitu retorting conditions. Various experiments will be designed and implemented to characterize different process conditions of the Geokinetics in situ retorting process. The results of these experiments will aid in the design of process equipment and instrumentation on future field retorting experiments.

The retort simulator consists of a steel vessel 10 inches wide by 20 inches high by 72 inches long, enclosed in cinder blocks) and the following process equipment:

1. Roots air-in blower (7 scfm @ 6 psi)
2. Dayton air-out blower
3. Mist elimination system
4. Electrostatic precipitator
5. Oil separator tank
6. Recycle line
7. Recycle heat-exchanger
8. Flare

Instrumentation for the In Situ Retort Simulator:

1. Rotometer
2. Thermocouples (15 TC located along the retort axis, 5 rows - 3 TC levels/row)

VII. OIL PRODUCTION AND HANDLING

The burn of Retort #18, which was in progress at the beginning of the year, was completed in May. Retort #24 was ignited on December 1, 1980, and continued to burn into 1981. These two retorts produced 4,891 barrels of shale oil during 1980. During the year, 353 barrels of oil were sold to Plateau, Inc. for use in their refinery at Roosevelt, Utah, and 5,189 barrels of oil were sold to the Western Refining Company (WESRECO) at Salt Lake City, Utah. One thousand barrels were sold to Hydrocarbon Research, Inc. (HRI) at Lawrenceville, New Jersey.

Increasing oil production made it necessary to expand oil storage facilities in 1980. A second 3,000 barrel tank was erected at the field site tank battery, giving a total storage capacity of 7000 barrels.

A 1.5 acre evaporation pond was constructed. This pond was designed to dispose of retort wastewater to be produced during the remainder of the research project. Total evaporation pond area is now 1.8 acres.

Geokinetics continued to perform analyses of shale oil produced by in situ retorting and served as a source of shale oil for other researchers, including the U. S. Department of Defense, Hydrocarbon Research, Inc., the National Aeronautics and Space Administration (NASA) Lewis Research Center, and the DOE Laramie Energy Technology Center (LETC).

Efforts to blend shale oil with Altamont crude oil at the Roosevelt refinery indicated an incompatibility between the two crudes. In order to investigate the causes of the incompatibility, and compare the characteristics of the two crudes, a series of tests were run by Dr. F. V. Hanson at the University of Utah. These are summarized in Appendix B. The tests indicated that the shale oil was much higher in mononuclear and dinuclear aromatics, soft resins, and eluted asphaltenes than the Altamont crude, and much lower in saturates. The distillation curves showed the shale oil was higher in mid distillates, and lower in the +1000 and -400 range. (See Appendix C.)

Geokinetics shipped 1,000 barrels of shale oil to Hydrocarbon Research, Inc. at Lawrenceville, New Jersey, for hydrotreating studies conducted for the U. S. Department of Defense. The 1,000 barrels were successfully hydrotreated; 40 percent of the yield was military specification grade jet fuel and the remainder was an excellent FCC (fluid catalytic cracker) feedstock. The fuel will be used by the Air Force for performance tests on military jet engines.

WESRECO took delivery of 5,200 barrels of oil. This oil was blended with #5 fuel oil, and marketed to selected industrial customers in the Salt Lake City area.

VIII. POST-BLAST AND POST-BURN EXAMINATIONS

Post-Blast Studies

Seven core holes were drilled in Retort #25 after the blast to investigate the blast-induced rock breakage. Improved breakage in the lower portion of the retort, as compared with Retort #24, was indicated.

Four of the seven core holes were angled holes which were cased with plastic pipe after coring. This preserved the core holes so they could be used to obtain natural gamma radiation logs. The remaining three holes were vertical holes which were cased with 2-inch diameter steel casing to enable their use as observation wells. Stratigraphic and breakage sections of each post-blast core hole were prepared to determine the breakage distribution with respect to blasthole powder columns, rock types, and selected marker beds.

One of the major objectives of the study is to compare the breakages of Retorts #24 and #25 and correlate this comparison with differences in the blast designs for the retorts. Generally, similarities and differences in the blast designs are:

1. Both patterns contained blastholes of similar spacing but slightly different diameters.
2. The explosive charges in all blast rounds and rows within both retorts were ignited at the same relative times.
3. Delay differences between rows and rounds were modified.
4. Powder factors were slightly changed from one retort to the other.

These relatively minor changes in blast design have apparently resulted in a significant difference in breakage between the two retorts.

The major differences in breakage are:

1. The zone of major breakage and rubble in Retort #25 is much thicker and lower in position with respect to blasthole explosive columns and stratigraphy than in Retort #24.
2. The fluid transport path in Retort #24 is dissimilar to that of Retort #25, because of the extensive bottom breakage observed throughout #25.

Natural gamma radiation logging was performed on Retorts #23, #24 and #25 in 1980. The logging was performed by Sandia National Laboratories and is proving to be of great value. By comparing

abnormality can be recognized. This has been of great help when there is a loss of core recovery and where core footages become questionable or key marker beds are unobservable.

Besides post-blast coring, gamma logging and re-entry drilling logs, other types of information were obtained to aid in the blast evaluation of Retort #25. Three extensive surveys were performed in 1980 for blast evaluation purposes: pre-blast topographic, post-blast topographic, and target or flag position surveys.

A heave contour map was prepared by comparing the pre-blast topographic map with the post-blast topographic map. The maximum post-blast heave for Retort #25 was 13 feet. (See Figures 12 and 13.)

Pre-blast and post-blast surveys of target coordinates and elevations were conducted on Retort #25. These surveys, in conjunction with the fracture map, indicate overburden "block" movement and flexure.

Another type of post-blast study was the running of downhole krypton (Kr^{85}) tracer tests by Sandia National Laboratories. Sandia conducted tracer studies on Retorts #19, #21, #22, #23, #24 and #25 in 1980. The test was used to study flow through the fragmented in situ retorts. A pulse of Kr^{85} was introduced into an injection well and the arrival of that pulse measured in a recovery well. The data can provide information on the number of flow paths and their location, size and character (fracture, rubble, etc.) as well as a flow log of the recovery well.

Post-Burn Studies

A post-burn tracer test was conducted on Retort #18 by personnel from LETC. The purpose of the test was to determine the amount of gas leakage from the retort surface. Helium was injected into Retort #18 air-in wells and measured at the air-out wells to determine the quantity recovered. There was substantial interference from steam in the retort; however, and the test results may not be meaningful. The tracer study results are undergoing evaluation at LETC.

A post-burn core sampling program was carried out on Retorts #16 and #17. The program was jointly funded by the U. S. Environmental Protection Agency (EPA) and the DOE. More than 1,625 feet of core was recovered from 26 core holes on Retorts #16 and #17 (see Figures 8 and 9) under the supervision of DOE scientists from Laramie. The objective of the program was to obtain and evaluate representative post-burn core samples from a horizontal retort in oil shale in the Green River Formation. Splits of the cores were sent to various laboratories by EPA and will be analyzed for leachable minerals that could constitute a source of groundwater contamination. Geokinetics has not yet been advised of any

results from the program, but anticipates that valuable information related to the retorting process will be derived from the cores in addition to the environmental data.

Representative sections of the recovered post-burn core samples were displayed during a core showing held in July at Geokinetics' Vernal office. The following organizations sent representatives to examine the cores: DOE/LETC, Sandia National Laboratories, Lawrence Livermore National Laboratory, Lawrence Berkeley Laboratory, Los Alamos Scientific Laboratory, Occidental Oil Shale, General Electric TEMPO, Colorado State University and Steve's Drilling.

IX. ENVIRONMENTAL RESEARCH

Program History and Goals

The Geokinetics environmental program has grown along with the technical research program. Prior to 1977, the field research program was limited in scope and environmental concerns were addressed by periodic environmental assessments. In 1977 it was determined that a formal environmental research plan was needed to systematically assess the impacts that the enlarged technical research program could impose upon the local environment. The first "Environmental Research Plan for the Geokinetics Investigation of the Horizontal In Situ Oil Shale Retorting Process" (ERP) was completed in November 1977. The document was subsequently revised in December 1977 and February 1978. It became apparent that although the format selected was functional, it could provide the needed flexibility only at an inordinate cost in labor to revise the document as the plan evolved.

The ERP was restructured in 1979 to consist of two parts. The "Research Program Outline" defines the ERP goals and objectives. A second section, to be updated periodically and entitled the "Research Record," describes the actual research conducted.

The goals of the Geokinetics environmental program, in broad form, are to:

1. Describe the environment of the field site as it existed prior to disturbance.
2. Determine the nature and extent of environmental changes caused by program activities.
3. Develop and implement measures to minimize any adverse impacts.
4. Develop and implement reclamation procedures which will return the affected land to its original level of productivity and environmental durability.
5. Coordinate measures to protect the health and safety of persons and animals.
6. Ensure compliance with all pertinent environmental laws and regulations.

