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Developing the Geokinetics/Department of Energy Horizontal In Situ Retorting Process

Final Report

By
M.A. Lekas

June 1985

Work Performed Under Contract No.: DE-FC20-78LC10787

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Laramie Projects Office
Laramie, Wyoming

By
Geokinetics, Inc.
Salt Lake City, Utah

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I. INTRODUCTION

A. Scope of the Final Report

This report summarizes work performed under a cooperative agreement between Geokinetics Inc., and the U. S. Department of Energy, spanning an eight year period. A large body of experimental data was generated which has been previously reported in a series of published and unpublished reports, as indicated in Chapter VII. The report summarizes research work performed from April of 1975 to August 15, 1985, but emphasizes data generated during the final three years of the project, when five large retorts were tested. The report draws conclusions based upon the total program, including work performed by Geokinetics prior to entering into the Cooperative Agreement, and presents the initial parameters useful for scaleup and design of a commercial scale operation, including data useful for assessing the environmental impacts and criteria for mitigation of such impacts. Specific details concerning the various aspects of the program may be obtained from the many previous reports that have been generated from the date of project initiation. A list of these reports is presented in Chapter VII.

B. HISTORICAL

In 1974, The Geokinetics Group began developing a process for in-situ retorting of shale oil. The Geokinetics Group was a joint operation between Geokinetics Inc., and Aminoil USA. Geokinetics acted as Operator for The Geokinetics Group and, later, as Project Manager for the industry-government cooperative venture. At the end of 1978, Aminoil withdrew from the project, leaving Geokinetics and the DOE as the remaining participants. In 1984 the DOE withdrew and Geokinetics completed the project at its own expense.

The concept of the process is to fracture oil shale beds with explosives, creating a permeable in-situ "retort", and then drive a fire front through the rubblized oil shale to release the oil, which collects at the bottom of the retorts, and is lifted to the surface through wells.

Initial test work was performed at Concord, California, during June through December of 1974. This was followed by field tests performed at a site near Vernal, Utah, beginning in April, 1975.

In 1976, ERDA, the predecessor of the DOE, issued a Program Opportunity Notice (PON), inviting interested parties to submit proposals for innovative technologies for producing shale oil. Geokinetics responded to the PON and theirs was one of five technologies selected to be developed. A contract was signed, effective November 1, 1976, to develop an in situ process for shale oil extraction. The R&D program lasted for eight years, until November 1, 1984. During this period, the parameters for a complete process was developed, and many problems were encountered and solved, including a blasting technique to fracture the oil shale bed with minimal fracturing of the overburden, low cost procedures for drilling wells through rubblized rock, ignition procedures, methods of controlling the fire front and minimizing channeling, techniques for minimizing gas leakage from the retorts, offgas cleanup, and waste water handling. Environmental effects were investigated, and methods of mitigating such effects were developed.

A total of $18,000,000 was spent on the program, $3,000,000 by Geokinetics, and $15,000,000 by DOE. Twenty-eight retorts were blasted, and 16 retorts were burned. In the course of the test burns, 136,000 barrels of shale oil were produced and sold.

C. DESCRIPTION OF THE PROCESS

The Geokinetics process is a true in situ process for extracting oil from oil shale. As the process was designed to minimize initial capital costs, it was named LOFRECO, an acronym for Low Front End Cost. In the process, the oil shale is fractured by means of explosives placed in blastholes drilled from the surface. After a specific area has been fractured, creating an in situ retort, air injection holes are drilled at one end, and oil and offgas recovery holes are drilled at the other. The fractured oil shale is ignited at the air injection well, 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 offgas wells, it burns the residual coke left from the retorted oil shale as fuel. The combustion gases are recovered at the offgas wells. As this gas is combustible, it can be used as fuel for power generation. The process is designed to retort oil shale beds under shallow overburden. However, the basic horizontal burn that has been 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 oil shale mine.

D. PRE CONTRACT ACTIVITIES

Research on the basic LOFRECO process was initiated by The Geokinetics Group prior to entering into the cooperative venture with DOE. Laboratory and pilot work were carried out at the Geokinetics facilities in Concord, California, during 1974 and early 1975, to examine the technical feasibility of establishing and maintaining a horizontally moving burn front through a random sized mass of rubblized oil shale. In March of 1975 leases on oil shale lands suitable for the process were acquired in the southern Uintah Basin of Utah. In April of 1975 field operations began.

The project site is located 70 miles south of Vernal, Utah, in the NE quarter of Section 2, T14S, R22E, on land owned by the State of Utah. Oil shale rights were leased from the State by Geokinetics, and 320 acres were dedicated as a test site. The oil shale bed is approximately 30 feet thick and has a grade of 22 gallons/ton. The beds strike in an east-west direction, and dip to the north at about 120 feet/mile. Overburden over the shale ranges from zero to a maximum of 120 feet.

Because of the remote location of the site, being 70 miles from the nearest supply center over poor roads, it was necessary to establish a fully self-contained camp, including living quarters, shops, warehousing, etc. During the pre-contract period, five retorts were constructed, and two were burned. The retorts ranged in size from 60 tons to 1,200 tons. During the pre-contract period, the outlines of the process were established, the basic components of the process were tested, and it was demonstrated that:

1) It was possible to drill a pattern of blastholes from the surface into the oil shale and fracture the shale in a manner to establish a zone of high permeability in the shale, with a relatively impermeable zone between the fragmented shale and the surface.

2) It was possible to drill through the rubblized material and construct the various wells necessary

for the operation, including air-in wells, offgas wells, oil recovery wells, and instrument wells.

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

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

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

E. CONTRACT OBJECTIVES

During the contract period, the following specific objectives were established:

1) Test a number of blasting techniques, and select one technique that is effective in producing a permeable zone in the oil shale at a minimum cost, and with good reliability.

2) Scale up the size of the blasting pattern to a size suitable for a commercial operation.

3) Burn the retorts created in the blasting tests, and test the retortability and oil recovery of the various blasting techniques.

4) Establish basic retorting parameters, such as air injection pressures, specific air injection rates, rates of fire front advance, oil recovery factors, offgas composition, etc.

5) Develop reliable ignition procedures.

6) Develop procedures for controlling the movement of the burn front.

7) Develop techniques for drilling and casing large and small diameter holes through the rubblized zone.

8) Determine potential environmental impacts on water, land, air, vegetation and animal life.

All experimental objectives were addressed, and the parameters of a complete, integrated process were developed and demonstrated.

Where the LOFRECO process is used as a secondary recovery technique, it can recover additional oil from a room and pillar mine by recovering oil in the pillars, and in low grade shale in the back and floor of the mine. This would approximately double the recoverable oil from the mine.

II. DEVELOPMENT OF MAJOR PROCESS COMPONENTS

A. INTRODUCTION

The process can be subdivided into a number of independent components. The development of each of these components will be discussed separately.

The components are:

1. Retort Fragmentation
2. Process Well Drilling and Completion

3. Ignition Procedures
4. Burn Operation and Control
5. Surface Facilities
6. Shutdown and Reclamation
7. Environmental Impact Mitigation Procedures

B. RETORT FRAGMENTATION

1. <u>Surface Preparation</u> - Surface preparation prior to drilling blast holes is an important step to minimize fugitive gas emissions, and expedite post burn surface reclamation.

a. Earth moving equipment is used to remove and stockpile soil and vegetation from the retort surface.

b. The subsoil is removed and stockpiled.

c. After drilling and blasting, the subsoil is placed back on the retort, and compacted to prevent fugitive emissions.

d. Upon completion of the burn, the well casings are removed, and the topsoil is replaced over the retort and seeded.

2. <u>Blast Hole Drilling</u> - Various techniques for drilling the blast holes were used during the program. As the retorts increased in size, the blast holes increased in number, diameter, and depth.

Initially the blast holes, up to three inches in diameter, were drilled with a rotary core drill. Diamond bits and carbide tipped bits were used. To reduce costs and speed operations, we went to a track mounted hammer drill. A

Gardner/Denver track drill, powered by a 750 cfm compressor, was used to drill holes up to five inches in diameter to depths of 50 feet.

As the hole diameter increased, we went to track mounted blast hole rigs. The first unit was a Chicago Pneumatic 650, which was effective for diameters of up to seven inches and depths of 120 feet. As depth and diameter requirements increased, we progressed to a track mounted Chicago Pneumatic 700, which was used to the end of the program. This drill effectively drilled up to 12 1/4 inch diameter holes to depths of 120 feet. Roller bits were used on all holes. Formations were soft and typically easy to drill, with the limitation to penetration rate being insufficient circulating air to maintain annular velocity and clean the hole.

A two acre commercial size retort, with 70 feet of overburden, would typically have 255 blast holes spaced about 20 feet apart, with diameters of 9 7/8 to 12 1/4 inches. To drill such a pattern using a single drill, 10 hour shift, would take approximately 50 working days.

3. Explosives - Various explosives were used during the program. Initially we used dynamite and packaged explosives such as "Aqua-Gel". We then used standard bagged ammonium nitrate (ANFO) explosive for retorts #3 to #19. In order to minimize problems with wet holes, we began using bulk slurry explosives. The IRECO Chemical Co. provided the explosive and the delivery service. The explosive components were transported to the site in tanker trucks, and were transferred to blending trucks that mixed the components and pumped the slurry into the holes. In most cases two energies of explosives were used in each hole. A high energy mix toe load constituted the lower one third of the charge, and a less energetic explosive the upper two

thirds of the charge. The slurry explosives gave good service; however their cost is greater than ANFO. In a production operation cost factors would favor ANFO.

Because of the precise timing required by the delay sequence, the performance of the time delay blasting caps is important. We utilized the Ensign Bickford NONEL (non electric) system. A major concern was the scatter in delay times within a given batch of blasting caps. In order to attain satisfactory precision, it was necessary to test production batches, and select those batches that had the minimum scatter.

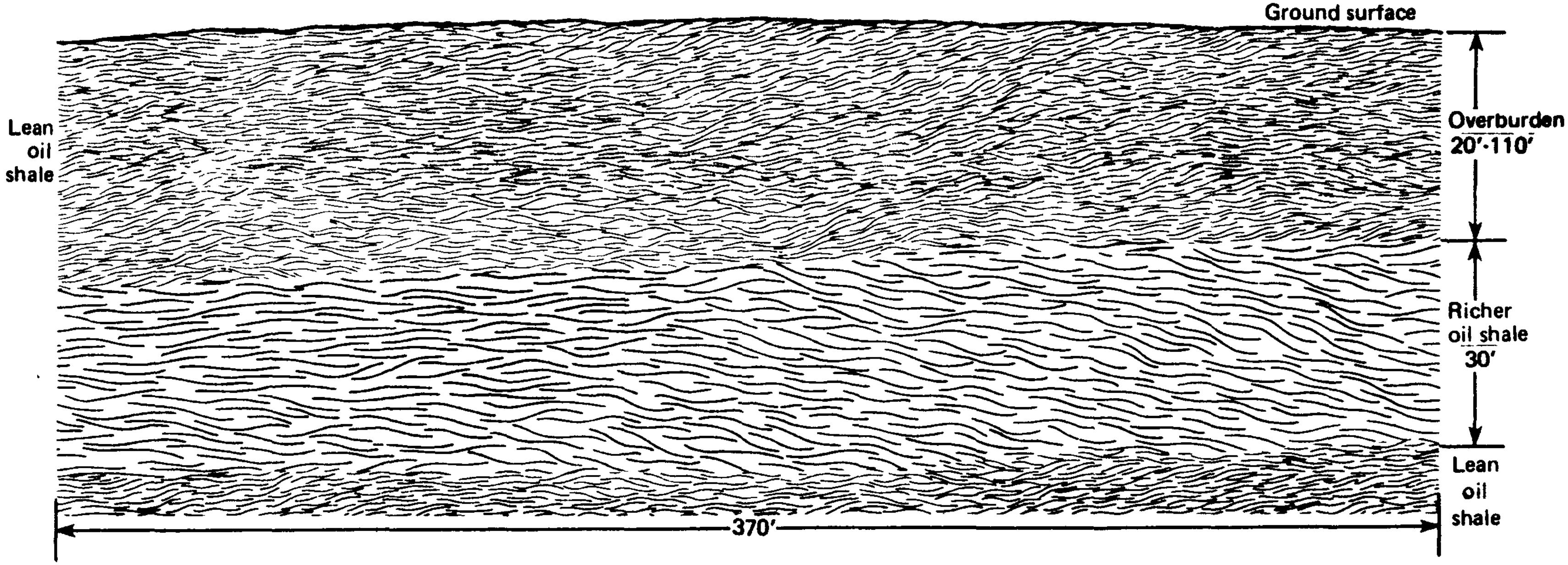
4. Loading and Firing - after the blast holes are drilled, they are dewatered. This can be accomplished by lowering an air hose to the bottom of the hole and blowing the water out with compressed air, or by use of a blast hole dewatering pump. The hole is then ready for the explosive charge. The time delay blasting cap is placed in a detonator charge having sufficient energy to initiate the slurry explosive. The cap and detonator are lowered to the bottom of the hole on a NONEL lead line. The slurry delivery hose is then lowered to the bottom of the hole, and a high energy explosive slurry is pumped into the bottom three to five feet of the hole. The remainder of the oil shale bearing section is then filled with a lower energy explosive. Three feet of crushed stone is placed on top of the explosive column, and the hole is filled to the surface with drill cuttings.

When all holes have been loaded and stemmed, the NONEL line from each hole is connected to a detonating cord on the surface. A single electric detonating cap is tied to the detonating cord, and the round is fired.

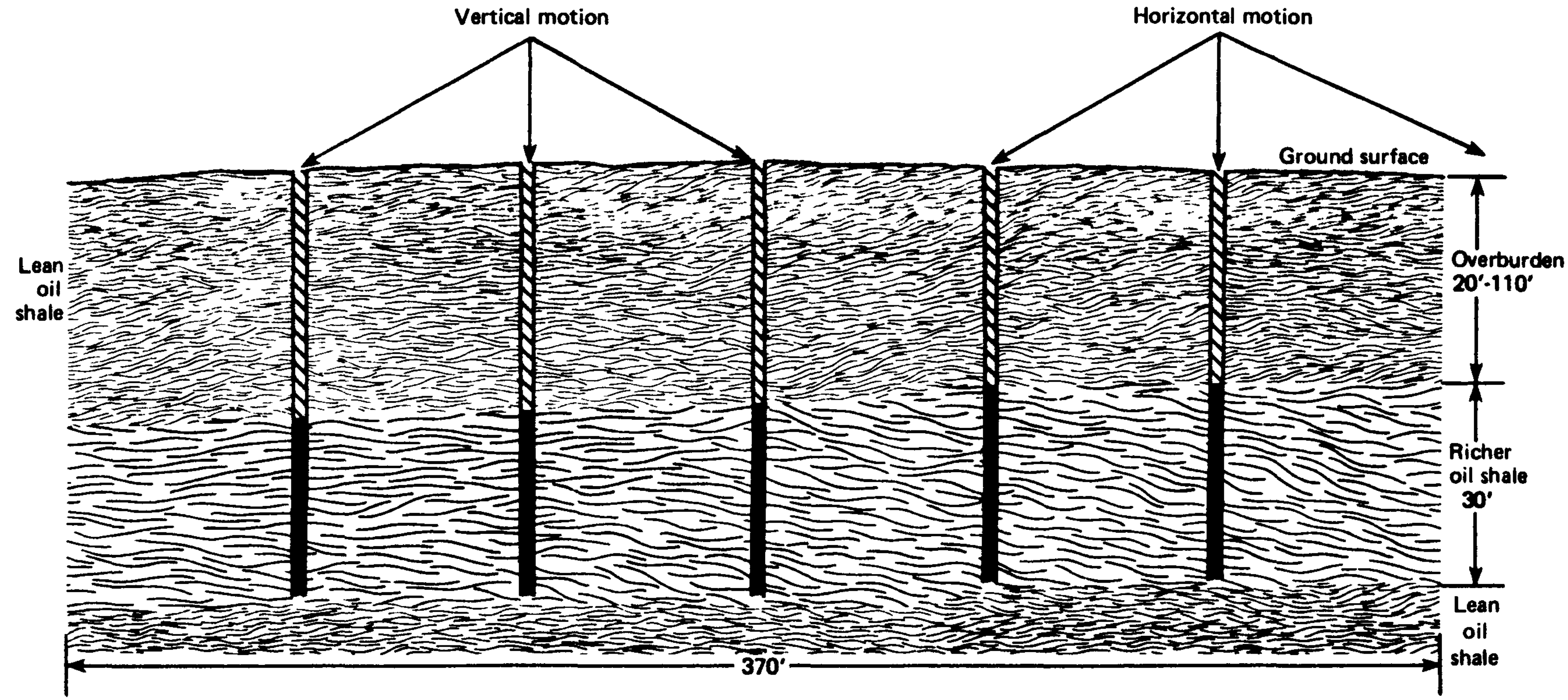
5. <u>Blast Design</u> - The blasting design used in the LOFRECO process is described in detail in Patent #4,175,490 and 4,205,610 and in published papers (See Retort Drilling and Blasting Reports, page 56). In this section, only the basic system will be described.