Generally, the environmental activities can be classified into four major categories: Atmospheric Resources, Hydrologic Resources, Ecological Resources and Cultural-Economic Resources. Environmental work performed in 1980 is summarized here.

Atmospheric Resources Research

1. Meteorological and Climatological

The data collection and monitoring network was reduced to two electrical weather stations (meteorological towers) and six stations housing mechanical instrumentation. Operation of six ecoclimatological stations was discontinued due to the completion of the two-year vegetation baseline study.

The meteorological and climatological report covering 1979 was completed and the results published in the third quarterly report of 1980. The maximum temperature recorded in 1979 was 100° Fahrenheit in August. The minimum temperature was minus 17°F, which was recorded in January 1979. Mean temperatures in 1979 ranged from 16°F in January to 73°F in July. Total precipitation for the year was 14.38 inches, with the monthly high of 4.41 inches occurring in September. The third quarter received 49 percent of the total precipitation. Of the total, 12.42 inches came from snow. Total net evaporation for the year was 64.9 inches. All months except January recorded positive values for net evaporation, with July registering the monthly high of 13.2 inches. Of the total evaporation, 43 percent was recorded in the third quarter. Wind speeds were highest during the spring quarter (April-June), averaging 17 miles per hour (mph). The fall quarter (October-December) wind speeds averaged the lowest at 5 mph. The maximum wind speed at the 33-foot level was 48 mph in June; the highest wind speed at the 100-foot level was 41 mph in October. Prevailing winds in 1979 were from the south-southwest.

Analysis and compilation of meteorological data from the first half of 1980 is near completion, with publication planned for early in 1981. Plans are to analyze 1980 meteorological data and report the results during 1981.

2. Air Quality

Two air quality studies were initiated with the burn of Retort #24. The objective of the "Process Gas Investigation" is to obtain concentrations of constituents in the process gas deemed significant from previous research in other areas in order to accomplish the following:

1. To determine if the constituents truly exist in Retort #24 process gas.
2. To evaluate the significance of each constituent.
3. Compare findings to those obtained from the stack gas investigation in order to evaluate afterburner incineration efficiencies.

4. Evaluate data to assess health hazards associated with possible gas leakage.

The purpose of the Stack Gas Investigation is to obtain concentrations for constituents in the stack gas deemed significant from previous external research, and effluent temperatures, in order to accomplish the following:

1. Determine what constituents exist at the top of the stack after undergoing incineration.

2. Evaluate the significance of each constituent.

3. Compare findings to those obtained from the process gas investigation in order to evaluate afterburner incineration efficiencies.

4. Obtain temperatures of the gases leaving the afterburner for use in modeling pollutant dispersion.

Samples will be collected twice monthly by laboratory personnel from a sampling tap located near the top of the afterburner. Ten constituents will be sampled for:

- sulfur dioxide (SO₂)
- hydrogen sulfide (H₂S)
- ammonia (NH₃)
- oxides of nitrogen (NO_x)
- total oxidant content (ozone)
- carbon monoxide (CO)
- particulates
- carbon dioxide (CO₂)
- oxygen (O₂) and
- hydrocarbons (HC)

All analyses will be performed at the Geokinetics laboratory. A report on the results of this stack gas study is scheduled to be completed by October 1981.

Two retorts were operating in 1980. Retort #18 burned from November 12, 1979 to May 11, 1980, and Retort #24 burned from December 1, 1980 to the end of the year. Total emissions for 1980 were:

SO ₂	36.2 Tons
NO _x	14.2 Tons

Average concentrations of other emissions as measured at the afterburner stack were:

Hydrocarbons	<5 ppm
Particulates	<5 mg/m ³
CO	<10 ppm
Ozone	<0.01 ppm

Retort #24 burned for one month (December). The results of the December sampling, based on six process gas sample suites, are as follows:

Average flow rate	3750 scfm
Average H ₂ S	350 ppm
Average SO ₂	255 lbs/day
Average SO ₂ (per MSCF)	0.046 lbs/MSCF
Average NH ₃	628 ppm
Average NO ₂	328 lbs/day
Average NO ₂ (per MSCF)	0.060 lbs/MSCF
Total SO ₂	7905 lbs.
Total NO ₂	10,168 lbs.

Stack gas measurements of carbon monoxide have demonstrated that the Retort #24 afterburner operated efficiently in 1980. The average concentration of carbon monoxide in stack emissions was estimated to be less than 10 ppm in December. Direct stack sampling for SO₂, NO_x, hydrocarbons and particulates will begin in 1981.

The burn of Retort #18 resulted in 89% of the sulfur dioxide and 65% of the nitrogen oxides generated during 1980. The delay of the burn of Retort #24 for nearly two months was instrumental in the total tons of sulfur dioxide and nitrogen oxides emitted being far less than emissions projected for 1980.

The design of a plan to monitor fugitive emissions from Retort #24 is underway. That study is expected to be implemented in March 1981. In addition to the studies described above, process gas, stack gas and fugitive emission studies for Retorts #23 and #25 will be designed and implemented in 1981. Reports of findings from the process and stack gas studies on Retorts #23 and #24 are tentatively scheduled to be completed by October 1981. Emissions estimates for all retorts burned during 1981, as well as running totals, will be developed and reported on a monthly basis in 1981.

Hydrologic Resource Research

1. Hydrology Studies

A native groundwater sampling study was conducted throughout 1980. The program provided 18 native groundwater samples and produced data for additional characterization of native groundwater existing directly above the mahogany oil shale zone. Three samples were collected every other month from twelve wells. The data will be compared with data from process and leached water investigations. The integration of data will assist in determining the effects that a modified in situ oil shale retorting process may have on groundwater supplies and quality.

Water samples from wells peripheral to Retort #15 were collected every three months since the retort burn terminated in July 1978. The investigation was terminated after samples were collected in April 1980. A preliminary assessment of the data indicated a trend for the water surrounding Retort #15 to return to the quality of native groundwater over time. Data evaluation is still underway; a report of findings is expected to be completed early in 1981. (See Figure 6.)

A three-phased water monitoring program was developed and implemented in 1980. The goals of the program are to:

1. Establish an understanding of the various changes selected constituents of retort water undergo during the burn of a full-size retort.

2. Evaluate the extent and rate of recovery to pre-ignition quality once the retort is shut in.

3. Determine the extent of horizontal and vertical communication from the retort.

Phase I was conducted in 1980; this consisted of pre-ignition samples of water from Retort #24 and twelve wells surrounding the retort. Phase 2 will consist of samples taken during the burn of Retort #24; Phase 3 will be a series of post-burn water samples beginning three months after the retort is shut in. (See Figure 7.)

Water monitoring programs similar to the one designed for Retort #24 will be designed and implemented on Retorts #23 and #25 in 1981.

2. Effluent Water Handling

A comprehensive evaluation of data from monthly evaporation pond samples collected from November 1978 through October 1979 was

completed. The investigation was undertaken to determine how the constituents of the pond water change with time and upon evaporation, as in an industrial waste pond. Evaluation of the water analysis data resulted in the following conclusions:

1. As expected, nearly all the constituents in the pond increase as evaporation leads to concentration. Turbidity and conductivity decreased with time, indicating that some complexation and precipitation is also taking place.

2. Among the species that show a general increase are those of environmental significance: arsenic, boron, cyanide, fluoride, phenol and thiocyanate. Of these species, arsenic and boron are in such concentrations as to warrant careful consideration prior to any disposal scheme.

An additional evaporation pond water sample analysis was completed in 1980; the results supported the above findings.

During 1980 a new 1.5-acre evaporation pond was constructed at the field site. The pond was designed to handle 110 barrels of effluent water per day for 23.5 months, with a volume capacity of 238,336 cubic feet. A 36-mil thick, chlorinated polyethylene reinforced-type impermeable liner was installed in the pond under the supervision of the Watersaver Company, manufacturer of the liner. A leak detection system was designed to insure that any significant leakage of wastewater from the evaporation pond will be promptly recognized.

Ecological Resource Research

1. Vegetation Studies

The final report on the two-year vegetation baseline studies performed by ERO Associates was completed in 1980. The report describes studies conducted at the field site in 1978 and 1979, and summarizes and correlates previously reported data and evaluations. A summary of the baseline studies, excerpted from the final report, is attached as Appendix A.

In 1981 Geokinetics plans to conduct phytosociological and productivity studies on one of the vegetation study plots used for baseline studies. An endangered species survey on Section 2 will also be conducted in 1981.

2. Wildlife Studies

One-year wildlife baseline studies were previously conducted between May 1978 and May 1979. Geokinetics plans to conduct an animal road kill survey, an endangered animal species survey and an animal species diversity survey during 1981.

3. Reclamation Activities

The study of revegetation on Retorts #9, #14 and #15 continued in 1980. Plantings were initiated on Retorts #5, #10, #11, #16, #17 and #18. The purpose of the revegetation research is to develop a revegetation program that will reestablish a vegetational regime that resembles the natural one prior to its disturbance; and be as productive or more productive than the original vegetation.

In November of 1979, Retorts #9, #14 and #15 were seeded with 13 species. In July 1980, these retorts were evaluated and of the species planted, intermediate wheatgrass, bluebunch wheatgrass, pubescent wheatgrass and Indian ricegrass were in evidence. Other species that had volunteered on the sites included lamb's-quarters, cheatgrass and summer cypress. The germination of the species was judged to be acceptable. Annual species are expected to decline as the cover of perennial grasses increases. A preliminary evaluation of productivity was less encouraging; productivity was low on all three retorts, and poorest on Retort #9. It is believed that the poor productivity was due to insufficient seedbed preparation methods. Snow fell within days of the seeding of Retorts #14 and #15, which apparently improved productivity considerably. Productivity on the sides of the retorts was also poor and was attributed to insufficient seedbed preparation. Contouring and furrowing of retort sides will be improved to increase the water retention needed for good productivity.

Revegetation studies on spent Retorts #5 and #11 were initiated in April 1980. The investigation is being conducted in cooperation with the U. S. Forest Service (USFS) Shrub Sciences Laboratory of Provo, Utah. The objective of the study in 1980 was to evaluate the survival and growth of 21 species of plants (14 shrubs, 4 forbs, 2 grasses and 1 tree) established by transplanting container grown planting stock. A total of 525 plants were started; 375 small varieties on Retort #11 and 150 larger varieties on Retort #5. Plant survival and growth rates were monitored throughout the summer. As of September 1980, the survival rate on Retort #5 was 34 percent. The data was broken down into two parts designated ON RETORT and OFF RETORT to see if location on the retort resulted in a different survival rate than off the retort. On Retort #5 ON RETORT and OFF RETORT survival rate was the same, height and width measurements were also nearly the same. It is believed that the low survival rate was due to two factors. First, the Russian thistle competition was overwhelming. The healthiest-looking plants were on relatively bare areas. Second, three of the species, *Amelanchier utahensis*, *Quercus gambelli* and *Rhus trilobata* are not found growing in the vicinity of the research site. They are found in the general area growing at a higher elevation.

The overall survival rate on Retort #11 was 80 percent. When the data was broken down into ON RETORT and OFF RETORT, survival OFF RETORT went up to 89 percent while ON RETORT dropped to 66 per-

cent. The height and width measurements were generally greater OFF RETORT and the plants off the retort look much healthier than those on the retort, particularly those on the flat ground in the area near the gate of the enclosure. There was not as much competition from Russian thistle in this area; in fact, there was very little competition from any other vegetation in the ON RETORT area. The reason the ON RETORT plants did not do as well as the others may have been due to the fact that when water fell on the raised ground area there was a lot of run-off. Consequently, the plants on top did not receive much water. Data will be taken on overwinter survival each May and on plant growth and survival each September for as long as the program provides useful information.

Retorts #10, #17 and #18 were seeded in the fall of 1980. Part of Retort #16, an abandoned stretch of dirt road between the offices and the tank battery, a small area north of the generator pads and the barrow pits at the north end of the research site were also seeded. Western wheatgrass, intermediate wheatgrass, bluebunch wheatgrass, pubescent wheatgrass, green needlegrass and Indian ricegrass seeds were spread. Site preparation consisted of contouring the areas, terracing slopes to improve water retention on sides of retorts, and disking. Seed was sown with a hand seeder, after which the areas were rediscs and lightly watered to reduce the chances of seed blowing away. A two-year success evaluation period is planned for Retorts #10, #16, #17 and #18. The evaluations will be conducted by Geokinetics personnel and representatives of ERO Associates. Species inventories and productivity studies will be conducted on all four retorts.

Plans are presently being formulated for a USFS experiment on Retort #10 and #18; phytosociological and productivity studies on Retorts #10, #14, #15, #17 and #18; and another reclamation study to be initiated in the fall of 1981.

Cultural-Economic Resources

Permits

During 1980 the Environmental Branch applied for and obtained the federal, state and local permits as listed below:

1. "PSD" Permit

On November 13, 1980, EPA issued a conditional permit to construct and operate five in situ retorts over the next three years, pursuant to federal Prevention of Significant Deterioration (PSD) of air quality regulations.

2. Air Quality Approval Order

On November 7, 1980, the Utah Air Conservation Committee issued an air quality approval order which authorized the conducting of

a research mode in situ oil shale retorting process using incineration of off gases.

3. Evaporation Pond Construction Permit

The Utah Water Pollution Committee issued a construction permit for the evaporation pond described in the effluent water handling section. The pond occupies 1.5 acres (256 feet to a side) with a depth of four feet and a slope to sides of 3:1. The pond will handle an inflow of 110 barrels of retort water per day for the duration of the research project.

4. Underground Disposal of Wastewater

On July 22, 1980, the Utah Board of Oil, Gas and Mining issued an Order authorizing underground disposal of wastewater following a hearing on the matter. Geokinetics was authorized to inject wastewater from its oil shale operations into the lower Mesa Verde formation at a depth interval of approximately 3,835 to 5,335 feet below the surface.

5. BLM Right-of-Way

On June 23, 1980, the Bureau of Land Management granted Right-of-Way U-45956 to Geokinetics. The action authorizes the use of a 20-acre area adjacent to the project site for a period of ten years. The tank battery, three portable skid-mounted generators and two 8,000-gallon capacity diesel fuel storage tanks are located on the property. The right-of-way obtained superseded temporary right-of-way authorizations granted earlier.

6. Approval to Appropriate Water

Authority to appropriate an increased amount of water (0.33 second-feet) from the Kamp Kerogen well was granted by the Utah Division of Water Rights. This authority updated the original water rights application.

7. Approval of Kamp Kerogen Domestic Wastewater System Plans

A consulting engineering firm was hired to design changes for expanding the capacity of the Kamp Kerogen sewage disposal system. The resulting plans and specifications were approved by the Uintah Basin District Health Department pending an inspection of the system after improvements are incorporated.

8. Burning Permits

Permits to burn debris at the field site were obtained intermittently throughout the year as necessary.

9. Notice of Intention to Commence Mining Operations

Geokinetics submitted "Notice of Intention to Commence Mining Operations" (MR Forms 1 and 2) to the Utah Division of Oil, Gas and Mining for approval to expand operations to the NW quarter of Section 2. Approval had not been received at the end of the year, but is expected.

Other Environmental Activities

The DOE's Oil Shale Task Force is considering participation in the Geokinetics environmental program in (1) the characterization and measurement of fugitive emissions from retort surfaces, (2) land reclamation activities, (3) the development and implementation of an employee health monitoring program, and (4) the pilot operation of a deep well injection system for retort water disposal. Coordination efforts are also being made in the areas of hydrology and industrial safety.

Soil and plant tissue samples from Retorts #14 and #15 were collected in September by Ed Redente, a range scientist from Colorado State University, in conjunction with cooperative reclamation efforts between Geokinetics and the Oil Shale Task Force. Control samples were also taken. The samples were subjected to toxicity level tests; results are not yet available.

Two industrial hygiene-related studies were being implemented by Geokinetics and Los Alamos Scientific Laboratory (LASL) as part of the Task Force assistance. A third study of industrial health involving physical examinations and monitoring of employees is presently being formulated by Geokinetics, LASL and the University of Utah. These programs are part of the DOE Oil Shale Task Force studies being conducted to examine and characterize the occupational environment and evaluate potential worker exposures associated with various oil shale recovery processes.

X. ANALYTICAL LABORATORY

Geokinetics maintains and operates a well-equipped Analytical Laboratory at Kamp Kerogen to support environmental research and retorting. The laboratory staff performs analyses of oil, gas, retort water and groundwater samples. During the year, 315 gas samples were analyzed for 5,282 constituents, 62 water samples were analyzed for 1,593 constituents, and 8 oil samples were analyzed for 32 constituents.

In 1980, significant improvements were made to the Hewlett-Packard 5840A gas chromatograph which will result in increased accuracy and efficiency. A capillary column conversion was installed which will result in better resolution for peak identification which will enable comparison of aromatic olefinic and parafinic constituents in relation to retorting conditions and different locations in the retort. This will aid in the development of a reliable index of coking and/or cracking during retorting.

In addition, a flame photometric detector (FPD) for the HP-5840A gas chromatograph was installed. The unit will be used in the analysis of retort gas streams for sulfur gases such as hydrogen sulfide (H_2S), carbonyl sulfide (CO_2S), carbon disulfide (CS_2), sulfur dioxide (SO_2) and light thiols. The addition of the FPD will reduce analysis time for those gas constituents from 2-4 hours per constituent to approximately 30 minutes for all constituents.