The purpose of the blast is to create permeability within the impermeable oil shale bed. This permeability must be sufficient to allow gas flow under low pressures and to allow oil and water to freely flow to the bottom of the retort. In order to achieve such permeability, space must be created between particles of broken rock, i.e., the rock mass must "swell" or increase in volume. To allow the rock to swell, the ground surface is permanently lifted over a portion of the retort.

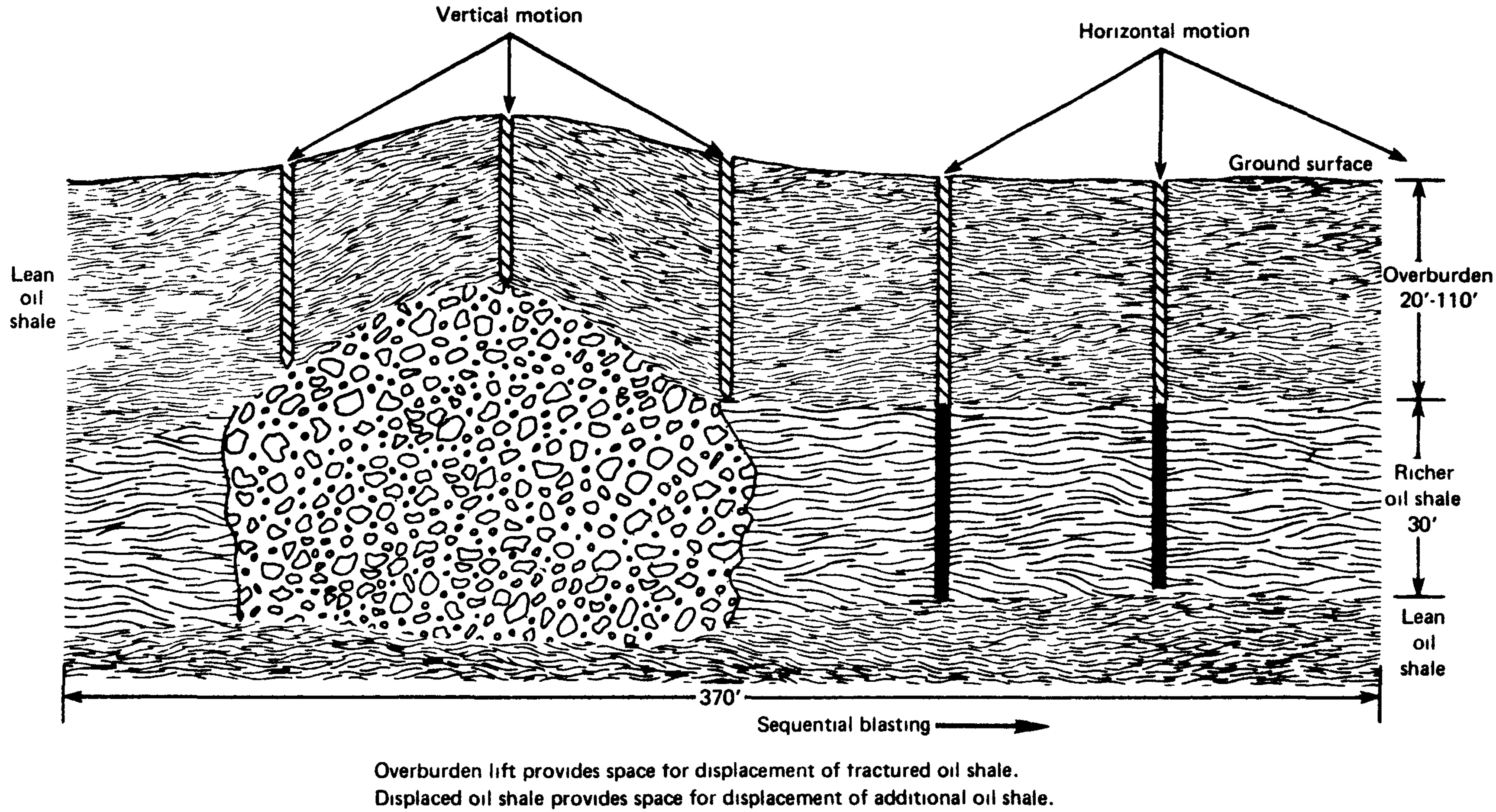
In a typical two acre retort, 250 blast holes will be drilled in a grid pattern, with hole diameters sufficient to give the desired powder factor. The retort is divided into two areas, the vertical motion area (VMA), and the lateral motion area (LMA), as shown in Figures 2 through 5. The VMA is fired first. The force of the explosive is directed to the closest free face, which is the surface. The surface is temporarily lifted to a height of 15 to 20 feet, as the shale bed is broken and expanded upward. At an appropriate delay, while the surface is still in upward motion (usually about 0.5 second) the first row of holes in the LMA is fired. As the closest free face is now the edge of the expanding VMA, the force of the explosive is directed laterally towards the VMA. Subsequent rows of the LMA are fired in sequence, with appropriate delays (usually about 0.01 second) until the entire round has been detonated. After the blast, all of the oil shale within the retort boundary has been rubblized, and the surface shows an uplift over the VMA of about 10 to 12 feet. Figures 1 through 6 illustrate the blast sequence.



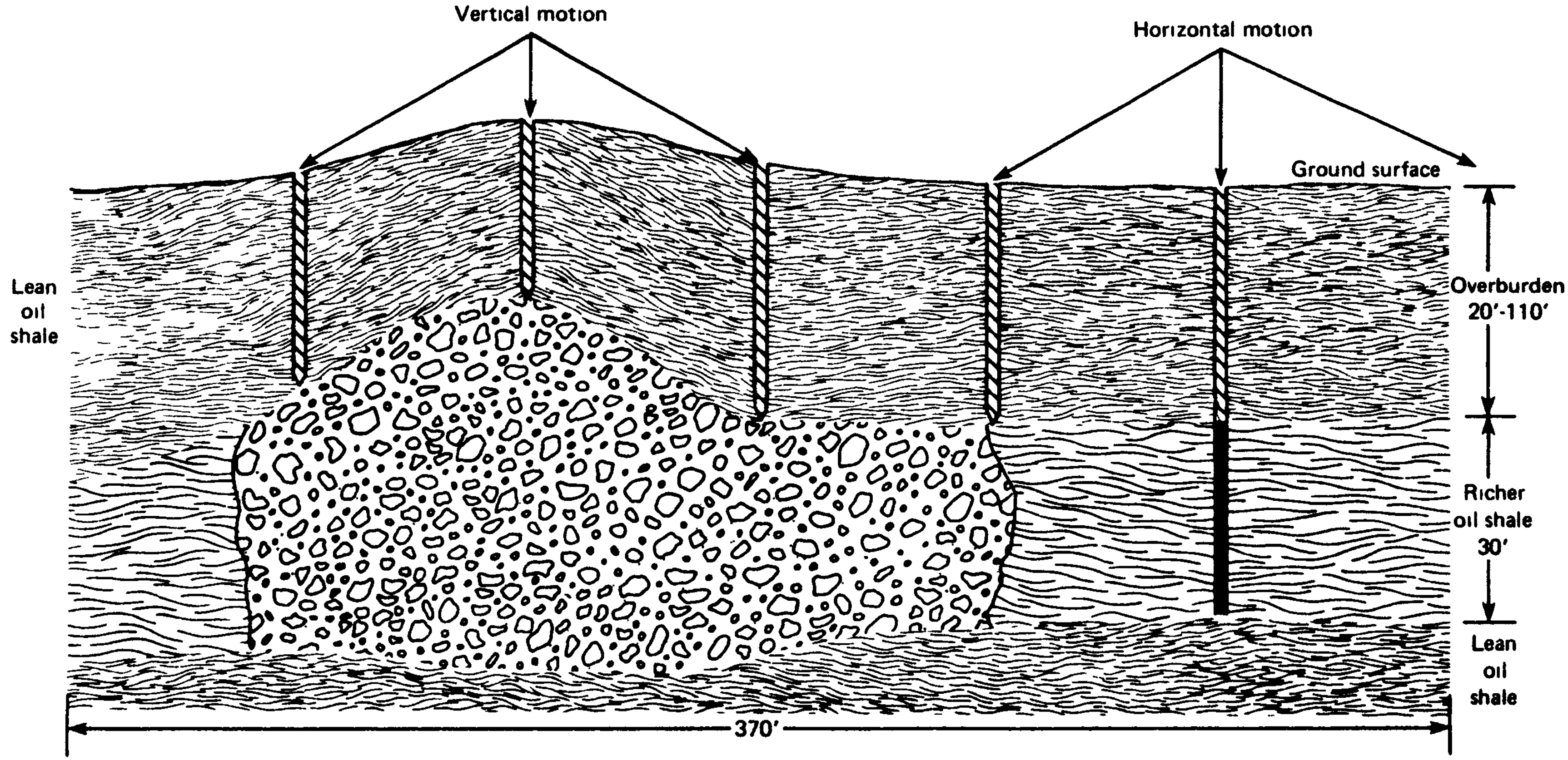
1. Blasting Sequence: Cross Section through Oil Shale Beds



2. Blasting Sequence: Drill Blast Holes and Place Explosive Charges

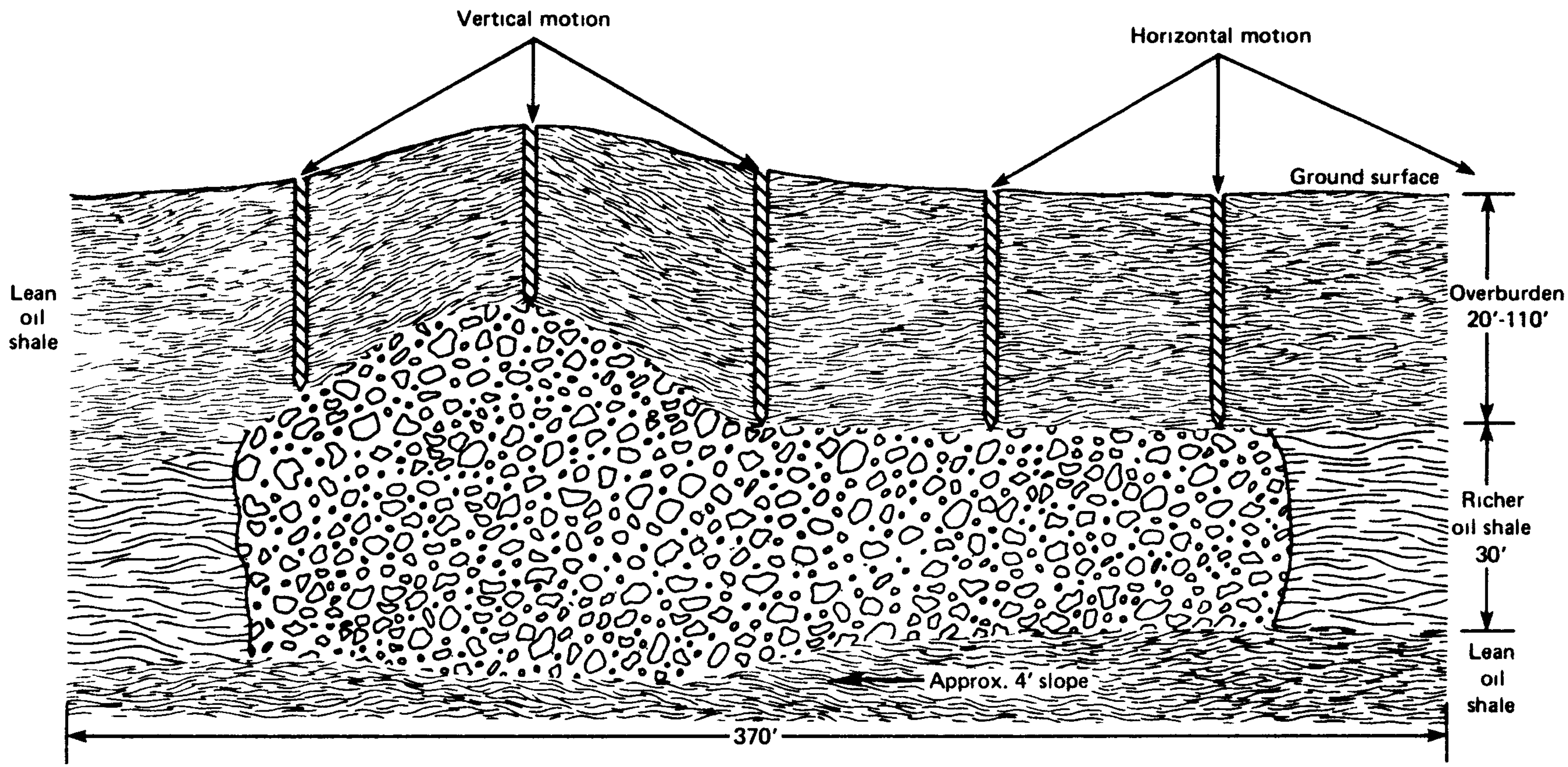


3. Blasting Sequence: Initiation of Blast: First Charges Initiate Vertical Uplift

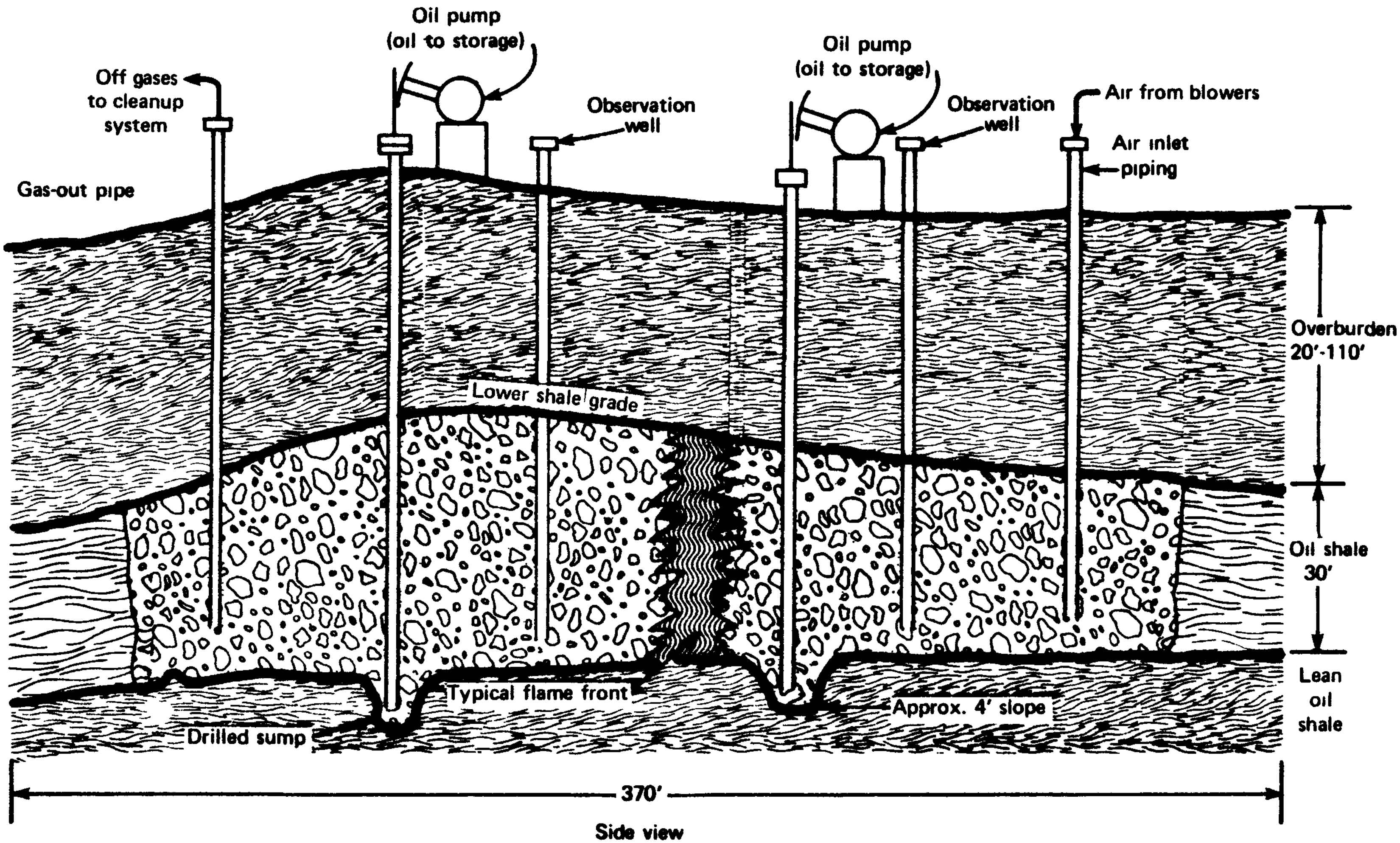


Fractured oil shale displaced into created void space.

4. Blasting Sequence: Subsequent Charges Break Laterally



5. End of Blasting Sequence



6. A Geokinetics Retort in Operation

C. PROCESS WELL DRILLING AND COMPLETION

Following the blasting of the retort, it is necessary to drill and complete a large number of wells into the broken rock. Because of the problems of drilling through rubblized rock, and the requirement to maintain permeability in the zone surrounding the well in the rubble zone, special drilling and completion techniques were developed.

Six types of holes were drilled:

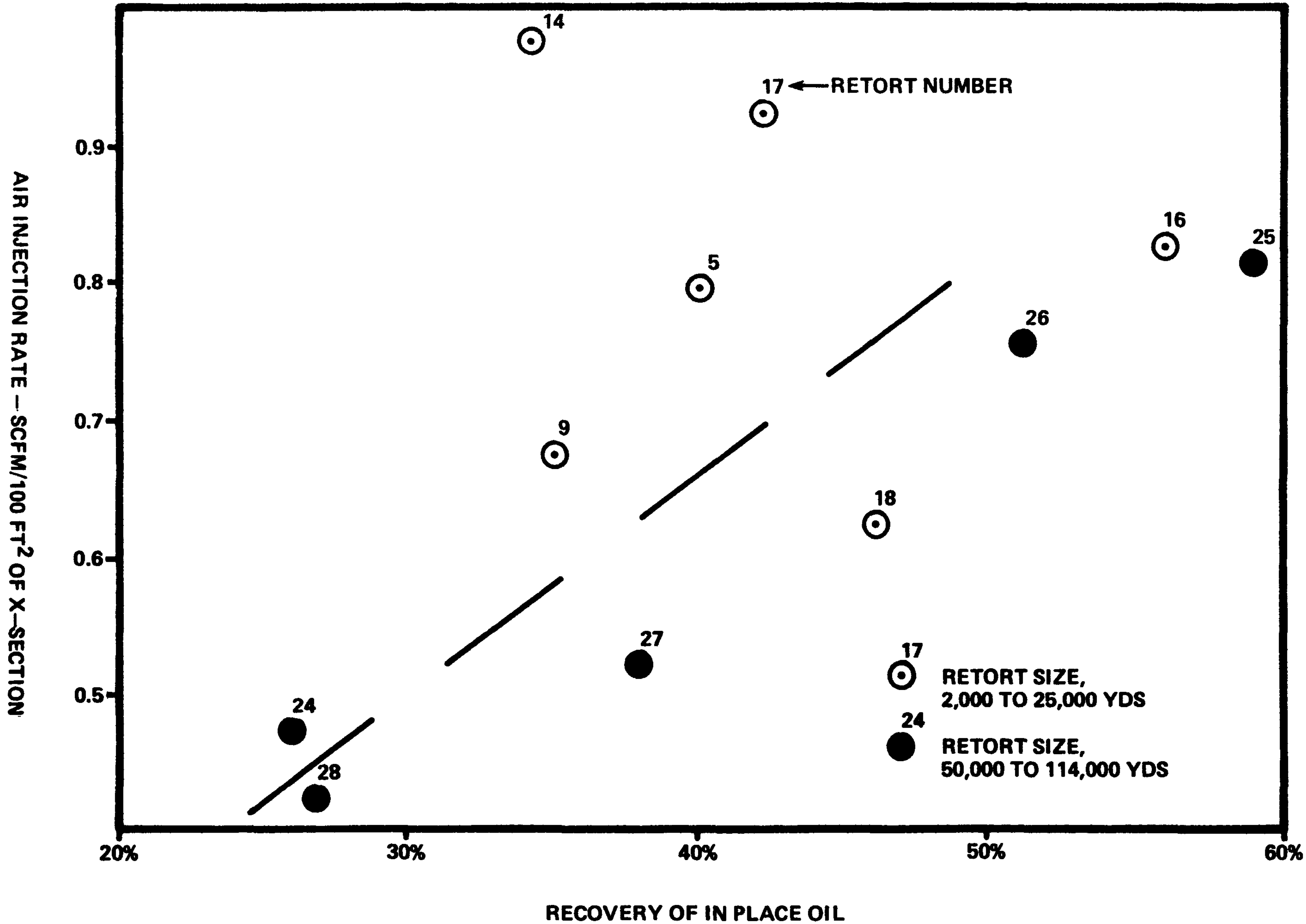
1. Air Injection Wells
2. Offgas Exhaust Wells
3. Oil Production Wells
4. Observation Wells
5. Thermocouple Wells
6. Gas Sample Wells

Figure 1 shows the layout of the process wells in a typical retort.

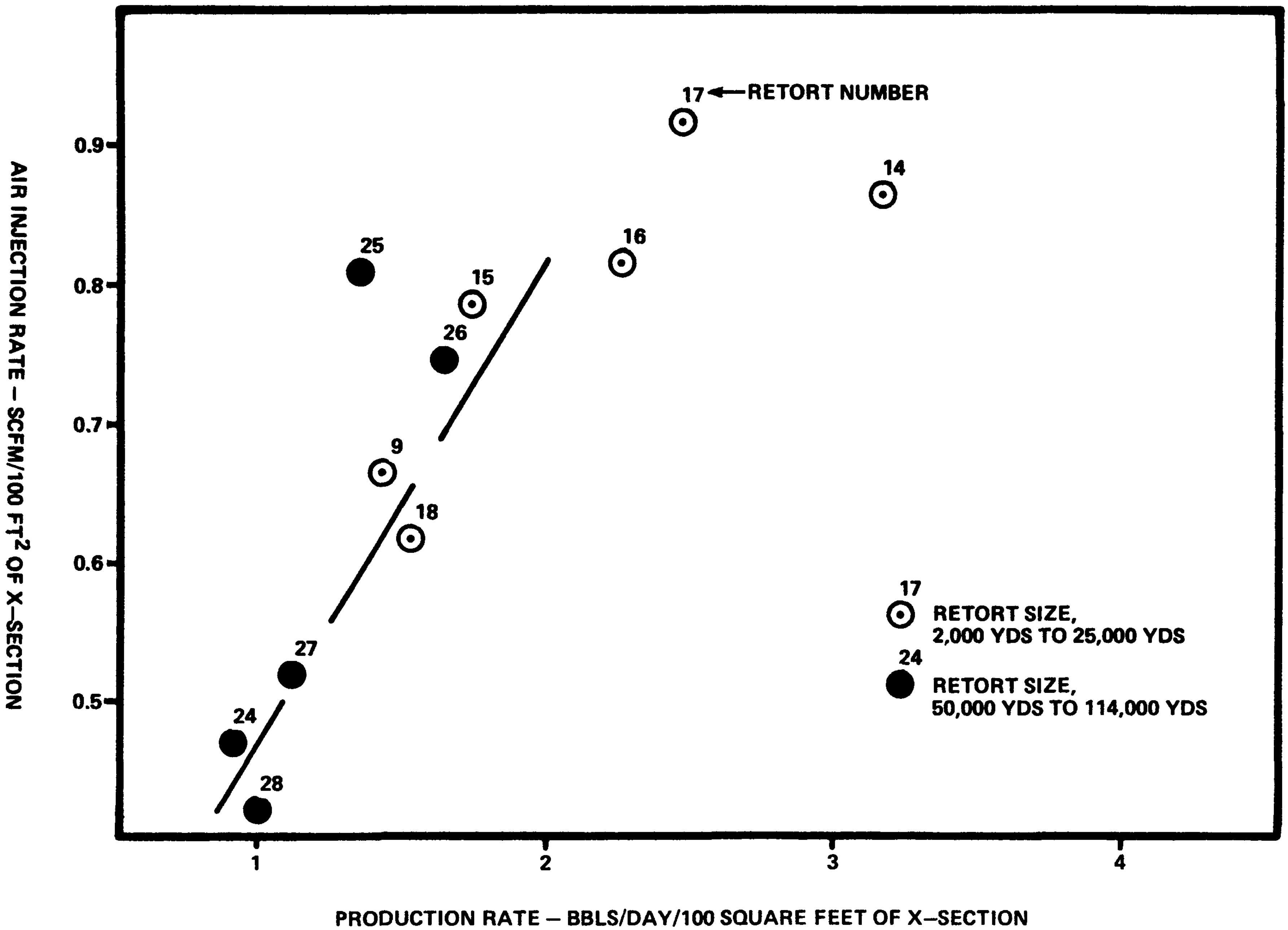
1. The Air Injection Wells - must deliver large volumes of air to the lower one third of the Retort Zone (RZ). The wells must have good communication with the formation to reduce the pressure required to force the air into the formation. Various methods were tested to develop a satisfactory technique for drilling and casing the wells and sealing the collars of the wells.

The process developed is as follows:

a. A 12 inch diameter hole is drilled to within 15 feet of the top of the RZ.



7. Relation of Oil Recovery to Air Injection Rate



8 Relation of Production to Air Injection Rate

b. The 12 inch bit is then removed, and the hole is continued with a 10 inch diameter bit to the bottom of the RZ.

c. Eight inch casing is run from the surface through 2/3 of the RZ. The bottom 1/3 of the RZ is left uncased. The casing has a flange welded on at a point where the flange will rest on the shoulder between the 12" hole and the 10" hole.

d. The annulus between the 12 inch hole and the eight inch casing is sealed with a mixture of cuttings and soil from the flange to the surface.

2. The Offgas Wells - remove large volumes of offgas from the lower one half of the rubble zone, and must have good communication with the formation to reduce vacuum requirements. The drilling and completion procedures are the same as for the air injection holes.

3. Oil Production Wells - produce oil from the retort. They must have good communication to the rubble zone to allow the oil to flow into the well. Many methods were tested to develop a satisfactory method for drilling, casing, perforating, and sealing the holes.

The process developed is as follows:

a. A 10 inch diameter hole is drilled to within 15 feet of the top of the RZ.

b. The 10 inch bit is then removed, and the hole is continued with an eight inch diameter bit to a point 10 inches below the bottom of the RZ.

c. Six inch casing is run to the bottom of the hole. The casing has a flange welded on at a point where the flange will rest on the shoulder between the 10 inch hole and the 8 inch hole.

d. The annulus between the 10 inch hole and the six inch casing is sealed with a mixture of cuttings and soil from the flange to the surface.

e. The casing in the lower 2/3 of the RZ is perforated with a wheel type casing perforator or with explosive jet perforators.

f. A stainless steel submersible pump is lowered in the hole on a 1 inch diameter production pipe to a point five feet below the bottom of the RZ. A flange is welded on the top of the casing and a plate with a packing gland is bolted on to provide a seal around the oil string and electric cable that provides power to the submersible oil pump.

4. Observation Wells - The observation wells are drilled adjacent to the oil wells, and provide a means of gauging the level of oil and water in the retort. They can also be used as oil production wells if needed. They are drilled and completed the same as the oil production wells.

5. Thermocouple Wells (TC wells) - The TC wells hold a string of four thermocouples, set at different vertical elevations in the RZ. The thermocouple wires are flexible and are bundled together to form a TC string. A five inch hole is drilled to the bottom of the RZ. Immediately after the drill pipe is pulled out of the hole, the thermocouple string, with a weight on the bottom, is lowered to the bottom of the hole. The top of the thermocouple string is attached to a short length of

one inch pipe driven into the ground adjacent to the hole. The hole is then stemmed.

6. Gas Sample Wells - The function of the gas sample well is to allow a sample of retort gas to be drawn from a discrete point in the retort.