XI. FIELD SITE CONSTRUCTION AND IMPROVEMENT

In order to support the expanded experimental program in 1980, a major expansion of the electrical supply system was carried out. Geokinetics purchased and installed a 650 kilowatt (KW) natural gas-powered electrical generating system, consisting of a Caterpillar G399 turbocharged and after-cooled engine driving a Kato 4160 volt generator. As backup to this generator, two 750 KW diesel powered generators, on loan from the Department of Defense, were put on line. A building equipped with special dust filters was constructed to house the system. Three transformers located near the generators supply 480 volt three-phase electricity to the warehouse/shop facility, tank battery, analytical laboratory, offices and housing. To supply power to the retorts, a 2,500 foot, 4160 volt underground power line was installed. Transformers near the retorts reduce the electricity to 480 volts.

A central control substation enables the use of any one of five generators. Besides the three large generators, a 200 KW and 100 KW diesel generator, and a 75 KW gas powered generator are available. These small units are operated at times of low power demand to reduce fuel consumption.

To handle the increased volume of retort water from the larger retorts, a new evaporation pond was constructed. The pond covers 1.5 acres, and is lined with a 36 mil CPR impermeable liner, manufactured by the Watersaver Company. The pond is designed to handle 110 barrels of water per day for two years, and has a volume capacity of 238,000 cubic feet. A system of eight leak detection wells surrounds the pond to permit prompt detection of any leakage from the pond.

The main road system in the camp was realigned, widened, and surfaced with crushed shale.

XII. GENERAL AND ADMINISTRATIVE

1. Safety Program

In 1980, Geokinetics arranged to participate in an Occupational Safety and Health Administration (OSHA) grant administered through the Safety and Health Programs of Utah Technical College (UTC). The grant provides consulting and assistance to small businesses for the development and improvement of safety programs. Safety meetings were held during the year and featured safety experts from UTC. Special sessions on electrical safety, the operation of cranes and hoists, personal protective equipment, machine safeguarding and hazardous materials were held. A two-part, eight-hour fire safety series was presented by a professional firefighter as part of the program. The fire series covered flammable liquids and firefighting techniques, and included a hands-on demonstration of fire extinguisher use. A Kamp Kerogen Health and Industrial Safety Program was prepared during the year and is being put into effect.

2. Research Data Handling

By the end of 1980, two computer systems were being prepared for handling data generated during the research project. A PDP-11/V03 system acquired earlier was activated during the year, and a Hewlett-Packard 1000 series Model 40 system was ordered in October, with delivery expected early in 1981.

The use of the computer systems will speed up data reduction and will add versatility in correlating process trends. The data stored on flexible disks will include daily gas chromatograph analysis, thermocouple temperatures, air-in and air-out flow rates, oil and water production, retort pressures, and carbon monoxide concentrations. Presently thermocouple temperatures are recorded on magnetic cassettes and the data can only be accessed sequentially. However, the data can be retrieved through a random access device if it is stored on flexible disks.

There are many other advantages to using a computer system in the field other than efficient and organized data storage. Histograms and some X-Y plots of process data can be accomplished. Field data can be used to test various computer models of in situ retorting. Gas chromatograph analysis of the retort gas and actual oil production can be used to evaluate materials balance programs developed to predict various oil degradation mechanisms (i.e., coking, cracking, combustion of oil). Eventually, pre-burn pumpdown fluid elevations could be stored on flexible disks and correlated by the computer with tracer data to develop a better understanding of void distribution within the retort. Ultimately, field computer access could have a significant impact on retorting, environmental, and blasting research programs.

3. Presentations and Public Relations

Geokinetics President Mitchell A. Lekas traveled to Morocco in October to participate in an Oil Shale Colloquium cosponsored by the Kingdom of Morocco, the Agency for International Development (U. S. Department of State) and the U. S. Department of Energy. The objective of the Colloquium was to present United States oil shale technology to Moroccan officials and acquaint them with U. S. companies interested in doing business in Morocco. The Kingdom of Morocco is planning to develop a 100,000 barrel per day oil shale industry and bring it on line as soon as possible.

Project Manager James M. Lekas presented a paper detailing Geokinetics' research progress at the DOE/LETG sponsored Third Annual Oil Shale Conversion Symposium in Denver, Colorado. Program history, achievements and objectives were summarized.

Geokinetics participated with three other oil shale development companies in the Utah Energy Expo '80. Geokinetics, Paraho, TOSCO, and the White River Shale Project presented an exhibit describing Utah's oil shale resource and current research activities. Free samples of oil shale rock were distributed to the public. Energy Expo '80 was sponsored by the Utah Energy Office.

Washington officials Russell Marane (Housing and Urban Development) and Paul Petzrick (DOE) attended a special meeting of the Uintah Basin Energy Planning and Development Council in Vernal, Utah. Dr. Polly Garrett (DOE-Region VIII) was also present. Geokinetics President M. A. Lekas attended the meeting and made a presentation on the Geokinetics shale oil recovery process. The major purpose of the visit was for HUD officials to inform local people of the HUD program for housing assistance to areas impacted by energy development and to assess the need for such assistance in the Uintah Basin of Utah.

A number of visitors toured the field operation during the year.

Mr. Jerry Roberts of Aerospace Corporation visited the project at the request of DOE Headquarters. He observed all phases of the operation and environmental impacts related to the retorting process.

Dr. Arnold Adicoff of the Department of Defense (DOD) Research and Development Office examined retorts in various stages of development.

Jose Luis Bergal-Fernandez and Luis C. Fernandez-Espinar of ENADIMSA (Empresa Nacional Adaro de Investigaciones Mineras, S.A., Spain) visited the field operation. They were briefed on the horizontal in situ oil shale retorting process.

Members and staff of the Utah State Land Board toured the field site in June. They were accompanied by the State Forester and other Utah Department of Natural Resources personnel. Develop-

ment activities were reviewed for the group. Representatives of the Utah Division of Oil, Gas and Mining also toured the project during November.

Representatives of Swan Resources (West Perth, Australia) visited Kamp Kerogen to observe the Geokinetics retorting process and discuss possible process applications to oil shale deposits controlled by Swan Resources in western Australia. Managing Director Dr. Jack Keay was accompanied by geologist Brian Breese and economist David Lance on one tour. John Mandelson and Hugh Van Herk from CSR, Inc. (Sydney, Australia) visited Kamp Kerogen. CSR, Inc. controls the Julia Creek shale oil deposit in north-eastern Australia.

Representatives of the Rocky Mountain Energy Company (RME), a subsidiary of Union Pacific, visited the field site during the quarter. RME has initiated a program to evaluate oil shale resources on Union Pacific land holdings in Wyoming. Initial inventory efforts are directed to identifying areas suitable for application of the Geokinetics process. Two geologic field crews began to look for potential areas in 1980. Core drilling will begin in 1981 if suitable areas are located.

Geokinetics provided a sampling site to the Institute of Gas Technology (IGT) for the collection of a 20-ton sample of Mahogany Zone oil shale. The shale will be used in tests of the IGT "HYTORT." DOE is funding the tests of IGT's hydrogen atmosphere above-ground retorting process. David Matthews of IGT visited the field operation during the sample collection.

Representatives of Plateau, Inc. toured the field site and discussed future cooperation between Plateau and Geokinetics regarding the purchase and refining of shale oil. Paul Liscomb, John Hearn and Lee Synder of Albuquerque, New Mexico, were accompanied by Lee Woodside and Jeff Utley of Plateau's refinery in Roosevelt, Utah.

Mike Breard (Research Analyst for the Dallas, Texas, investment banking firm of Eppler, Guerin & Turner) spent two days at the field site. Mr. Breard is preparing a financial research report on Geokinetics and the Geokinetics retorting process. The report has been distributed to the financial community.

Mr. Paul Hommert of Sandia Laboratories worked with Geokinetics personnel at the field site to increase the effective use of Geokinetics' computer system. Assistance was received in retort data storage and computer application as a predictive tool in materials balance calculations. Other Sandia personnel met with Geokinetics personnel numerous times during the year to discuss retort fragmentation and instrumentation.

Lawrence Livermore National Laboratory (LLNL) representatives visited Kamp Kerogen to discuss LLNL's interest in assisting the

Geokinetics retorting program. LLNL could provide data evaluation input in applying various gas and oil analysis techniques to develop indicators of retorting conditions.

The future managerial and technical manpower needs of Geokinetics were discussed during a visit by Bruce Brighton (Technical Programs Director) and others from the Uintah Basin Area Vocational Center.

A petroleum technology class from the Uintah Basin Area Vocational Center examined various stages of retort preparation, operation and revegetation.

A news team from CBS-affiliate KSL-TV (Channel 5) in Salt Lake City, Utah, conducted an interview at the test site. Mr. Charles R. Henderson represented the Uintah Basin Association of Governments' Energy Planning and Development Council at the event.

Mr. David Gustafson of the House Subcommittee on Energy and Power visited Kamp Kerogen on a tour of oil shale facilities.

Various persons from DOE/LETC met with Geokinetics personnel at Kamp Kerogen during the year. Discussions covered planning and budget, retort data collection and interpretation, permits, environmental research activities, and health and safety programs.

Vic Montenyohl of the Occidental Oil Shale, Inc. rock fragmentation group visited Kamp Kerogen to discuss post-blast core recovery techniques successfully utilized by Geokinetics.