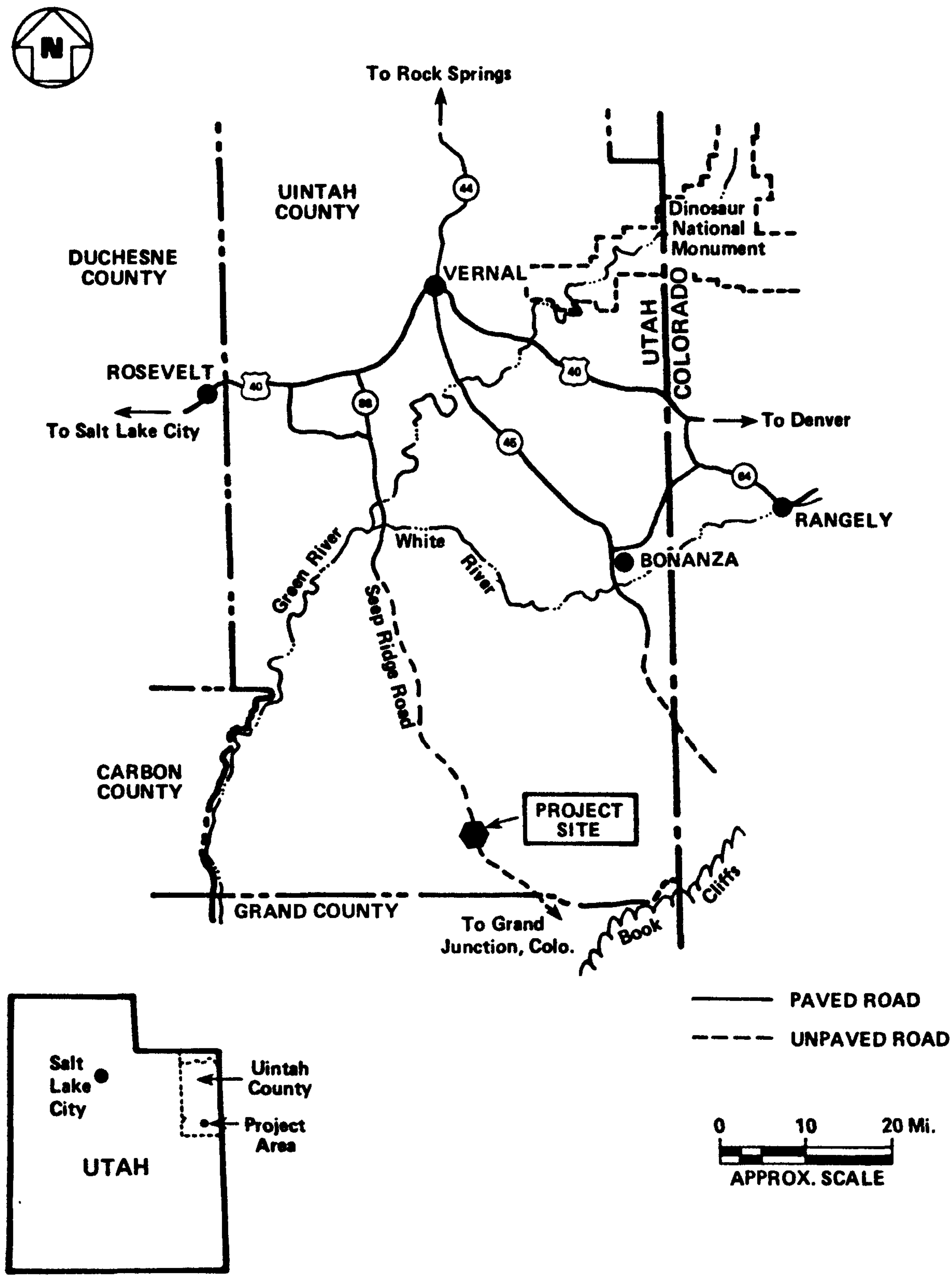
A five inch hole is drilled to the bottom of the RZ. Immediately after the drill string is pulled out of the hole, a 1/2 inch pipe is run to the bottom of the hole. The pipe is pre-slotted in the section that is set in the RZ. The hole is allowed to stand for two days, and is then stemmed. During the two day delay, the hole will cave and bridge, and the stemming will not plug off the perforated section.

D. IGNITION PROCEDURES

Two ignition techniques were developed: Charcoal ignition and diesel ignition. Variations of the charcoal method were used in retorts #1 through #26. The diesel method was used in retorts #27 and #28. It was concluded that the diesel method was the most satisfactory, and is the standard ignition method.

In the charcoal method, charcoal briquettes are poured down the air injection well, filling the open hole below the casing, and rising approximately two feet into the casing. In a typical hole, this will require 50 pounds of briquettes. Ten burning briquettes are dropped on top of the charcoal in the well. Air is injected at about 50 cfm until the charcoal in the casing burns out, and then the air volume is increased gradually over a two day period until the design volume is reached.

In the diesel method, a 1/2 inch pipe is run down the inside of the well to the bottom of the casing. Ten burning



9. Project Location Map

briquetts are dropped in the hole, the air flow is established at 50 cfm, and diesel is injected down the 1/2 inch pipe at a rate of 10 gallons per hour. The air volume is gradually increased over a two day period until the design volume is reached.

E. BURN OPERATION AND CONTROL

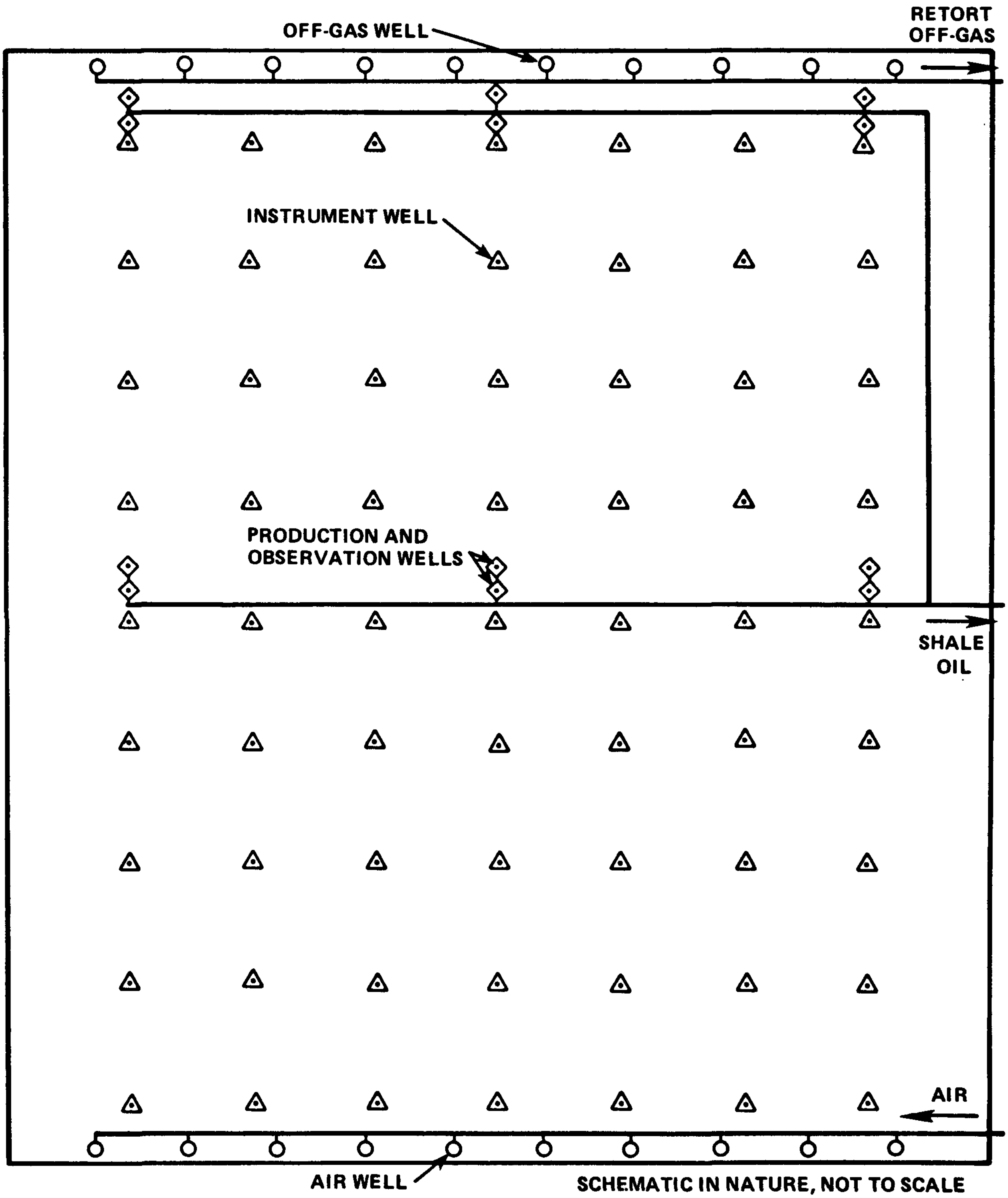
Operation and control of the burn involves a number of actions:

1. Air is injected into the retort at a steady volume at the design rate. Wellhead pressure will be about 2 psi, and pressure in the retort, 10 feet away from the injection well will be about 0.25 psi. The wellhead presure is primarily required to overcome the high resistance to air flow in the region adjacent to the well bore. Air flow volumes are about 1 scfm per square foot of retort cross section. Figure 10 shows the layout of process holes on a typical retort.

2. At the far end of the retort, offgases are being withdrawn under vacuum. Well head vacuum is about 3.0 psi and vacuum in the retort, 10 feet away from the wellbore is a negative 0.20 psi.

3. The fire front moves down the retort at a rate of about 1.0 foot per day.

4. Rows of thermocouple wells are located 50 feet apart across the retort. The wells are 40 feet apart within the rows. There are four thermocouples in each well. The thermocouple wells give data on the shape of the burn front, its location, and rate of movement. Data from the thermocouples is plotted daily. There are five gas sample wells located 60 feet apart on the longitudinal axis of the retort. Samples are analyzed for oxygen and total combustibles. Samples of offgas



10. Seep Ridge Project: Typical LOFRECO Retort and Manifold Layout

from the ten offgas wells are analyzed for oxygen and total combustibles.

Data from these various sources will indicate if the firefront is maintaining a uniform, steady foreward movement, or if portions are moving more rapidly ahead (tonguing). If tonguing is not detected and controlled early, it will reach an air out well ahead of the front and bypass areas of unretorted shale, reducing the total oil recovered from the retort. Tonguing is indicated by early temperature rise in individual thermowells in the row ahead of the front, and by increased oxygen in individual gas sample wells, and offgas wells. Remedial methods are as follows:

1) Air flow to the injection wells closest to the tongue is cut back by 50% to 75%.
2) Offgas withdrawal from the offgas wells closest to the tongue is cut back by 50% to 75%.
3) Air injection and offgas withdrawal on the remaining wells is increased to maintain the full design flow rate.

5. As the burn front approaches the offgas wells, the temperature of the gas will increase rapidly. At wellhead temperatures of $500^{o}F$, the well is shut in.

6. Oil is produced through oil production wells. Early in the program small sucker rod pumps, designed for use in water wells, were used to lift the oil to the surface. On the later retorts, submersible pumps, designed for water well use, were modified and used. Although the sucker rod pumps were satisfactory, the submersibles were much better from the standpoint of initial cost, operating cost, reliability, and lifting capacity. During the test program, it was necessary to

lift the oil from the retort as rapidly as it was produced, in order to measure daily the amount of oil generated by the retort. In a commercial operation, oil can be stored in the retort, and lifted at a constant rate. The observation wells are drilled adjacent to the oil wells, and are completed in the same manner. Fluid levels are measured in these wells, and they can be used as oil wells if the principal oil wells become plugged.

F. SURFACE FACILITIES

Surface facilities consist of the following components:

1. Pressure blowers to provide air to the retort manifolds.

2. Large diameter air lines and manifolds to deliver the air to the retorts.

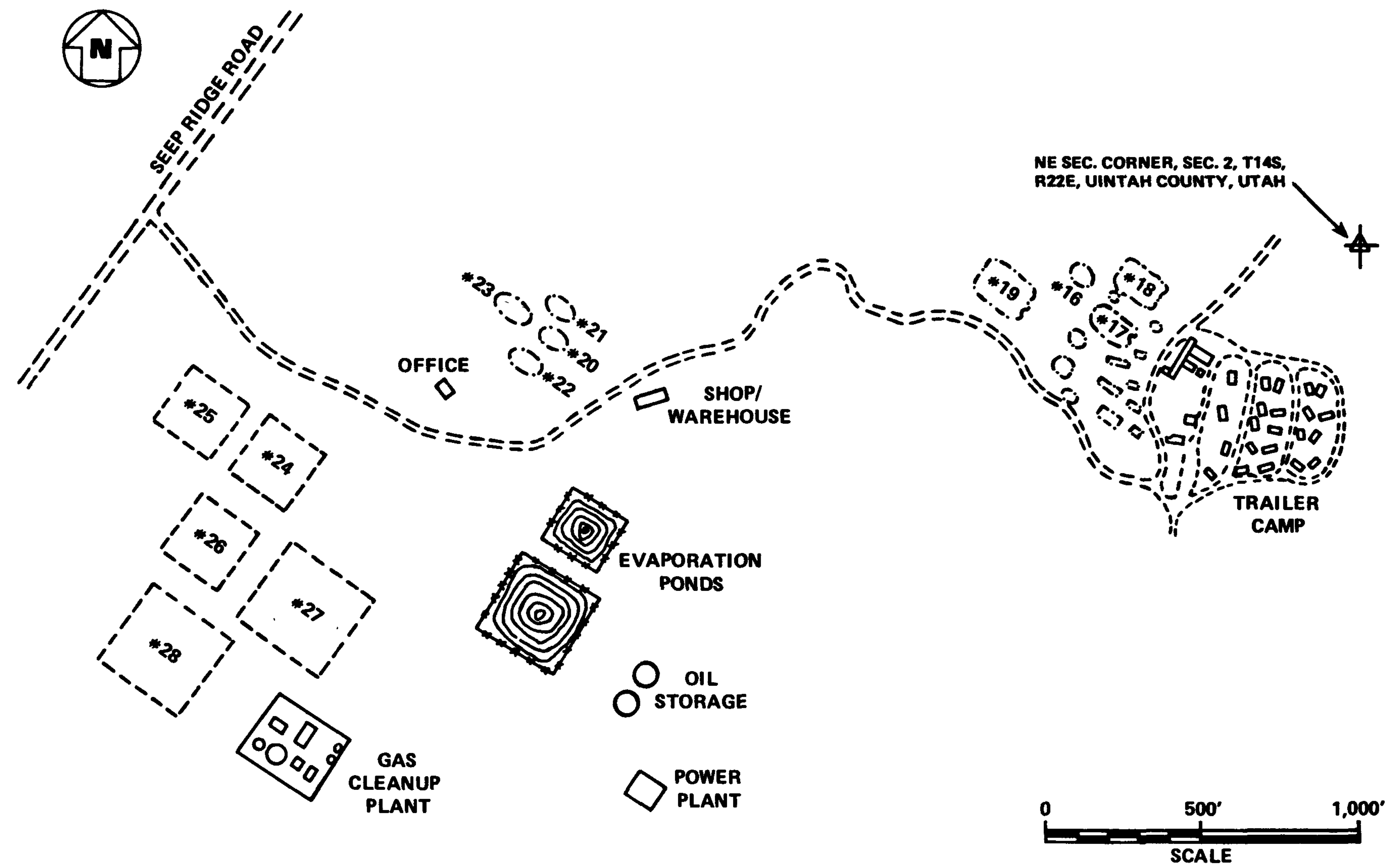
3. Flow meters and valves to measure and control the volume of air delivered to each well.

4. Vacuum blowers to draw vacuum on offgas manifolds.

5. Large diameter vacuum lines and manifolds to deliver off gas from the retorts to the vacuum blowers.

6. Mist separators to recover oil mist from the offgas stream.

7. Gas cleanup plant to remove H_2S from the offgas.



11. Geokinetics Field Site

8. Afterburner (combustion chamber) to burn the offgases to eliminate hydrocarbons and CO from the gas before venting to the atmosphere.

9. Surface oil handling and storage.

1. Pressure Blowers - Various types of blowers were used, delivering air at pressures ranging from 1/2 pound to 6 pounds. Centrifugal fans were used on the retorts #1 through #16. It was decided to use positive displacement blowers on all subsequent retorts in order to meet temporary increases in pressure demand. Lobe blowers with power requirements ranging from 200 HP to 400 HP were used, and all performed in a satisfactory manner.

2. Air Lines and Manifolds - A pipe manifold is used to deliver air from the air injection blower to each of the ten air injection wells. Air is delivered from the blower to the manifold through large diameter, thin wall pipe. The maximum diameter was 22 inches, with a 0.25 inch wall thickness.

3. Flow Metering and Valving - Air is delivered to each well through an individually metered and controlled line. Air flow to the individual air injection wells is measured by an orfice meter, and offgas flow from the individual offgas wells is measured with a pitot tube set in a flow straightening section of line. All air and gas flows are controlled by metal to metal butterfly values.

4. Vacuum Blowers - Various types of vacuum blowers were used, delivering air at pressures ranging from 0.5 pound to 6 pounds. Centrifugal fans were used on retorts #1 through #16. On all subsequent retorts, lobe type blowers were used to withdraw combustion gases from the retort, and deliver them under pressure to the gas processing plant.