Geokinetics and the other oil shale companies met with Utah Power & Light Company to discuss future shale industry power needs and the use of retort off gas for generating electricity.

4. Reports

The following reports were published covering work performed in 1980:

Monthly Reports - January through December

Quarterly Reports - January through December - Included in the Quarterly Reports were the following topical reports:

- a. Results of Retort #18 Shale Oil Chromatographic Analyses by GKI Analytical Laboratory
- b. Results of Shale Oil and Altamont Crude Analyses Performed by the University of Utah
- c. Retort #18 Summary Report
- d. Retort #18 Oil Analysis Results

- e. Evaporation Pond Water Investigation
- f. Final Environmental Research Report - Vegetation: Eco-climate and Soil Factors
- g. Native Groundwater Analysis Results
- h. Retort #24 Post-Blast Pre-Burn Water Sample Analysis Results
- i. Retort #24 Water Monitoring Program
- j. Leakage Monitoring of Evaporation Pond
- k. Retort #24 Stack Gas Investigation
- l. Retort #24 Process Gas Investigation
- m. Meteorological and Climatological Investigation: Review of July - December 1979 Investigative Period
- n. Industrial Health and Safety Program
- o. Retort #24 Gas Data Summary
- p. Instrumentation and Operational Plan for Geokinetics Retort No. 23

<u>Retort Number</u>	<u>Date Blasted</u>	<u>Date Ignited</u>	<u>Thickness of Shale</u>	<u>Average Overburden Thickness</u>	<u>Width</u>	<u>Length</u>	<u>Barrels of Shale Oil Recovered</u>
1	7/75	9/76	10'	0'	10'	50'	56
2	7/75	3/76	3'	10'	10'	30'	28
3	1/76	7/76	10'	17'	20'	40'	82
4	2/76	2/77	10'	16'	20'	40'	146
5	2/76	5/77	11'	19'	20'	81'	354
6	Abandoned-Not blasted						
7	11/76	----	10'	15'	20'	50'	----
8	11/76	----	23'	22'	20'	83'	----
9	12/76	9/77	22'	22'	40'	83'	1,007
10	12/76	1/79	11'	14'	20'	50'	445
11	3/77	4/77	12'	14'	20'	45'	272
12	3/77	----	11'	31'	30'	50'	----
13	6/77	----	11'	31'	30'	50'	----
14	6/77	2/78	12'	29'	40'	70'	384
15	7/77	5/78	20'	31'	50'	75'	1,003
16	8/77	8/78	20'	41'	62'	87'	2,067
17	5/78	6/79	17'	26'	72'	156'	3,700
18	7/78	11/79	17'	27'	108'	156'	5,500
19	12/78	----	30'	50'	126'	182'	----
20	4/79	----	24'	36'	40'	100'	----
21	6/79	----	23'	35'	40'	100'	----
22	6/79	----	23'	34'	50'	100'	----
23	9/79	----	24'	36'	50'	100'	----
24	11/79	12/80	28'	45'	217'	230'	----
25	7/80	----	28'	55'	217'	230'	----

Figure 2. Summary of Data on Retorts #1 through #25
(to 12/31/80)

Figure 3. Geokinetics Field Site at Kamp Kerogen, Showing Location of Retorts #1 Through #19

Figure 4. Geokinetics Field Site at Kamp Kerogen,
Showing Locations of all Retorts

Figure 5. Plan and Cross-Section of a Typical Horizontal In Situ Retort

Figure 6. Hydrologic Monitoring Wells, Retort 15

Figure 7. Hydrologic Monitoring Wells, Retort 24

Figure 8. Post-Burn Core Hole Locations, Retort #16

Figure 9. Post-Burn Core Hole Locations, Retort #17

Figure 10. Surface Facilities Layout, Retort #18

Figure 11. Surface Facilities Layout, Retort #24

Figure 12. Blast-Induced Surface Uplift (Heave), Retort #24

Figure 13. Blast-Induced Surface Uplift (Heave), Retort #25

APPENDIX A

SUMMARY EXCERPTS FROM THE TWO-YEAR
VEGETATION BASELINE STUDIES REPORT

**FINAL ENVIRONMENTAL
RESEARCH REPORT:**

**VEGETATION
ECOCLIMATIC AND SOILS FACTORS
1978-1979**

**LOFRECO FIELD RESEARCH SITE
GEOKINETICS, INC.
UINTAH COUNTY, UTAH**

**PREPARED BY
ERO ASSOCIATES, CONSULTING ECOLOGISTS
CONIFER, COLORADO**

Erik R. Olgeirson, Ph. D.

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The environmental studies reported in this volume were conducted under the direction of Dr. Erik Olgeirson, ERO Associates. Individuals who contributed to these studies include:

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- o Larry England, Bureau of Land Management
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INTRODUCTION

The Geokinetics Inc., in-situ oil shale retort experimental research site, known as the LOFRECO site, is located in the southern Uintah Basin, Uintah County, Utah. The research site occupies Section 2 of Township 14 South, Range 22 East, approximately 50 miles south of Vernal Utah.

Vegetation studies were begun on the LOFRECO site during the spring of 1978 and continued through the summer of 1979. The principal components of the two year intensive study include collection and analysis of data in the areas of vegetation, ecoclimate, and soils as detailed below:

- Vegetation Studies:
 - Vegetation Mapping
 - Floristics
 - Reconnaissance and collection of vascular plants on the site
 - Rare and endangered species inventory
 - Phytosociological Studies
 - Qualitative and quantitative descriptions of the structural and compositional features of each major vegetation type on the site
 - Primary Productivity Studies
 - Measurement of the above-ground biomass of the herbaceous biomass of the site (shrubby vegetation was also measured in selected areas)
- Ecoclimatological Monitoring Studies
 - Continuous recording measurement of ecoclimatic parameters (temperature and precipitation in the zone influenced by plant growth) in the major vegetation types
- Soil Survey and Analysis Studies
 - Qualitative and quantitative descriptions of the major soil types
 - Quantitative description of the soil characteristics on in-situ retort sites
 - Mapping of major soil series types

This report contains the results of the two-year study, presenting data collected from the three main study topics and interpretive analyses of intra-topical correlations. First year (1978) data, including one-time soil studies, have been previously presented in a series of reports (Olgeirson and Martin 1978, Olgeirson 1979a, 1979b, 1979c). Data collected during the second year of study are presented in this report along with first year information (Appendices A through D and Map Pockets).

The body of the report combines and correlates data from the permanent sampling sites for both of the years studied. Vegetation, soils, and ecoclimate data are considered separately in these discussions. Correlations and interrelationships between the three main topics are discussed in later sections. Conclusions of the studies are given as a summation of the separate and interrelated findings and as a basis for recommended monitoring programs. An attempt has been made to increase readability by restricting the large amount of data to inclusion into textual areas of the report only as summarized figures and tables. Supporting data have all been placed in the appendices.

OBJECTIVES

The objectives of the studies discussed in this report are given below. These primary goals relate operational facets of the in-situ shale oil retort research to the environmental characteristics of the site.

- To produce a descriptive data base that can be applied to an understanding of the carrying capacity of site
- To define dynamic relationships between vegetation and primary factors that influence vegetation, such as soils and ecoclimate
- To use the qualitative and quantitative information obtained in preparing revegetation plans, impact mitigation plans, and long-term monitoring plans
- To employ the qualitative and quantitative data in making distinctions between natural environmental trends and man-induced perturbations

DESCRIPTION OF THE STUDY AREA

The LOFRECO site is located in the Uintah Basin floristic section of the Intermountain West (Cronquist et al. 1972). This area is a cold desert region dominated by open pinyon-juniper woodlands and sagebrush-dominated shrublands. Herbaceous species do not predominate in any of the plant communities of the study site. Cool-season grasses, such as blue grama and western wheatgrass, are an important, but limited, source of forage for domestic cattle. Forbaceous species are infrequent and include a number of ubiquitous species, such as copper globemallow and long-leaf phlox, as well as species known to be restricted to the Uintah Basin including *Townsendia mensana*, *Parthenium ligulatum*, and *Eriogonum ephedroides*.

Primary productivity of the area is low in comparison to the Great Plains Province and the adjacent Piceance Basin floristic area. Low rainfall (< 25cm/year) (Bradley 1976) and poor soil quality are the major factors limiting vegetation productivity. Other environmental extremes, particularly temperature, also contribute to the depauperate nature of the vegetation.

Major land uses of the study area include grazing of domestic cattle; wood-cutting; oil and gas exploration; and oil shale exploration. Wildlife utilization of the area is notably limited (Stoecker 1979).

RESULTS AND DISCUSSION

VEGETATION STUDIES

Vegetation Mapping

The four vegetation types identified and sampled during the two-year environmental research study on the LOFRECO site are mapped on Pocket Figure 1. Mapped units also include several salient features and habitat units, as shown below, included with topographic and political features:

- South-facing pinyon-juniper woodlands (*Pinus edulis-Juniperus osteosperma*) permanent sampling sites V10 and V11
- North-facing pinyon-juniper woodlands (*Pinus edulis-Juniperus osteosperma*) permanent sampling sites V20 and V21
- Sagebrush-rabbitbrush lowlands (*Artemisia tridentata-Chrysothamnus nauseosus*) permanent sampling sites V30 and V31
- Sagebrush-wheatgrass uplands (*Artemisia tridentata-Agropyron smithii*) permanent sampling sites V40 and V41
- Shaley slopes and Rimrock

Floristics

Herbaceous, woody, and succulent plants occurring on the LOFRECO site are listed in Table 1. Species are listed by scientific and common name by general life form category: herbs (flowering plants and grasses), shrubs (including stem succulents), and trees. Appendix A also contains a list of these plants, the abbreviations used in computer manipulations, and specific life form classifications (Tables A1.1 and A1.2). (Tidestrom 1925, Harrington 1964).

Several herbaceous species listed as rare, restricted, endangered, and/or threatened have been encountered on the LOFRECO site. These species are listed in Table 1 and described in Appendix B. Several of these species have been recommended for delisting (Welsh 1979) and/or are relatively common on the site, as listed below:

- *Parthenium ligulatum*: recommended for delisting (Welsh 1979); common
- *Townsendia mensana*: locally common
- *Eriogonum ephedroides*; locally common

Two of these species, *Parthenium ligulatum* and *Townsendia mensana* were frequently encountered in the phytosociological sampling. This relative abundance suggests that the populations of these plants will not be threatened by the experimental facilities operating on the LOFRECO site. Moreover, the distribution of these species tends to coincide with shaley knolls that lie along the shale outcrop, and, therefore outside of the area potentially to be disturbed by site activities. The remaining species that is considered locally abundant, *Eriogonum ephedroides*, has not been encountered frequently in sampling, but can be termed common. The distribution of this species coincides with that of *Parthenium ligulatum* and *Townsendia mensana*.

Two other species occurring on Federal and State lists of endangered species have been located on the site: *Enceliopsis nutans* and *Penstemon grahamii*. These species have been encountered infrequently; *Penstemon grahamii* has been observed, but not collected. There is not sufficient information on the distribution of either species on the LOFRECO site to provide guidelines for mitigation of potential damage to these species' populations. It is apparent from literature-derived descriptions of *Enceliopsis nutans* (Nelson 1909) that this species occupies habitats similar to the plants discussed above. Information on *Penstemon grahamii* (Welsh 1979) indicates its occurrence in these types of habitats, as well. The plants observed on the LOFRECO site have been on roadsides and other waste areas.

Systematic monitoring studies designed to locate and map the distribution of all the species discussed in this section have been initiated. When this study has been completed its results will be presented to the Federal agency having jurisdiction over this general region, assumedly the Bureau of Land Management.

TABLE 1
LIST OF VASCULAR PLANTS
OCCURRING ON THE LOFRECO SITE

Scientific Name

Common Name

Trees:

Juniperus osteosperma
Juniperus scopulorum
Pinus edulis

Utah juniper
Rocky Mountain juniper
pinyon pine

Shrubs, Half-Shrubs, and Stem Succulents:

Artemisia cana
Artemisia frigida
Artemisia tridentata
Atriplex canescens
Ceratoides lanata=*Eurotia lanata*
Cercocarpus montanus
Chrysothamnus depressus
Chrysothamnus greenei
Chrysothamnus greenei greenei
Chrysothamnus nauseosus
Chrysothamnus viscidiflorus elegans
Chrysothamnus viscidiflorus
Coryphantha vivipara=*Mammalaria vivipara*
Ephedra viridis
Gutierrezia sarothrae=*Xanthocephalum sarothrae*
Leptodactylon pungens
Opuntia polyacantha
Purshia tridentata
Sambucus sp.
Symphoricarpos oreophilus
Tetradymia canescens
Tetradymia spinosa
Yucca biglovei

silver sagebrush
pasture sage
big sagebrush
saltbush
winter fat
mountain mahogany
dwarf rabbitbrush
Greene's rabbitbrush
Greene's rabbitbrush
rubber rabbitbrush
small rabbitbrush
stick-leaf rabbitbrush
nipple cactus
green ephedra
snakeweed

prickly gilia
prickly pear cactus
antelope bitterbrush
elder
snowberry
horsebrush
spiny horsebrush
yucca

Herbs:

Agropyron cristatum
Agropyron smithii
Agropyron spicatum
Allium geeyeri
Ambrosia artemisifolia
Antennaria parvifolia
Arabis divaricarpa

crested wheatgrass
western wheatgrass
bluebunch wheatgrass
wild onion
ragweed
pussytoes
rockcress

TABLE 1 (CONTINUED)

<u>Scientific Name</u>	<u>Common Name</u>
<u>Herbs:</u>	
<i>Arenaria compacta</i>	dwarf sandwort
<i>Arenaria eastwoodiae</i>	sandwort
<i>Aster arenosus</i> = <i>Leucelene ericoides</i>	aster
<i>Aster fremontii</i>	Fremont's aster
<i>Astragalus calycosa</i>	milkvetch
<i>Astragalus kentrophyta</i>	skeleton milkvetch
<i>Bouteloua gracilis</i>	blue grama grass
<i>Bromus tectorum</i>	cheat grass
<i>Calochortus gunnisonii</i>	sego lily
<i>Carex filifolia</i>	thread-leaf sedge
<i>Casteilleja chromosa</i>	Indian paintbrush
<i>Chaenactis douglasii</i>	false yarrow
<i>Chenopodium album</i>	lamb'squarters
<i>Chenopodium rubrum</i>	pig weed
<i>Cordylanthus wrightii</i>	birdsbeak
<i>Crepis acuminata</i>	hawksbeard
<i>Cryptantha flavoculata</i>	cryptanthe
<i>Cryptantha sericea</i>	cryptanthe
<i>Dephinium nelsonii</i>	larkspur
<i>Descurainia pinnata</i>	tansy mustard
<i>Draba brachycarpa</i>	whitlowgrass
<i>Enceliopsis nutans</i> (rare, restricted)	sunray
<i>Erigeron utahensis</i>	Utah fleabane daisy
<i>Eriogonum caespitosum</i>	prostrate knotweed
<i>Eriogonum ephedroides</i> (threatened)	ephedra buckwheat
<i>Eriogonum kearnyi</i>	knotweed
<i>Euphorbia robusta</i>	leafy spurge
<i>Erysimum capitatum</i>	wallflower
<i>Haplopappus acaulis</i>	stemless goldenweed
<i>Haplopappus nuttallii</i>	goldenweed
<i>Hilaria jamesia</i>	galleta
<i>Hordeum jubatum</i>	foxtail barley
<i>Hymenoxys acaulis</i>	actinea
<i>Iva xanthifolia</i>	marsh-elder
<i>Lappula redowskii</i>	stickseed
<i>Lepidium virginianum</i>	pepperweed
<i>Linum lewisia</i>	false flax
<i>Lithospermum ruderae</i>	puccoon
<i>Musineon divaricatum</i>	leafy musineon
<i>Oenothera caespitosa</i>	evening primrose
<i>Oenothera strigosa</i>	yellow evening primrose
<i>Oryzopsis hymenoides</i>	Indian ricegrass
<i>Oryzopsis micrantha</i>	little ricegrass
<i>Parthenium ligulatum</i> (endangered)	fever few
<i>Penstemon grahamii</i> (endangered)	Graham's beardtongue
<i>Penstemon strictus</i>	penstemon
<i>Physaria floribunda</i>	double bladderpod
<i>Phlox longifolia</i>	long-leaf phlox

TABLE 1 (CONCLUDED)

<u>Scientific Name</u>	<u>Common Name</u>
<u>Herbs:</u>	
<i>Poa sandbergii</i>	Sandberg's bluegrass
<i>Salsola iberica</i>	Russian thistle
<i>Senecio multilobatus</i>	groundsel
<i>Sisymbrium altissimum</i>	tumble mustard
<i>Sisymbrium elegans</i>	tumble mustard
<i>Sisymbrium linifolium</i>	tumble mustard
<i>Sitanion longifolium</i>	squirreltail grass
<i>Sphaeralcea coccinea</i>	copper globemallow
<i>Stipa viridula</i>	green needle-and-thread
<i>Taraxacum officinale</i>	dandelion
<i>Townsendia mensana</i> (threatened)	easter daisy
<i>Verbascum thapsus</i>	mullein