5. Vacuum Lines and Manifolds - were constructed in the same manner as the air lines and manifolds.

6. Mist Separators - The offgases were passed through a variety of mist separators before going to the vacuum blower. The function of the mist separator is to separate entrained droplets of oil and water from the gas stream. Beginning with retort #24, a fin-fan gas cooler was placed ahead of the mist collector to cool the gases and condense some of the steam and oil vapor. The prime purpose of the gas cooler was to drop the gas temperature, during the end of the burn, to the tolerance level of the vacuum blower (180^{o}F). Less than 5% of the total recovered oil was recovered from the gas stream, and most of this was during the final 10% of the retort burn.

7. Gas Cleanup Plant - On retorts #1 through #26, no attempt was made to remove H_2S from the offgas. For retort #27 and #28, a plant was constructed to treat the retort offgas. The objective was twofold: 1) to reduce NO_x and SO_2 emissions to meet the requirements of the PSD permit, and 2) to test a new process for removal of H_2S. The original design for Retorts #27 and #28 was to burn both retorts simultaneously, and to take the combined offgases through a Stretford plant with a capacity to handle 15,000 scfm of gas with a H_2S content of 2000 ppm. After the plant had been erected, we decided to modify the plant to test the ARI "Lo-Cat" process. This process is similar to the Stretford, but uses a nontoxic solution. In the Stretford process, the gases are scrubbed with the Stretford solution in a packed tower. The solution absorbs the H_2S, which is oxidized to elemental sulfer with air in a separate vessel. The oxidizing air acts as a froth flotation process, and the sulfur froth flows out the top of the vessel. The oxidation step regenerates the solution, which is returned to the scrubbing tower.

In the ARI "Lo-Cat" process, the gases are scrubbed with the Lo-Cat solution. Absorption and oxidation occur almost simultaneously in the absorbing tower. The solution, with elemental sulfur in suspension, flows to the bottom of the packed tower and into an oxidizer tank, where the sulfur settles to the bottom, and the solution is regenerated by air oxidation.

During the first two months of operation the ARI "Lo Cat" plant operated at close to 100% efficiency. Then the pressure drop across the absorber tower increased as sulfur began to collect on the packing. As plugging increased, the recovery efficiency and gas throughput decreased. It is not clear why sulfur began to accumulate on the packing after two months of trouble free operation. It is suspected that condensible hydrocarbons in the offgas coated the packing material, and the sulfur began to accumulate on the coated surfaces. Another possibility is the type of packing used in the absorber. A higher void volume packing may be more suitable.

In order to reduce the sulfur load on the absorber tower, a venturi scrubber was installed ahead of the tower. The venturi scrubber removed approximately 50% of the sulfur.

It is our conclusion that the ARI "Lo-Cat" solution is effective in removing H_2S from shale oil retort gases. The problems encountered were mechanical, and with a properly designed plant can be eliminated. Such a plant would incorporate a unit to recover condensible hydrocarbons, a venturi scrubber to remove approximately 50% of the sulfur, followed by a packed tower to remove the balance. The tower would utilize packing specifically designed to minimize plugging. The tower would incorporate high pressure sprays to periodically flush the packing free of accumulated sulfur.

For a detailed description of the plant and its operation, see "Report on Burning the Geokinetics Experimental Retorts #27 and 28", referenced in Chapter VII.

8. Afterburner - The offgases contain CO and hydrocarbon gases, and are combustible. Because of the low BTU content (less than 100 BTU/cubic feet.), combustion conditions must be carefully controlled to assure complete combustion. In order to minimize NO_x, combustion temperatures must be controlled.

On retorts #1 through #26, the only requirement of the afterburner was complete combustion of hydrocarbons and CO. The afterburner consisted of a large vertical cylindrical steel vessel, lined with refractory. The afterburner volume was selected to give adequate residence time for the gases to burn completely within the vessel. Excess air is mixed with the retort gas and the mixture is fed tangentially into the base of the afterburner through a horizontal pipe. As an ignitor and pilot flame, a small burner is operated continuously. The offgases burned cleanly, and no smoke was visible at the top of the afterburner.

On retorts #27 and #28, the afterburner was designed to minimize NO_x production, utilizing a Low NO_x combustor. The combustor controls NO_x by reducing the combustion temperature within the stack. This is done by partially combusting the offgas in the lower chamber and finishing the combustion process in the upper chamber, and also by quenching the gas with water. By controlling the temperature within the stack, the resultant gas does not have the activation energy needed for the oxidation of the nitrogen.

Air is injected into the offgas at the bottom of the combuster at a rate which is lower than the stoichimetric ratio. This ratio of offgas and air allows the combustion process to begin in the lower third of the stack. The combustion process is completed approximately half way up the stack, where an excess of air is injected. Water is sprayed into the chamber at this point to control the temperature in the upper half of the stack.

The afterburner was a cylindrical steel vessel, 13 feet in diameter by 52 feet high with the inside wall of the vessel lined with refractory. Four water spray nozzles were installed 33 feet above ground level. At 25 feet above ground level, seven horizontal eight inch pipes were installed across the afterburner for the injection of secondary air. The afterburner was also equipped with a natural gas burner, which functioned as a pilot flame.

A primary air blower with a capacity of 10,000 scfm at three inches of water pressure supplied combustion air to the lower combustion chamber. A secondary air blower supplied combustion air to the upper combustion chamber. This blower was rated at 3000 scfm at twenty inches of water pressure. The optimum operating conditions were determined to be as follows:

Primary Air Injection Rate:	75% of the stoichiometric ratio.
Secondary Air Injection Rate:	15% excess air overall.
Water Spray Rate:	6.5 to 11.7 gpm. Adjust to achieve gas temperature of approximate 1700°F.

During stable operations, utilizing the above mentioned parameters, the concentration of NO_x discharged in the stack gas was less than 100 parts per million, independent of the ammonia concentration in the offgas or the offgas flow rate.

9. Surface Oil Handling and Storage - The oil well pumps deliver to the surface a mixture of oil, water, and an emulsion of oil and water. This goes through an electronic measuring unit (net oil analyser) that measures oil and water components of the mixture. A small amount of emulsion breaking chemical is added to the mixture, and it is delivered to a heated wash tank, where is is retained for 12 hours at temperatures of about 160°F. Under the influence of the chemical, heat and time, the emulsion separates into water and oil. The water is gravity drained to the evaporation pond, and the clean oil is pumped to storage at the tank farm.

The produced water disposal facility consisted of two ponds with a combined surface area of 4.15 acres, and liquid storage capacity of 30,000 barrels. Solar evaporation at a rate of 48 inches per year eliminated the waste water.

The tank farm consisted of two 500 barrel wash tanks and two 10,000 barrel storage tanks, which were heated by internal steam coils. Heating was utilized only in winter and when shipping of oil was active.

G. SHUTDOWN AND SURFACE RECLAMATION

After the burn is completed, generally when the off gas temperatures reach 500°F, the air supply is turned off, and all valves are closed. This extinguishes the fire. About a month is allowed for cooldown. During this period, the surface piping and equipment are moved off of the retort. After cooldown, the casing is pulled from all of the wells, and the holes are backfilled with dirt. Earth moving equipment is brought in to rip the compacted surface of the retort, and shape it to be compatible with the surrounding topography. The topsoil that had been removed and stockpiled is placed back on the retort surface, and seeded with an appropriate seed mixture.

III. SUMMARY OF RETORT OPERATIONS

A total of 28 test retorts were designed. Twenty of these were blasted and burned, six were blasted, but not burned, one was a misfire, and one was abandoned prior to blasting. Retorts one through nine established the blasting method, and the basic retorting parameters. Retorts 11, 12, and 13 tested a different blast design. Retorts 14 through 19 developed the Walking W blast design, and progressively scaled the retorts up to a larger size. Retorts 20 through 23 were tests to improve the blast design. Retorts 24 to 28 were final scale up to commercial size. The data of these tests are summarized in tabular form in Tables 1 and 2. A detailed report has been prepared on the operation of each retort, as indicated in Chapter VII.

IV. SIGNIFICANT OPERATIONAL PARAMETERS

A. INTRODUCTION

Basic design and operational parameters necessary to design a LOFRECO commercial operation were developed. These are as follows:

1. Air Injection Rates
2. Recovery Efficiency
3. Production Rate
4. Air Requirement per Barrel Produced
5. Rate of Fire Front Advance
6. Air Injection Pressures

TABLE 1

BLASTING PARAMETERS

Rtrt No	Date Blstd	Shale Thkns Blstd ft	Over-brdn Thkns ft	Lnth ft	Wdth ft	Yards of Shale Blstd	Yards to Surfc	Total Explsv lbs	Powder Factor lbs/yd Shale	Powder Factor lbs/yd Surfce
1	7/75	10.0	10.0	50	10	185	0	140	0.8	0.76
2	7/75	3.0	10.0	30	10	33	111	140	4.2	1.26
3	1/76	10.0	17.0	40	20	148	506	650	4.4	1.28
4	2/76	12.0	16.0	33	21	308	411	880	2.9	2.14 [1]
5	2/76	11.5	19.5	84	20	716	1,213	2,165	3.0	1.78
6	Not Blasted									
7	11/76	10.0	15.0	50	20	370	556	856	2.3	1.54
8	11/76	23.0	22.0	83	20	1,414	1,353	Misfire		
9	12/76	22.0	22.0	83	40	2,705	5,410	6,230	2.3	1.15
10	12/76	11.0	18.0	50	24	489	1,289	1,163	2.4	0.91 [2]
11	3/77	12.0	16.0	50	20	444	1,037	750	1.7	0.72 [3]
12	3/77	11.6	31.0	50	30	644	2,367	1,657	2.6	0.70 [3]
13	6/77	11.0	31.0	50	30	611	2,278	1,830	3.0	0.80 [3]
14	6/77	10.0	30.0	70	40	1,037	4,148	4,150	4.0	1.00
15	7/77	20.0	30.0	75	50	2,778	6,944	7,112	2.6	1.02
16	8/77	19.0	42.0	86	63	3,813	12,241	12,100	3.2	1.00
17	5/78	17.6	28.0	156	72	7,322	19,000	11,530	1.6	0.61
18	7/78	18.6	25.0	156	108	11,600	21,800	16,290	1.4	0.75
19	12/78	30.0	50.0	182	126	24,480	67,900	49,500	2.0	0.73
20	4/79	24.0	36.0	100	40	3,560	5,333	7,460	2.1	1.40 [4]
21	6/79	23.0	35.0	100	40	3,410	5,185	9,616	2.8	1.85 [4]
22	6/79	23.0	34.0	100	50	4,260	6,296	10,350	2.4	1.64 [4]
23	9/79	24.0	36.0	100	50	4,440	6,667	11,930	2.7	1.79 [4]
24	11/79	28.0	45.0	230	217	51,800	135,000	136,700	2.6	1.01
25	7/80	30.0	55.0	230	217	55,500	157,100	158,800	2.9	1.01
26	8/81	30.0	60.0	230	217	55,500	166,400	171,700	3.1	1.03
27	2/82	30.0	70.0	330	305	111,800	373,000	281,900	2.5	0.76
28	8/82	30.0	60-90	340	301	113,700	454,800	354,300	3.1	0.78

1 & 2...Discontinued Blast Design

3.......Initial Testing of Initiation Round

4.......Final Testing of Initiation Round

TABLE 2

RETORTING PARAMETERS

Retort No.	Date Ignited	Days Retorted	Total Oil in Place bbls	(1) Oil Recov bbls	Oil Recov %	Oil Prod Rate bbls/day	Retort X Sect sq ft	Air Inject Rate SCFM	Air Injected MMSCF	Oil Prod bbls/day/ 100 sq ft of X Sect	Air Injec SCFM/sq ft of X Sect Unblasted	Air Injected SCF/bbl	Rate/Fire Front Advance ft/day	Water Produced bbls	Water /Oil Ratio
1	9/76	30	214	56	26%	1.9	100	100	4.3	1.9	1.0	77,000	1.2	91	1.6
2	3/76	23	48	28	58%	1.2	30	50	1.7	2.4	1.7	61,000	1.3		
3	7/76	20	444	82	18%	2.1	200	220	6.3	1.05	1.1	54,000	2.0	93	1.1
4	2/77	34	483	146	30%	4.3	252	250	12.2	1.70	1.0	84,000	1.1	153	1.05
5	5/77	103	949	364	37%	3.4	230	265	39.3	1.45	1.15	108,000	1.0	412	1.13
6	Not Retorted. . . .														
7	Not Retorted. . . .														
8	Not Retorted. . . .														
9	9/77		2,917	1,007	35%	12.0	880	588	73.0	1.36	0.67	72,000	1.2	998	0.99
10	1/79	100	531	364	69%	3.6		268	41.0	1.36	1.02			769	2.11
11	4/77	37	529	272	51%	7.4	240	200	10.4	3.1	0.83	38,000	1.9	199	0.73
12	4/78	31	626	10	Burn Terminated. . . .										
13	Not Retorted. . . .														
14	2/78		1,120	384	34%	10.4	330	368	19.6	2.6	0.97	51,000	1.8	407	1.06
15	5/78	65	2,781	1,100	40%	16.9	400	788	71.5	1.7	0.79	65,000	1.0	1,742	1.58
16	8/78	113	3,703	2,067	56%	18.0	1000	977	153.4	1.7	0.82	74,000	0.9	2,013	0.97
17	6/79	186	7,557	3,159	42%	30.4	1197	1162	174.3	2.4	0.92	55,000	1.1	3,007	0.95
18	11/79	181	12,175	5,547	46%	30.6	1009	1252	227.0	1.5	0.62	59,000	0.8	6,583	1.19
19	Not Retorted. . . .														
20	Not Retorted. . . .														
21	Not Retorted. . . .														
22	Not Retorted. . . .														
23 (2)	3/81	105	4,000	991	25%	-	1200	-	-	-	-	-	-	-	-
24	12/80	234	49,200	12,000	26%	54.4	6100	2869	671.0	0.89	0.47	77,000	1.0	13,711	1.14
25	8/81	243	35,500	21,000	59%	91.9	6500	5276	1900.0	1.3	0.81	90,000	0.9	39,723	1.89
26	7/82	230	45,400	23,100	51%	100.9	6500	4558	1523.0	1.6	0.75	65,000	1.0	27,934	1.21
27	8/83	320	86,076	32,562	38%	101.8	9150	4473	2061.0	1.1	0.52	63,000	1.0	45,798	1.41
28	9/83	311	105,415	28,751	27%	92.5	9720	4700	2105.0	1.0	0.42	73,000	1.1	33,955	1.20

(1) As oil in the tank. No credit for condensible Hydrocarbons in the retort offgases.

(2) Parameters of Retort #23 varied during operation.

7. Oil Composition
8. Gas Composition
9. Composition of Retort Water

B. AIR INJECTION RATES

Specific air injection rates per square foot of retort cross section (Superficial Gas Velocity = SGV) ranged from 0.40 SCFM to 0.97 SCFM. There is a relationship between SGV, recovery efficiency, and rate of oil production. An increase in SGV up to 0.8 or 1.0 has a beneficial effect on all these parameters, as shown in Figures 7 and 8. For design purposes, the air plant should have a capacity of at least 1.0 SGV.

C. RECOVERY EFFICIENCY

Recovery efficiency is defined as the percentage of in place oil, within the retort boundries, that is recovered as oil in the tanks. Recovery rates ranged from 26% to 59% (Table 2). Recovery efficiency is closely related to SGV (Figure 7). At SGV of 0.8 recovery efficiencies of over 50% can be expected. For design purposes, a recovery of 50% can be used.

D. PRODUCTION RATE

Oil production rates ranged from 1.0 to 3.1 barrels/day/100 square feet of retort cross section (Table 2). The oil production rate is related to the SGV (Figure 8). As the SGV increases, so does the production rate. At SGV of 0.80, a production rate of 1.9 is predicted. For design purposes a production rate of 1.9 can be used.

E. AIR REQUIREMENT PER BARREL PRODUCED

As the SGV increases, the amount of air required for each barrel produced decreases. At 0.80, the air requirement is 58,000 scf/barrel (Table 2).

F. RATE OF FIRE FRONT ADVANCE

SGV appears to have little effect on rate of firefront advance within the limits tested. Advance rates clustered around 1.0 foot per day.

G. AIR INJECTION PRESSURES

Wellhead pressures were 1.0 to 3.0 psi, and pressure in the retort, 10 feet downstream from the well were 0.25 psi. Most of the wellhead pressure is required to overcome the resistance in the formation adjacent to the wellbore, and this can vary depending on the well completion method. Any plugging of fractures adjacent to the borehole by cuttings will increase the pressure requirements.

H. OIL COMPOSITION

Oil composition will vary from retort to retort and will also vary with time within a retort. A composite analysis of oil from retorts 27 and 28 is shown in Table 3.

I. GAS COMPOSITION

TABLE 3

TYPICAL CRUDE SHALE OIL SPECIFICATIONS[1]

Gravity		25-26 Deg. API
Viscosity:	@ 100 Deg. F	12-16 CST
	@ 140 Deg. F	6 8 CST
Flash Point (ASTM D93-23):		180-200 Deg. F
BS & W (Maximum):		1.0 Wt. %
Ash:		0.015-0.030 Wt. %
Pour Point:		70-80 Deg. F
Asphaltenes:		0.5 - 1.5 Wt. %
Elemental Analysis:		
Carbon:		83.0 - 84.7 Wt. %
Hydrogen:		11.8 - 11.9
Oxygen:		0.9 - 1.6
Nitrogen:		1.5 - 1.6
Sulfur:		0.6 - 1.0
Metals:		
Iron:		87 - 740 ppm
Arsenic:		8 - 11
Vanadium:		1 - 3
Nickel:		6 - 58
Heat of Combustion (Gross):		19,000-19,500 BTU/lb

Distillation (ASTM D1160):

Vol %	Deg. F
IBP	160 - 255
10	420 - 470
30	520 - 580
50	600 - 675
70	775 - 790
90	900 - 920
FBP	980 - 1150

[1] Data derived from analysis of raw shale oil samples produced from Retorts #27 and #28 during Geokinetics' development program.

TABLE 4

Days	API Gravity	Pour Point °F	Nitrogen %	Sulfur %	Engler Distillation - DEGREES F											
					IBP	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	Residue %
1- 6	24.4	55	1.88	0.91	210	398	436	501	548	594	630	670	732	736	752	6
7-10	25.0	60	1.83	0.92	302	384	431	496	552	605	644	689	734	753	-	14
11-15	25.6	66	1.67	0.84	212	382	438	490	550	599	640	672	710	743	-	13
16-20	25.8	65	1.55	0.81	230	416	452	501	548	589	630	680	705	729	750	9
21-25	26.2	64	1.66	0.78	232	407	444	498	546	589	634	685	712	738	753	3
26-30	25.8	69	1.46	0.77	223	416	449	502	547	592	641	672	709	741	755	6
31-35	26.4	60	1.45	0.83	205	408	444	503	555	598	643	692	728	739	755	5
36-40	26.7	63	1.42	0.80	214	406	441	493	543	588	627	670	709	734	755	6
41-45	26.7	65	1.19	0.77	238	383	436	486	529	571	616	657	700	737	754	6
46-51	26.5	64	1.28	0.91	223	439	466	510	548	589	627	670	709	734	748	6
Avg.	25.9	63	1.54	0.83	229	404	444	498	547	591	633	676	715	738	754	7

Change in Characteristics of Shale Oil During Retorting, Retort 14

Five Day Composite Samples

Daily analyses of offgas composition were made on retorts #24 through #28. The gas composition varied from day to day within a retort, and from retort to retort. Table 5 gives an average gas composition for a number of retorts, and Table 6 shows how gas composition varied over the life of a retort.

J. COMPOSITION OF RETORT WATER

Oil and water are produced from the retorts. Part of the water is lifted as free water, and the remainder is emulsified with the oil. The ratio of water to oil is approximately 1:1. The water is separated from the oil, and can be disposed of by a variety of methods. In order to design a water cleanup process, the composition of the water must be established. Numerous water analysis were performed on the individual retort water, samples, and on composite samples. The results are given in Table 7.

V. SUMMARY OF ENVIRONMENTAL, SAFETY, AND HEALTH RESEARCH

A. INTRODUCTION

Environmental, safety, and health (ES&H) activities at the Geokinetics research and development site were conducted between 1977 and 1984. Initial activities were directed by an Environmental Program Outline (EPO) which was one of two documents of an Environmental Research Plan developed by Geokinetics. The EPO defined the general goals and objectives of the environmental research program.

The second document, the Research Record, was developed as part of the Environmental Research Plan and detailed

Table 5

COMPOSITION OF RETORT GASES

Constituent		Retort #26	Retort #27	Retort #28	Average
Hydrogen	Volume %	7.3	7.4	7.8	7.5
Carbon Monoxide	Volume %	4.9	5.2	4.6	4.9
Methane	Volume %	1.3	1.5	1.4	1.4
Ethane and Heavier	Volume %	1.0	0.8	0.8	0.9
Carbon Dioxide	Volume %	20.9	18.9	19.4	19.7
Oxygen	Volume %	4.2	4.0	3.5	3.9
Hydrogen Sulfide	ppm *	1279	684	585	849
Ammonia	ppm *	709	724	677	703
High Heating Value, BTU/cubic foot		74	77	77	76

*Parts per Million, by Weight

TABLE 6

Days	Volume Percent: Nitrogen	Carbon Dioxide	Oxygen	Hydrogen	Carbon Monoxide	Methane	C2-C6	H_2S Concentration (ppm)	NH_3 Concentration (ppm)	Avg. High Heating Value* (BTU/SCF)
1- 10	63.130	23.415	1.624	6.462	3.113	1.247	.723	28	22	65.3
11- 20	63.992	19.958	5.219	5.992	2.807	1.117	.607	42	16	60.0
21- 30	58.895	23.287	2.389	7.290	5.787	1.422	.605	27	64	79.1
31- 40	54.778	23.356	2.168	9.936	7.019	1.422	.853	85	277	100.9
41- 50	58.307	21.306	3.864	8.589	6.068	1.134	.470	353	561	75.9
51- 60	59.286	17.910	4.124	7.576	5.411	1.865	.527	1418	828	80.6
61- 70	58.615	18.944	5.532	8.069	6.387	1.284	.678	1840	674	82.6
71- 80	62.960	16.546	7.022	7.122	4.446	.890	.439	1505	1215	62.9
81- 90	64.287	16.096	7.150	7.314	3.527	.619	.453	1399	1054	58.5
91-100	62.733	19.352	4.114	7.176	4.511	.815	.537	1274	963	66.1
101-110	59.218	22.522	1.983	7.863	5.691	1.112	.871	1496	939	83.5
111-120	55.526	20.854	5.496	8.813	6.351	2.116	.525	1609	979	90.4
121-130	58.607	18.913	4.999	9.478	5.945	1.145	.568	2054	893	83.9
131-140	58.017	23.358	1.304	8.346	6.510	1.450	.679	1804	1198	87.9
141-150	57.888	24.210	1.355	7.803	6.234	1.522	.574	1835	893	80.2
151-160	59.075	22.691	2.967	7.888	5.293	1.331	.483	1627	663	73.8
161-170	55.221	25.343	2.444	8.074	6.352	1.881	.593	1907	692	86.3
171-180	62.823	22.651	3.324	4.984	4.222	1.329	1.992	1640	780	102.7
181-190	61.611	20.689	5.814	5.563	4.128	1.325	.598	1708	1075	63.6
191-200	64.860	18.792	6.659	4.630	3.343	1.037	.470	1667	792	51.4
201-210	60.537	22.094	5.753	5.629	3.971	1.101	.558	1887	205	62.2
211-220	66.275	17.325	7.071	5.123	2.512	.983	.474	1288	702	49.8
221-228	62.691	20.530	3.427	7.567	2.897	1.966	.703	1304	695	73.0
Average	60.5	20.7	4.3	7.2	4.9	1.3	.65	1295	703	73.6

CHANGE IN CHARACTERISTICS OF RETORT GAS DURING RETORTING RETORT 26

*Average High Heating Value - Heating value of the gas before subtracting the latent heat of condensation of the water produced during combustion.

Table 7

Comparison of Retort Process Water with Undisturbed Shallow Groundwater

Retorts 25 and 26

	PROCESS WATER Range (Mg/l)	SHALLOW GROUNDWATER Range (Mg/l)
INORGANICS		
Lithium	<0.3	---
Sodium	2,294 - 15,520	461 - 14,150
Potasium	12 - 196	4.6 - 81
Magnesium	0.6 - 24.8	1.2 - 47
Calcium	2.7 - 7.8	1.26 - 20
Strontium	0.2 - 2.8	0.12 - 0.46
Fluoride	8.3 - 127.0	10.1 - 66.0
Chloride	510 - 2,030	42 - 7,440
Bromide	<1	<1 - 119
Phosphate	<2	---
Nitrate	5 - 2,960	3.6 - 8.0
Nitrite	0.5 - 490	---
Sulfate	159 - 5,820	10.4 - 13,009
Bicarbonate	11,660 - 28,050	1,600 - 61,264
Carbonate	1,020 - 4,150	12 - 7,633
Sulfide	1 - 680	0 - 7.5
Thiosulfate	1,281 - 3,081	1.9 - 27.0
Thiocyanate	130 - 432	0.1 - 335
Ammonia	19 - 1,910	0.9 - 10.5
Ammonium	1,010 - 4,840	1.4 - 37.7
Antimony	0.13 - 0.74	---
Arsenic	12.50 - 37.63	0.006 - 0.2
Boron	66 - 829	15 - 950
Iron	<0.01 - 2.19	0.07 - 15.11
Lead	<0.05	0 - 0.72
Silicon	5.1 - 18.9	1.9 - 15.0
Molybdenum	0.74 - 16.5	0.11 - 1.21
ORGANICS		
Oil and Grease	190 - 400	---
Phenol	21 - 95	0.01 - 5.4
Cresol	0.02 - 0.09	---
Cyanide	19 - 1,900	0 - 187
QUALITY INDICATORS		
Alkalinity	12,430 - 24,150	1,700 - 62,957
Chemical Oxygen Demand	2,410 - 12,280	406 - 45,920
Conductivity	16,800 - 26,200	4,220 - 24,100
pH	8.26 - 9.49	8.52 - 9.74
Total Dissolved Solids	9,857 - 39,740	1,348 - 61,094
Total Suspended Solids	1.3 - 301	2 - 1,581

the actual research projects performed at the site between 1977 and January 1982.

The two documents complied with the provisions set forth in the DOE/Geokinetics cooperative agreement, an environmental assessment written by DOE, and in DOE order 5480.1 (Environmental Safety and Health Plan). ES&H activities following January 1982 were presented in similar form in the quarterly and annual reports of 1982 and 1983.

A summary of the ES&H activities between 1977 and 1984 are presented in the following pages. Several individual areas are discussed and include:

1) Atmospheric Resources;
2) Hydrologic Resources;
3) Ecological Resources;
4) Cultural-Economic Resources;
5) Environmental Permits; and
6) Industrial Safety and Health.

B. ATMOSPHERIC RESOURCE RESEARCH

Atmospheric resource studies conducted at the Geokinetics site were designed to comply with: 1) the monitoring requirements established in the project Environmental Assessment plan; and 2) state and federal air quality regulations.

Two separate categories of research were implemented to meet the above design: 1) Meteorological and Climatological; and 2) Air Quality. A summary of the various research activities, and the conclusions drawn, are discussed as follows:

1. Meterological and Climatological - During 1978 a program of data collection on a continuous basis was initiated.

The objective was to obtain knowledge of the structure and flexibility of the local microclimate, evaluate trends associated with the locale, and monitor for project-induced changes in the local microclimate.

The program was continued for approximately five years. During this time, the program underwent several changes and/or modifications in equipment, location, and design, which were necessary to provide a reliable, and quality controlled monitoring program. The resultant changes, however, reduced the amount of useful data. Only three years worth of data were considered reliable in describing the meteorological characterization of the research project area. Because of the reduced quantity of reliable data, it was not possible to evaluate long term trends or identify possible project induced changes.

A brief summation of the short term meteorological and climatological trends that were developed are presented in Table 8.

In January 1983, a new meteorological program was initiated to provide data for air quality modeling. The program was designed to meet the stringent data collection requirements of the Prevention of Significant Deterioration (PSD) Program under the Clean Air Act.

The program was conducted for approximately 18 months, during which time one year's worth of approved data (by the Utah Bureau of Air Quality) was collected.

2. <u>Air Quality Investigations</u> - In 1978, air quality investigations were initiated to: 1) determine the

Table 8

MEAN ANNUAL CLIMATOLOGICAL DATA BETWEEN 1978 - 1984

TEMPERATURE	
Minimum:	$-19^{o}F$
Maximum:	$100^{o}F$
Mean :	$46^{o}F$
PRECIPITATION	
Minimum:	8.4 in.
Maximum:	23.3 in.
Mean :	12.7 in.
NET EVAPORATION	
Mean :	48 in.
WIND DIRECTION	
Prevailing:	South-Southwest
WIND SPEED	
Maximum:	62 mph
Mean :	9 mph

TABLE - 9

List of Environmental Permits Obtained
for
Geokinetics Research Project

PERMIT	DATE OBTAINED
Federal:	
Toxic Substance Control Act Compliance	1978
Prevention of Significant Deterioration of Air Quality	1980
BLM Right-of-Way	1980
State:	
Utah Mineral Lease	1967
Utah Mining Permit	1979
Burning Permit	Annually
Sanitary Landfill Permit	1979
- Amended	1980
- Amended	1982
Wastewater Disposal Permit	1980
- Amended	1983
Utah Historical Clearance	1979
Utah Air Construction Permit	1980
- Amended	1983
Wastewater Injection Permit	1980
County:	
Zoning Adjustment	1978
Building Permit	1978
- Amended	1979
Drinking Water - Wastewater	1980
Disposal Permit - Amended	1981

nature and extent of any gaseous pollutants contained within the various effluent streams: 2) determine the types of emission control devices and methods suitable for use with the process during various stages of the research and for commercial operation; and 3) identify and eliminate conditions that could evolve to a level where certain pollutants might exceed standards protective of human and/or environmental health.

Three categories of research were implemented at the site to meet the above goals: Process gas; stack gas; and fugitive emissions.

3. Process Gas Studies - commenced during the burn of Retort #16 and continued through burns of Retorts #27 and #28. The studies involved monitoring the unburned gases produced by the LOFRECO process. Significant gas components were analyzed by gas chromatography in an in-house laboratory. The following gas components were analyzed: Nitrogen; hydrogen; oxygen; carbon dioxide; carbon monoxide; hydrocarbons; hydrogen sulfide; carbonyl sulfide; ammonia; and heating value.

Monitoring the process gas for composition, as well as heating value was essential in determining process efficiences and selecting pollution control measures. The data acquired from the studies was also used for comparitive analysis with data obtained from the stack gas and fugitive emission studies. See Tables 5, 6 and 10.

4. Stack Gas - studies were conducted to comply with the monitoring requirements of the PSD approval order (permit issued by either EPA or the Utah Bureau of Air Quality). Tests determined the gaseous constitutents collected at the top of the afterburner following incineration. Stack gas testing was

TABLE 10

AVERAGE EMISSION VALUES
FOR RETORTS 24, 25, AND 26

(All Values in lb/hr.)