Retort Soils

The values for most soil constituents in retort soils are comparable with those of the native soils discussed above; Figures 18 through 30, illustrate a comparison of some of the more important soil characteristics. This is also true of the constituents determined in the special analysis Appendix D. Several points of significance are, however, apparent from the analysis. The first of these is ostensibly the result of activities on the retorts prior to blasting. There is a noted increase in nitrate nitrogen in some of the retort soils (Figure 18). This is the result of spillage of ANFO during the process of loading blast holes. The effects of this spillage are, however, not deleterious. In fact, they appear to have a positive effect on plant growth since ANFO is primarily composed of nitrates. The only potential damage due to ANFO might occur if an excess of this material created a nitrate inhibition of potassium and phosphorus. The second type of significant soil alteration ostensibly caused by retorting is the alteration in soil structure. The analyses show a significant change in two soil parameters that relate to structure and to water holding capacity (although the first is of greater significance). The concentration of clay sized particles is decreased after the burning of retorts (Appendix D, Table 19). Bulk density of the soil samples shows a significant increase following burning of the retorts (Figure 20). Although the changes in these two parameters are the apparent result of retorting, they must be considered, instead, to be significant changes caused by the process of creating the retort mounds. The decrease in percent clay content is most probably the result of the loss of these particles during wind erosion. This alteration can be controlled through the use of temporary physical erosion control measures. The increase in bulk density is the apparent result of compaction due to drilling and other traffic. This increase occurs in the soil surface

than 3-4%). The electrical conductivity of all surface soil horizons is acceptable (ca. 0.5-1.5 mmhos/cm). The subsoil of the Havre loam has excessive electrical conductivity values (greater than 6 mmhos/cm). The cation exchange capacity of all soil horizons is normal (less than 20 meq/100gm) to slightly low. Trace element concentrations of Manganese, Copper, Zinc, Molybdenum, and Cobalt are in acceptable ranges for all soils. Iron is normal in all soils at approximately 2.5 to 5 ppm. Boron is slightly high in all soils (greater than 1 ppm), but can not be termed excessive. Selenium concentrations are not problematical (less than 2 ppm). Arsenic is slightly high in most soils at greater than 0.5 ppm. The range of the sodium absorption ratio is acceptable in all soils (less than 8%). Available water capacity is moderate to low in all soils (compared with a mean adequate level of greater than 0.25 cm H₂O/cm soil).

The general reclamation potential of all soils is acceptable. Figure 17 illustrates a comparison of the levels of soil parameters typically evaluated in determining a soils reclamation potential (Wyoming DEQ 1976). The comparisons made in this figure reveal no special problems likely to be encountered in reclaiming sites based on soil properties. However, it must be noted that the lowermost horizons of the Havre and Luhon loams may present problems in terms of electrical conductivity and sulfate-sulfur.

Although there are no apparent reclamation problems indicated by the comparison of certain soil constituents with standard values, other considerations of soils must be made in terms of reclamation. The low nutrient status of the native soils may require fertilization during the reclamation process. In addition, the relatively high erodability of soils, particularly susceptibility to wind erosion, must be considered during revegetation activities. Finally, the interactions between various soil constituents, such as the effects of nitrates on potassium and phosphorus must be considered during the reclamation of soils that demonstrate high

layer and can be reversed by roughing during the revegetation of the retorts. The last soil alteration requiring discussion is the increase in sulfate-sulfur. Although this parameter does not increase to excessive levels it should be carefully monitored as a potential source of problems in reclamation.

The soil constituents analyzed in samples collected from retorts before blasting and after burning were subjected to a paired t-test in order to assess any significance of change in any parameter. The results of this test are given in Table 7. This table shows that two significant alterations before blasting and after burning occurred at the 95% confidence interval. These alterations were in the decrease of percent clay and increase of bulk density. The remaining differences in soil constituents were determined to be of no real significance. It should also be noted that the natural variation in soil characteristics revealed by all of the data presented (Tables D1.1-D1.7) is a further indication of the low level change in the soil constituents of the surface layer on retorts.

SUMMARY AND CONCLUSIONS

The two year intensive baseline study of vegetation, ecoclimate, and soils has shown the presence of four distinct vegetation environments. These plant-soil-ecoclimate units have significance to a general understanding of the natural system on the LOFRECO site and to impact mitigation and reclamation of areas disturbed by the experimental in-situ retorting operations on the site. Significant results of the two year baseline can be partitioned in to the following categories; as will be discussed below:

- The significance of populations of rare and endangered plants species occurring on the LOFRECO site
- The significance of herbaceous productivity to large herbivores, particularly domestic cattle
- The significance of vegetation structural features; and soils and ecoclimatic conditions to mitigating impacts and to the successful reclamation of disturbed areas
- The significance of the baseline data to making future separations between man-induced perturbations and natural trends and/or cycles

Rare and Endangered Species

The bulk of the plant species listed as rare, restricted, endangered, and/or threatened are apparently restricted to special environmental conditions, such as those that prevail on the LOFRECO site. Many of these conditions are listed in the literature (Welsh et al. 1975) as soil related. These same environmental conditions are common to the Uintah Basin, as well.

As a result, the populations occurring on the LOFRECO site do not apparently represent a critical segment of these species' range. In fact, the majority of the rare and endangered species found on the LOFRECO site are locally common in fair abundance. It is also possible that the endemic nature of many of the rare and endangered species in the Uintah Basin may not be truly endemic, but rather epibiotic, indicating that these plants are of young species that have not expanded their range outside the limits of

the basin. On the other hand, the energy resource development currently affecting the southern Uintah Basin may pose a threat to these plants, which are considered a valuable natural resource in themselves.

Three areas of consideration have been given to the rare and endangered species on the LOFRECO site in this report:

- Development of preliminary distribution information showing that the occurrence of most large population segments are on areas outside the development zone on the LOFRECO site
- Location and mapping of individual species is in progress in order to provide the Bureau of Land Management with information useful to this agency in monitoring regional populations of rare and endangered species
- Development of quantitative information significant to documentation of species occurrence and to the understanding of specific habitat affinities of the species found

Herbaceous Productivity Relationships to Large Herbivores

The primary herbaceous productivity of the LOFRECO site is extremely limited. Table 20 represents production on the LOFRECO site in comparison with that of other areas in the region. This table illustrates that the production values discussed in this report are substantially lower than regional values. Sagebrush uplands are similar to other sites during years of greater rainfall (1979 values on Table 20). The lower rainfall received during 1978 had an apparent direct influence on herbaceous standing crop. The increased spring rainfall received during 1979 increased the herbaceous production values to a significant level in terms of available forage (if not in terms of statistical significance). Important in this increased production is the production of blue grama grass, western wheatgrass, and other perennial grasses. Half-shrubs also respond positively to increased moisture, although not as directly as the grasses. The net result of the productivity relationships with precipitation is the cyclic nature of this correlation. Wetter years will produce additional forage, most available

in late spring and early summer. During drier years, the inverse will occur. Total changes in production are, however, not significant between years and not substantial enough to increase animal unit months on any given site. Another important feature of the cyclic nature of the herbaceous productivity is the stable nature of the shrub resource. Sagebrush is utilized by both cattle and big game (more by the former), and may supply an important source of browse during dry years or periods. This factor is significant in considering revegetation plans, and indicates the advisability of including shrubs (as transplants, particularly) in revegetated areas. Moreover, the shrub islands of the upland sagebrush sites tend to increase snow catchment and increase rainfall interception, thus increasing the effectiveness of any precipitation received by a site.

Importance of Vegetation Structure, Soils and Ecoclimatic Conditions to Reclamation of Disturbed Areas

The major factor interaction between ecoclimate and vegetation is the interrelationship between temperature and moisture, and the shrub or tree canopy. In general, the vegetation canopy tends to mitigate some of the extreme influences of temperature and aid in accumulating precipitation as snow and rain. The canopy also tends to obviate some positive effects of climate, such as incident light and rainfall received at the surface of dense shrub communities. Soil conditions also interact with vegetation, especially in terms of their low nutrient status and textural properties. Through these conditions they limit growth in terms of biomass accumulation and germination as a result of single factor interactions or combinations of factors, such as available soil moisture; the dessicating effects of vesicular and channery soils; and soil toxigens (Thatcher and Hart 1979).

The information obtained on these parameters is given priority in its usefulness to the reclamation of the four vegetation types that may be disturbed during the development of the LOFRECO site. These data reveal that the primary problem areas potentially encountered in any revegetation effort on the LOFRECO site and their potential solutions are as follows:

- The control of surface temperature and associated soil water budgets, by using mulches and roughened surfaces
- Increasing interception, accumulation, and effectiveness of any precipitation received, as in open, rough-surfaced shrub stands
- Maintaining moderate air temperature maximums by favoring vertical mixing of air, as in open shrub communities
- Enhancing maximum biomass accumulation in revegetated sites by mitigating soil hazards, such as erosion and toxicity, and increasing soil nutrient status
- Avoiding germination failure through seed dessication, by not developing vesicular soil conditions on channery soils
- Decrease invasion of annuals by increasing conditions favorable to perennials (especially grasses), such as roughened soils and increased effective soil moisture

The Use of Baseline Data in Distinguishing Man-Induced Perturbations From Natural Trends and Cycles

The comparisons of various baseline data by means of coefficient of similarity and analysis of variance tests demonstrate that there are no significant differences between control and development sites or between the same sites among the two baseline years that will interfere with the monitoring of natural cycles and trends during development activities. The level of sensitivity of these tests is sufficiently high to assure detection of natural changes based on the parameters measured and their behavior over the two year period.

The majority of perturbation on the LOFRECO site related to development activities are of a gross nature, such as direct disturbance or removal of the natural vegetation environment. The baseline data provides an adequate basis from which to monitor the success of revegetation in terms of restoring essential vegetation environment conditions.

The effects of potential increased toxigens released in ambient air as a result of any development-related activities can be monitored through

subsequent changes in vegetation type species composition, structure, or productivity. The relationship between vegetation parameters and changes in physical environmental parameters are well-documented and can be used to distinguish between natural and man-induced effects. Potential effects of increased soil toxicity as the result of retort operations are not anticipated, as shown by the sampling of soil overlying retorts.

The following ecoclimatic parameters will be of importance in distinguishing between perturbations and natural cycles:

- Correlations between spring precipitation and perennial grass production
- Correlations between air and soil surface maximum temperatures and perennial grass and half-shrub production

Baseline study methodology and sampling locations are well-documented and amenable to reproducibility during future years. The ranges of values obtained for the parameters studied have been shown to be reliable in making repetitive samples that equally characterize the natural system on the LOFRECO site.

APPENDIX B

RESULTS OF SHALE OIL AND
ALTAMONT CRUDE ANALYSES

Dr. F. V. Hanson at the University of Utah performed gradient elution chromatographic analyses and distillation tests on samples of Geokinetics shale oil and Altamont crude. The samples were analyzed for Geokinetics and the Plateau Refinery in Roosevelt, Utah, in conjunction with efforts to determine the cause of incompatibility when shale oil is blended with Altamont crude.

FIGURE 2

DISTILLATION FRACTIONS
ALTAMONT CRUDE
GEOKINETICS SHALE DERIVED LIQUID

F. V. Hanson
3 April 1980

FIGURE 3

DISTILLATION CURVES
ALTAMONT CRUDE
GEOKINETICS SHALE DERIVED LIQUID

F. V. Hanson
3 April 1960

TABLE 1

Gradient Elution Chromatographic Analysis

Shale Derived Liquid

Geokinetics Inc.

<u>Fraction Identification</u>	<u>Weight Percent</u>	<u>Fraction Appearance</u>
Saturates	11.7	white crystalline solid suspended in colorless liquid
Mononuclear and Dinuclear Aromatics	41.0	lime colored solid; liquifies slightly above room temperature (35-40°C)
Polynuclear Aromatics	0.1	light yellow solid
Soft Resins	15.9	dark brown liquid
Hard Resins	3.8	dark brown semi-solid at room temperature
Polar Resins	2.4	black-brown solid
Asphaltenes (Eluted)	24.0	black-brown semi-solid at room temperature
Asphaltenes (Non-eluted)	1.2	-----
	<hr/> 100.1	

F. V. Hanson
3 April 1980

Table 2

Gradient Elution Chromatographic Analysis
 Altamont Crude Sample
 Roosevelt Refinery
 Plateau, Inc.

<u>Fraction Identification</u>	<u>Weight Percent</u>	<u>Fraction Appearance</u>
Saturates	79.0	milk white paraffin wax; solid at room temperature; liquid above 36°C (96.8°F); readily soluble in n-hexane
Mononuclear and Dinuclear Aromatics	14.7	straw yellow solid at room temperature; liquid at temperature slightly above room temperature; sparingly soluble in paraffinic solvents; readily soluble in aromatic solvents
Polynuclear Aromatics	0.2	light yellow solid
Soft Resins	2.8	light reddish brown; solid at room temperature
Hard Resins	0.6	light brown solid at room temperature
Polar Resins	0.2	dark brown solid at room temperature
Asphaltenes (eluted)	0.8	brown-black solid at room temperature
Asphaltenes (benzene eluted)	1.2	brown-black solid at room temperature
	<hr/> 99.5	

F. V. Hanson
 3 April 1980

TABLE 3

Simulated Distillation Analysis
Altamont Crude
Vs.
Geokinetics Shale Derived Liquid

<u>Fraction Boiling Range (°F) IBP</u>	<u>Altamont Crude 154°F (Wt.%)</u>	<u>Shale Derived Liquid 275°F (Wt.%)</u>
IBP-290	4.9	0.4
290-400	6.9	2.7
400-650	19.3	33.7
650-1000	31.6	46.8
1000+	<u>37.3</u>	<u>16.5</u>
	100.0	100.1

Francis V. Hanson
3 April 1980

Table B-4

ANALYSIS OF GEOKINETICS SHALE OIL
(Performed by Occidental Oil Shale, Inc.)

PARAMETER	REFERENCE	GEOKINETICS SAMPLE (5-23-80)
% BS&W	ASTM-D-96-23	0.10
API Gravity 60°	ASTM-D-1298-23	26.5
Pour Pt. °F	ASTM-D-97-23	70
Kinematic Visc. @ 100°F cSt's 140°F cSt's		12.54 6.17
Cleveland Open Cup Flash °F Fire °F	ASTM-D-92-23	245 260
Pensky Martin Flash Pt. °F	ASTM-D-9323	185
% Sulfur	ASTM-D-129-23	0.61
Gross HTC. Value BTU/lb.	ASTM-D-240-23	18,700
% Asphaltenes	UOP-614-68	0.26
% Nitrogen	ASTM-D-3228-25	1.64
Arsenic, ppm	UOP-837-62	8

APPENDIX C

RESULTS OF RETORT #18 SHALE OIL

CHROMATOGRAPHIC ANALYSES

Complex kerogen molecules break down under pyrolysis and produce oil, gas and water. The composition of the oil and the gas changes with the retorting temperature and also with heating rate. Analyzing the oil using a gas chromatograph to determine composition provides information as to the conditions under which the oil was produced from the kerogen.

Three parameters are listed: oil volume percent by carbon number, 1-alkene/n-alkane ratios, and a total volume percent n-alkanes.

The oil volume percent by carbon number serves as a simulated distillation. This gives an idea as to whether the whole oil is being recovered, just the light ends or a combination somewhere in the middle (the usual case). This parameter can also indicate the general quality of the oil.

The 1-alkene/n-alkane ratio provides an index as to the retorting temperature that produces the oil. Generally speaking, the greater the number, the higher the temperature.

The C₁₇ and C₁₈ isomers (thought to be pristane and phytane) are recorded to observe trends. These two components are of biological origin and will be destroyed by excessive heat.

The total volume percent n-alkanes is an index as to the quality of the oil. Within limits and very generally, the greater the percent of n-alkanes, the better the oil quality.

RESULTS OF RETORT #18 SHALE OIL CHROMATOGRAPHIC ANALYSES BY GEOKINETICS ANALYTICAL LABORATORY

Date Produced:	1-02-80	1-02-80	1-07-80	1-21-80	1-21-80	1-21-80	1-21-80	1-28-80
Sample Point:	PW-3	PW-4	PW-3	PW-1	PW-2	PW-3	PW-4	PW-1

Volume Percent

<C8	0.30	0.37	0.47	0.24	0.49	0.75	2.09	0.89
C9 -C10	2.58	3.19	3.66	3.36	3.93	4.42	6.44	3.48
C11-C12	9.70	10.64	11.73	9.57	10.22	10.34	11.92	10.16
C13-C14	16.17	16.81	17.52	14.25	16.42	14.31	14.84	10.51
C15-C16	15.44	15.56	15.89	15.81	15.78	15.83	14.90	17.63
C17-C18	17.26	16.67	16.50	16.90	17.58	16.94	15.62	16.46
C19-C20	12.98	12.30	13.60	11.51	10.01	14.00	12.73	14.62
C21-C24	12.94/	11.90/	7.42	12.08	4.95	8.22	9.22	9.31
C-3 C25+	10.11 2.51	10.36 2.20	1.45	2.55	1.96	1.50	1.48	2.17

1-alkene/ n-alkane

C6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C7	0.00	0.00	0.00	0.00	0.00	0.00	.265	0.00
C8	.354	.336	.303	0.00	0.00	0.00	.370	.301
C9	.745	.713	.655	.524	.510	.494	.491	.509
C10	.557	.570	.566	.681	.695	.684	.720	.674
C11	.279	.274	.263	.348	.335	.334	.330	.346
C12	.525	.525	.395	.544	.519	.533	.522	.518
C13	.417	.417	.460	.392	.328	.338	.373	.334
C14	.702	.606	.267	.447	0.00	.467	0.00	0.00
C15	0.00	0.00	.559	0.00	0.00	0.00	0.00	0.00
C17	0.00	0.00	1.524	1.409	1.337	1.450	1.416	1.517
C18	0.00	0.00	1.415	1.600	1.538	1.721	1.684	1.848

Total n-alkanes	40.18	38.93	39.543	48.81	47.48	48.01	45.80	47.77
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