RETORT	SO_2	NO_x	HC	PARTICULATES	CO
24	26.7	17.8	0.19	0.03	0.10
25	45.5	22.1	0.20	0.25	0.30
26	66.0	26.8	0.20	0.30	0.20

conducted throughout the research period. Various operating conditions effected the amount and condition of incinerated gas. This was especially evident during the burns of early retorts. Analysis of later retorts exhibited more consistancy; however, variability in results still existed.

A summary of the results of later burns is presented in Table 10.

5. <u>Fugitive Emission Investigations</u> - were conducted to quantify the seepage rate of fugitive process gas to the ambient air and analyze the data to determine effective emission control measures.

An initial emission study was conducted in 1979 by the Monsanto Research Corporation under the sponsorship of the EPA. During the study, small areas of the surface of a burning retort (#17) were enclosed with airtight compartments. The compartments were flushed at periodic intervals with nitrogen gas. The exhaust was then collected in sample containers and analyzed for concentrations of carbon monoxide and hydrocarbons. The results of the analysis indicated that fugitive emission rates would be significant. The results obtained, however, were not indicative of normal retort operations. Monsanto's samples were collected when the offgas vacuum blower was not in operation, therefore eliminating a slight negative pressure condition normally present in the retort. The lack of forced ventilation through the retort significantly enhanced seepage rate of fugitive retort offgases through the overburden and surface fractures.

In order to determine rates of fugitive emissions during normal operations, studies were conducted by Geokinetics utilizing the Monsanto sampling procedures. These studies were initiated with Retort #24 and continued through Retort #28. Emission samples were collected periodically during normal burn operations of each retort.

Initial results from Retorts #24 - #26 were inconclusive. The data provided some information on the seepage rates of emissions through the retort surface, however a wide difference in concentration levels indicated a need to continue the sampling effort to reduce the variability <4>.

Sampling efforts were again instituted on Retort #28. Study design and sampling procedures were modified somewhat to reflect knowledge gained from previous studies. Results from the Retort #28 study presented relatively low values of both carbon monoxide and hydrocarbons. Only a few samples taken had elevated values that could be significant. These samples were similar in composistion to those collected by Los Alamos National Laboratory in a worker exposure study <5> where samples were taken at ground level from small cracks in the surface of Retort #24.

Due to the inconclusive results of the Monsanto-type fugitive emission studies, a different approach was taken in 1984 to determine the effects of fugitive emissions upon the environment. A tracer test conducted by North American Weather Consultants (NAWC) was initiated on Retort #28. The study was designed to provide an independent measure of the air quality impact resulting from fugitive emissions associated with the LOFRECO process. The analysis focused on two aspects: emission rates and dispersion <6>.

Results from the test show very low levels of carbon monoxide and only natural levels of hydrocarbons from the burning of Retort #28. These results verified the previous fugitive emission studies. The measurements indicated 1.0 ppm CO as an average on the site, with a maximum of 1.5 ppm.

Dispersion values were also determined and modeled under various wind stability classes. The information will be valuable in modeling future project impacts from the LOFRECO process.

C. HYDROLOGIC CHARACTERIZATION

Studies were designed to determine the configuration of the geological framework and assess the changes to water movement from the effects of the retorting process.

Studies were initiated in 1978 to characterize the movement and composition of shallow ground water. Potentiometric surfaces were monitored adjacent to retorts and in undisturbed areas <7>. Results from the undisturbed studies indicated that ground water movement is complex and moves under unequal hydraulic gradient; that is, moving readily through fracture and joint systems under different gradients determined by the hydrogeologic framework. In contrast, monitoring adjacent to blasted retorts indicated that ground water movement was directly influenced by blasting as water movement was perpendicular to equal gradients <8>.

In order to verify these results, as well as assess other potential effects of the retorting operation upon the site hydrology, several studies were conducted between 1980 and 1984. These studies are separated into sub-surface and surface impacts and are discussed as follows:

1. <u>Surface Impact Studies</u> - Several of the activities associated with the retorting process at the site have the potential to impact the surface hydrologic system. These impacts are primarily related to retort blasting and equipment traffic on

disturbed surfaces. Two separate studies were conducted at the site to assess these impacts: 1) A cursory soil infiltration study directed by the Environmental Protection Agency; 2) an in depth infiltration study directed by the Utah State University Foundation <9>.

Both studies determined that the surface disturbance associated with retorting considerably decreased soil infiltration rates. As reported by Hawkins <10>, a decrease by greater than 10-fold occurs from retort compaction in comparison to undisturbed surfaces which will result in greater surface runoff and increased soil erosion.

The results of these studies will assist in developing impact mitigation measures taken to offset or prevent onsite or offsite effects of the retorting operation upon the surface hydrology.

2. Subsurface Impact Studies - were directed to further assess the impacts of retort blasting upon the hydraulic properties of the retorting zone, as well as overlying and underlying rock zones adjacent to the retorts. Three separate studies were conducted to quantify the potential effects in order to provide information for developing future mitigation measures, if necessary.

Two of the studies tested and compared the permeability of the rock adjacent to the retorts in undisturbed areas <11, 12>. These studies resulted in the determination that an increase in permeability of two to three orders of magnitude occurs for a distance of 50 feet horizontally away from a blasted retort both in the overlying and adjacent rock. Little or no disturbance occurred beneath the retort.

These results indicate that an increase in the volumetric rate of ground water flow through the retorting zone and adjacent strata may be occurring.

In order to quantify this finding, a third study was conducted to monitor the actual movement of groundwater near a blasted retort. A tracer test was performed to provide estimates of ground water flow velocities, directions, and hydrodynamic dispersion in and around a retort <13>.

Ground water dispersion was calculated from tracer migration data collected during the study. A solute transport model was used in the study which provided a reasonable representation of fluid movement away from a retort. It was concluded that blasting of a retort greatly increases the permeability and porosity of the oil shale within the retort. However, the effect of blasting on permeability does not extend beyond 50 feet from the edge of the retort.

The study provided direct measurements of the hydraulic properties of the retorting zone in its natural state and near a blasted retort. The information will allow for a more direct assessment of the potential impacts of the LOFRECO process upon the ground water system in future operations, and allow evaluation of the effectiveness of any measures to mitigate undesirable effects.

3. Water Quality - studies were initiated in 1978 to characterize, identify and quantify the chemical constituents in ground water in both undisturbed and disturbed rock. These studies focused on the differences between the chemical quality of the undisturbed and disturbed ground water with the quality of the process wastewater. The results showed some differences between water types and an overall poor quality of all three of

the waters analyzed <14>. Further analysis also depicted wide differences in chemical quality over time with the ground water, as well as spatial variability between sampled wells <15>.

In conjunction with the baseline ground water quality studies, chemical analysis of the process wastewater was conducted during the burn of several retorts.

The quality of the process water is similar to the shallow ground water, with high concentrations of dissolved salts, and numerous trace elements <17>. This characteristic was expected since process water is partially derived from the shallow ground water within the retort.

There were, however, some differences between the process water and the natural ground water. Nitrate, ammonia, ammonium, arsenic, phenol and cyanide all were higher in the process water than in the natural ground water.

These differences in values, with the exception of the high nitrate concentration are the result of the contact of the ground water with the shale oil during the retorting process.

Subsequent water quality studies began in 1980 to verify these initial results, as well as further the understanding of these findings.

A baseline shallow ground water quality study was initiated in 1980 utilizing a series of wells removed from the retorting activity <16>. The study was conducted for two years and resulted in the following conclusions:

1) A large degree of variability in the quality of the shallow ground water both spatially and seasonably; and

2) The shallow ground water is highly mineralized with dissolved solids ranging from 1350 to 43,000 mg/l. Sodium is the prevalent cation and bicarbonate, sulfite and chloride are the prevalent anions. Boron is also present in large concentrations.

3) The elevated nitrate values most likely derive their origin from residue of the ammonium nitrate explosive used to rubbilize the oil shale bed.

The remaining water quality studies monitored changes in shallow ground water quality adjacent to burned retorts. Two peripheral well studies (Retort #23 and #24) were initiated prior to their respective burns and continued until approximately 18 months following the burn termination <18>.

Monitoring wells were constructed adjacent to and beneath the retorting zone. Wells were located on both the major and minor axis of the natural joint system in the rock, providing for upstream and downstream sampling points.

In general, the quality of the peripheral shallow ground water did not vary from the baseline quality. The significant finding of the study was the high degree of difference in concentration of chemical constituents in the water samples, irregardless of the location of the wells from which the samples were taken. A few of the wells in close proximity of the retorts did show slight elevations of cyanide concentrations, however, the results were not statiscally significant. The only indication of solute migration away from the retorts appeared in a up-dip well from Retort #24, adjacent to the retorting zone approximately 70 feet from the retort edge. A light film of oil was recovered from the well during routine sampling. Analysis of the oil determined its characteristic, similar to mist oil recovered from the offgas created during the burn process. Further analysis of subsequent samples from the well did not detect the presence of any oil. It is believed that the slight pressure build-up occurring within the retort following shut-in forced gases outward through joints or fractures. These gases entrained oil which cooled and precipitated the oil into the ground water. This occurance was observed only once and it may have been atypical. Nevertheless, it could appear in future operations and would necessitate mitigation measures for future operations.

D. ECOLOGICAL RESOURCE RESEARCH

Ecological resource research at the Geokinetics' site was designed to develop an understanding of the effect of the process upon the ecological environment for the purpose of developing sound reclamation techniques and complying with conditions set in existing permits or required by future permits.

To this end, baseline vegetation, soils, and wildlife studies were initiated at the site to characterize existing conditions <19, 20>. These studies were completed in 1979 and provided a basis for determining future impacts to the local ecological system from the LOFRECO process.

Following baseline studies, site specific studies were initiated to establish mitigation measures for minimizing the potential effects of the process upon the land surface. Two categories of research were established: 1) Land Reclamation Research; and 2) Wildlife Impact Research. A summary of the research and conclusions drawn are discussed as follows:

1. <u>Land Reclamation Reasearch</u> - Early reclamation research was conducted by Geokinetics and concentrated on Retorts #14, #15, and #17. The goal of the research was to initiate the development and implementation of an effective reclamation program on burned retorts.

The first objective of the research was to test revegetation techniques that required little effort and expense (i.e., broadcast seeding, no use of soil amendments or mulches, or use of irrigation, etc.). Retorts #14 and #15 were revegetated successfully employing such techniques. Similar efforts were again tested on #17, but results were unsatisfactory following two growing seasons.

The discrepancy between these revegetation efforts was not totally resolved, but results suggest that the techniques utilized would not be consistently successful in a semi-arid environment with changes in climatic factors from one year to the next.

In order to establish techniques suitable for the conditions at the site, outside assistance was requested from the U.S. Forest Service (USFS) Land Reclamation Group at Logan, Utah. A cooperative agreement between Geokinetics and the USFS was initiation early in 1983 to establish a revegetation research plot on a burned retort <21>. The study was designed to yield information on alternative cultural methods and suitable herbaceous and shrubby species for establishing a level of vegetative cover adequate to meet state regulation requirements. Several study objectives were established and are as follows:

1) To determine the relative success of direct seeding in conjunction with three mulching treatments (straw, wood fiber, or no mulch);

2) to evaluate the vegetative stand obtained when only herbaceous species are used or when both herbaceous and shrubby species are used;

3) to obtain preliminary information on the value of supplemental water, applied by irrigation during the growing season, on successful vegetation establishment;

4) to assess the effect of season of direct seeding (spring and fall) on vegetation establishment; and

5) to determine the success of establishment of several native shrub species when seeded in association with perennial grasses.

Retort #24 was selected as the test site for the study. Half of the retort was treated in the spring of 1983, and the remaining half was treated in the fall of 1983. Each half was treated in the same manner to meet the above objectives. Data were taken in the summer of 1983 (spring side only) and the summer of 1984. Both percent frequency of species occurrence and percent cover data were taken.

The study has not been completed, but preliminary results indicate that the retorts can be revegetated successfully utilizing the techniques implemented on Retort #24. The early results show that the use of soil amendments and mulches have a beneficial effect. Irrigation has not significantly increased vegetation establishment and success over that measured in non-irrigated areas. There is, however, greater establishment of shrubby species on non-irrigated areas, as herbaceous species are highly competitive when irrigated. There is no evidence that the season of seeding (spring vs. fall) is a determining factor on vegetation establishment or success.

E. WILDLIFE IMPACT RESEARCH

During 1978 and 1979 investigations were conducted to provide baseline information on the presence and status of wildlife populations at and in the vicinity of the research site <22>. These investigations provided a basis for monitoring wildlife during process activities.

In the spring of 1983 wildlife monitoring studies were initiated at the site under the direction of Stoecker-Keammerer and Associates, Boulder, Colorado. Five studies were implemented <23>:

1. Pellet transect studies
2. Pellet counts on revegetated surfaces
3. Road counts
4. Raptor observations, and
5. Threatened and endangered species

1. Pellet Transect Studies - were designed to obtain abundance data twice each year (spring and fall) on mule deer, elk, cottontails, coyotes, pocket gophers and domestic cattle. The main objective was to check for indications of relative differences in animal abundance between areas located near retorting activities, and areas located some distance away.

Eight transects were located on the study site, with four transects within the pinion-juniper and four transects within the sagebrush habitat types. Each transect consisted of 80 quadrants, 10 square meters each, spaced at 10 meter intervals.

The results of the mule deer pellet counts indicated that the deer were not being displaced by retorting activities. In fact, the highest pellet counts of mule deer occurred on a transect closest to the research site.

The presence of elk occurred infrequently. Only during one sampling period were elk pellets observed on the transects.

Data obtained for other wildlife (cottontails, coyotes, etc.) and cattle from the pellet counts provided information on general levels of abundance, habitat affinities, and seasonal differences in population sizes. In the future, these data could become useful for evaluating differences between revegetated and control sites.

2. Pellet Count on Revegetated Surfaces - were similar in purpose to the pellet transect studies. The study consisted of two small plots (approximately 0.08 acres each) on retorts #14 and #15. Five quadrants (10 square meters each) were placed on each of the plots: one quadrant in the approximate center of the plot, and four five meters away in each of the cardinal directions.

The results of the counts established that the usage by mule deer of the revegetated retorts was minimal. This may be due to the relatively small size of the retorts.

No evidence of other wildlife (elk, cottontails, gophers, etc.) was observed on the plots. However, the presence of cattle was evident during the sampling.

3. Road Counts - were conducted to record numbers of deer, and deer road kills, in the vicinity of the Seep Ridge site. Sightings of raptorial birds also were recorded.

Road count information on deer is particularly useful for determining whether important crossings occur. Potential road kill problems, and hazards to motorists, can thereby be more meaningfully evaluated.

The results of the road counts conducted suggest only moderate numbers of deer within five miles of the project. These findings are consistent with the estimates of deer pellet-group densities from the transect studies. There were no indications of important road crossing locations.

Raptorial birds were observed during several road counts. Three species were identified, the rough-legged hawk, red-tailed hawk, and the bald eagle.

4. Raptor Observations - studies were conducted in May 1981 in an attempt to locate nesting raptorial birds. The project site and a surrounding one mile zone were searched. No nesting raptors were located and it seems unlikely that nesting raptors are common in the immediate vicinity of the retorting facility due to the lack of rock cliffs or large dead trees suitable as nesting habitat.

5. Threatened and Endangered Species - observations were conducted along with the raptor study, as well as in the baseline wildlife study. Only one observation of an endangered species, a bald eagle, was observed. This occurred during the road count study as previously mentioned. This bird was observed in flight, and no reports of bald eagle roost sites are known for the vicinity. There is no reason to believe that roosting habitats are present within the study area zone, or for any other endangered wildlife species on the federal list.

F. CULTURAL-ECONOMIC RESOURCE RESEARCH

Cultural-economic resource research at the Geokinetics' research facility were designed to comply with requirements established in the environmental assessment <24>; and 2) the conditions outlined in environmental permits administered under state and federal regulations.

In order to meet the above purposes, cultural-economic resource research was divided into two categories: 1) Historical Resources; and 2) Social and Economic Conditions.

1. Historical Resources - Studies were conducted to assess potential impacts and avoid or mitigate disruption or distruction of historical resources that could occur on the project site <25>.

Locating and identifying historical resources on the site were accomplished by conducting literature reviews of national and state historical registers, as well as consulting with the Utah Division of State History to obtain known information about the site. In addition, archeological surveys were conducted on site.

The results of the historical investigations concluded the following:

a. Ten sites were identified for inclusion in the study;

b. All sites lacked observed depth and had been adversely impacted by natural erosion; and

c. Mitigation measures were not required because of the sparce artifact density, lack of diagnostic cultural indicators, and low level significance ascribed to each site.

2. Socio-Economic Conditions - In order to assess the potential socio-economic impacts Geokinetics activity could have on the Uintah Basin and to develop and implement strategies to avoid or mitigate significant adverse impacts, if any, the following procedures were conducted:

a. Socio-economic data pertaining to the Uintah Basin were assembled;

b. Projections of Geokinetics employment and expenditures were generated; and

c. The above information was evaluated in terms of potential impacts of Geokinetics activities.

The results of the investigation concluded that Geokinetics impact would be minimal in the Uintah Basin. This conclusion is in concurrence with local and regional officials.

G. ENVIRONMENTAL PERMITS

Major Federal environmental, health and safety laws applicable to oil shale development included but were not limited to:

- National Environmental Policy Act
- Clean Air Act
- Clean Water Act
- Resource Conservation and Recovery Act
- Toxic Substances Control Act
- Safe Drinking Water Act
- Occupational Safety and Health Act

In addition, several state and local laws and regulations were applicable to the project.

During the course of the operation, numerous permits were applied for and obtained by Geokinetics. A list of the permits obtained is given in Table 9.

All permit stipulations were adhered to according to the requirements and guidelines of each permit. At no time during research activities was Geokinetics in violation of any permit requirement.

H. INDUSTRIAL SAFETY AND HEALTH

The industrial safety and health program for the research and development facility was designed to comply with requirements of the DOE/GKI cooperative agreement. The goal of the program was to ensure safe and healthful working conditions for workers at the site, and to comply with the provisions of the Environmental Research Plan Program Outline <26>.

A general health and safety plan was developed early in the research operation which established a management safety committee to make and enforce operation policies. The committee provided for supervision, training and education of all employees in the areas of fire protection, support planning (electrical power, potable water, and natural gas), and special operations including welding, power equipment and flamable liquids.

The training and education programs prepared personnel to deal with emergency situations that could occur at the site.

Monitoring worker health was also important during the research operation. Several investigations were conducted at the site to identify hazards to health that may have occurred as a result of the process activities <27>.

Possible health hazards to employees were monitored, or workers were instructed to be aware of and avoid or mitigate unsafe working conditions. The primary potential hazards were gases, dust, noise, and the contact with process products (shale oil, produced water, and other waste products).

Gases from the retorting process were potentially hazardous to employees working on or near, the retorts. Several gas constituents were monitored to ensure that acceptable levels in the workplace were maintained. Regular and routine monitoring of gases was conducted.

An independent investigation by the Rocky Mountain Center for Occupational and Environmental Health and the Los Alamos National Laboratory on worker health was conducted at the site in 1980 and 1981. The investigation consisted of field industrial hygiene surveys and sampling, and medical evaluations of workers and spouses living at the facility <28>.

Industrial hygiene surveys and sampling were conducted during early, middle, and late phases of the burn of Retort #24. An attempt was made to sample areas of expected maximum concentrations in order to characterize air contaminants near process units or areas. Samples were collected for analysis of dust and a number of selected gases and vapors in air, and limited monitoring was conducted for noise.

Medical evaluations consisted of medical history, physical examinations, pulmonary ventilation function tests, chest x-ray, and blood and urine tests.

Results of the hygiene surveys and sampling showed very low concentrations of dust, gases and vapors in most areas above the oil shale retort. Higher concentrations were observed in small cracks in the ground surface above the retort and near a leaking fan that carried retort offgases. Also, higher concentrations were monitored in a confined area adjacent to tanks used for separation and storage of shale oil and process water. However, observed breathing-zone air concentrations did not exceed established occupational health standards, even if employees were to be exposed eight hours.

Results of the medical examinations showed the health status of the workers and their spouses to be generally good. Respiratory function of the workers was excellent.

I. REFERENCES

<1> U. S. Department of Energy 1979. "Environmental Assessment, Geokinetics Oil Shale Research Project, Uinitah County, Utah."

<2> Unpublished data records at the Geokinetics Research Facility.

<3> Monsanto Rearch Corporation 1980. "Environmental Characterization of Geokinetics' In Situ Oil Shale Retorting Technology", Contract Number 68-03-2550. EPA, Cincinnati, Ohio.

<4> Lundberg, David A., W. L. Sharrer, H. K. L. Spradlin 1983. "Investigation of the Horizontal In Situ Oil Shale Retorting Process - Environmental Research Record", DOE/LC/1078-111.

<5> Hargis, K. M., et al. 1983. "Occupational Health Study at the Geokinetics True In Situ Oil Shale Retorting Facility". Los Alamos National Laboratory, LA-9659-MS.

<6> Schanot, Allen V. Jr., H. Robert Swart 1985. "A Gaseous Tracer Field Study for Determining Dispersion Characteristics and Fugitive Emission of CO and Hydrocarbons of the Geokinetics Inc. LOFRECO Retort". North American Weather Consultants. SLAQ 84-13.

<7> Lundberg 1983.

<8> Kaman Tempo 1981. "Infiltration and Permeability Testing at the Geokinetics Oil Shale Site". EPA Contract Number 68-03-2449.

<9> Hawkins, Richard 1983. "Soil Infiltration Investigation on Undisturbed and Retorted Surfaces at the Geokinetics Research Facility". Utah State University Foundation

<10> Hawkins 1983.

<11> Kaman Temp 1981.

<12> Henderson, Kenneth B. 1984. "Investigation of the Geokinetics Horizontal In Situ Oil Shale Retorting Process", 1983 Fourth Quarterly Report, DOE/LC-10787-126.

<13> James Grant and Associates 1985. "Tracer Test Studies Seep Ridge Site-Uintah, County, Utah."

<14> Lundberg 1983.

<15> Lundberg 1983.

<16> Lundberg 1983.

<17> Henderson, Kenneth B. 1983, "Investigation of the Geokinetics Horizontal In Situ Oil Shale Retorting Process". 1983 2nd Quarterly Report, DOE/LC-10787-118.

<18> Lundberg 1983.

<19> Olgeirson, Erik R. 1978, "Final Vegetation Research Report", (Presented to Geokinetics Inc., Salt Lake City, Utah).

<20> Olgeirson 1978.

<21> Henderson 1983.

<22> Stoecker, Robert E. 1979, "Wildlife Studies for the Holberg Oil Shale Site, Uintah County, Utah"

<23> Stoecker, Robert E. 1983, "Wildlife Monitoring Studies for the Seep Ridge Site: A Two Year Summary, 1981-1983".

<24> Lundberg 1983.

<25> Hutchinson, David L. 1979, "Investigation of the Geokinetics Horizontal In Situ Oil Shale Retorting Process", 1978 Fourth Quarterly Report.

<26> Spradlin, H. K. L. 1979, "Environmental Research Program Outline", DOE/LC 10787.

<27> Lundberg 1983.

<28> Hargis 1983.

VI. SANDIA LABORATORY ACTIVITIES

Sandia National Laboratories participated in the Geokinetics Inc., research and development program from 1978 through 1981. Field activities included providing instrumentation on retort bed preparation experiments (Retorts 17-25) and the instrumentation and execution of a small scale retorting experiment (Retort 23). Associated theoretical work included the development of numerical models to simulate the overburden motion during blasting of the retort beds and development of retort process models. New and innovative instrumentation techniques were also developed and employed during this work.

BED PREPARATION EXPERIMENTS

In near surface true in situ retort bed preparation, the void space is created by heaving of the overburden. The amount and distribution of the induced void are dependent on overburden depth, blast design, detonation timing, explosive performance, and rock properties. Quantitative diagnostic and response measurements were made during the blasting for use in the assessment of the fracturing techniques.

The blast designs included timing delays between rows of explosive columns. Knowledge of the actual detonation times was necessary for a meaningful assessment of the delay sequence. Lot sample testing of commercially available blasting caps was conducted at various conditions (high and low temperatures, during and after exposure to water, etc.). The statistical variation in the delay times of blasting caps of several delay periods was determined for the different environments. In some cases, this variation was found to be greater than the scheduled delay between rows of explosives. Adjustments to the blast design (i.e., use of multiple caps, protection from water, etc.) made after these tests resulted in improved fracturing. The actual explosive detonation times were also measured during several of the retort blasts. These data permitted a more accurate assessment of the effect of the delay times on the fragmentation.

The explosive detonation velocity was measured on Retorts 20-24. The detonation velocity, together with the emplaced density, permitted determination of the actual explosive energy.

The overburden motion was measured on nine retort blasts. High speed framing cameras, tracking the movement of targets anchored beneath the surface, provided measurements of the surface motion. Extensometers were used to measure both the vertical rock motion and the overburden motion. (Significantly, only about 15% of the surface motion was due to overburden fluffing; 85% of the surface uplift was providing void space for rubbling of the shale.) The lateral rock motion was determined by time integration of accelerometer data on six blasts.

Numerical models were developed that simulated the overburden motion during blasting. Parametric studies of alternate design proposals made with these models were used in assessment of proposed blasting methods.

RETORT EXPERIMENTS

Sandia cooperated with Geokinetics in the execution of a small scale, low void retort experiment (Retort 23). The heavily instrumented, explosively fractured oil shale bed, containing 12% void, was combustion retorted using a number of distinct operating conditions, including air at high and low flow rates and air plus 30% combusted recycle gas. A number of techniques were used to evaluate the effectiveness of these various processing modes. An extensive suite of thermocouples allowed continuous monitoring of the steam and retorting fronts and estimation of oil coking losses and total shale retorted. Actual sweep efficiency, based on these data, was 79%. Sweep efficiency estimates from steam front data were nearly identical, both in total shale contacted and spatial distribution of the swept zone. The thermal data also provided a direct means of assessing the validity of a number of retort diagnostic techniques based on fluid product (offgas and oil) analyses. Offgas material balance calculation estimates of sweep efficiency, for example, were 77%, while retorting efficiency was 58% of Fischer Assay, with a 27% oil loss to combustion and a 15% loss to coking. Oil loss estimates based on oil analyses were similar. The experiment demonstrated that true in situ retorting of thin-seam rubbled shale beds with low void volume is practical using horizontal burn techniques and that existing retort diagnostics are capable of providing a detailed analysis of the process.

During the operation of Retort 23 it was observed that approximately 30% of the potential liquid product was produced in the vapor phase as hydrocarbons with carbon numbers between 5 and 12. The low concentrations of these species in the offgas make their recovery difficult. The product can be utilized by combusting the offgas or by collection to increase total liquid yield.

Special instrumentation techniques were also used in the assessment of retort beds prior to retorting and to examine the combustion and retorting fronts during retorting. Wellbore-to-wellbore air flow and tracer gas measurements were made on Retorts 19 through 24 to examine the flow characteristics. These results showed, for example, that the Retort 19 blast had not provided a suitable bed for retorting. (This resulted in blast design modifications.) The flow characteristics obtained by these measurements were compared to data obtained during retorting on Retort 23. The airflow/tracer method was shown to provide an economical means of assessing retort blast designs.

Resistivity (CSAMT) techniques were employed on Retort 24 to track the retorting and combustion fronts. Results showed that the retorting and combustion front contours determined by these techniques compared favorably with those determined using thermal data.

VII. SUMMARY AND CONCLUSIONS

The research program developed the basic technology and procedures required for an in situ oil shale extraction process. Basic design parameters were developed that can be used for additional test work or as guidelines in designing a prototype commercial size process.

It is concluded that the information developed during this program is adequate for initial design purposes and that additional test work or experience gained through actual operation of a commercial size operation will result in an improvement and refinement of the data base. This in turn would permit a more reliable design base, probably improved economics, and a broader area of application.

VIII. PRIOR REPORTS

During the course of the contract, numerous reports were submitted to the DOE. Monthly, Quarterly and Annual Reports covering the period January 1977 to December 1984 were prepared. The quarterly reports from October 1978, to August 1984, and the Annual Reports from 1979 through 1983 have been published by the National Technical Information Service. Some reports were published in technical books and journals. In the case of such published reports, reference to the publication is given following the title and author.

Numerous individual Topical Reports, covering retort fragmentation, retort operation, environmental studies, etc. were also prepared and submitted to the DOE. These reports presented data, observations, and conclusions as the program was in progress. All reports submitted to the DOE are listed below. These reports are available on microfiche from the U. S. Department of Energy, Office of Scientific and Technical Information, Box 62, Oak Ridge, Tennessee 37831.

A. PERIODIC REPORTS

1. Monthly Reports
   January 1977 to December 1984 - 96 reports

2. Quarterly Reports
   January 1977 to December 1984 - 32 reports

3. Annual Reports
   1977 to 1983 - 7 reports

B. TOPICAL REPORTS

1. Retort Operating Reports

a. Report on Burning In Situ Shale Oil Retort #1. September 16 to October 16, 1976, and October 30 to November 15, 1976, by M. G. Leidich.

b. Blasting and Burning of Retort #2, Kamp Kerogen, Uintah County, Utah, by Mitchell A. Lekas.

c. Report on Burning of In Situ Shale Oil Retort #3. July 26 to August 15, 1976, by Mitchell A. Lekas.

d. Report on Burning the Geokinetics In Situ Shale Oil Retort #4. February 4 to March 10, 1977, by Mitchell A. Lekas.

e. Report on Burning The Geokinetics In Situ Oil Shale Retort #5, by Mitchell A. Lekas.

f. Blasting and Burning of Retort #9, Kamp Kerogen, Uintah County, Utah, by Mitchell A. Lekas.

g. Report on Burning The Geokinetics In Situ Shale Oil Retort #10, by James M. Lekas, Edward G. Costomiris and H. Eric Robinson.

h. Report on Burning The Geokinetics In Situ Shale Oil Retort #11. April 25 to May 10, 1977, by Mitchell A. Lekas.

i. Report on Burning The Geokinetics In Situ Retort #12, by James M. Lekas.

j. Report on Burning The Geokinetics In Situ Shale Retort #14, by James M. Lekas and Herbert Pierce.

k. Report on Burning The Geokinetics In Situ Shale Oil Retort #15, by James M. Lekas.

l. Report on Burning The Geokinetics In Situ Oil Shale Retort #16, by James M. Lekas, Edward G. Costomiris and Eric H. Robinson.

m. Report on Burning The Geokinetics In Situ Shale Oil Retort #17. June 7, 1979 to December 10, 1979, by Edward G. Costomiris, James M. Lekas and William M. Zaslove.

n. Report on Burning The Geokinetics In Situ Shale Oil Retort #18, November 12, 1979, to May 11, 1980, by William M. Zaslove, Edward G. Costomiris and James M. Lekas.

o. Burning The Geokinetics Experimental Retort #24, by Edward Costomiris, Jen-Sheng Tzeng and K. C. Weh.

p. The Construction and Operation of The Geokinetics In Situ Retort #25, by Edward G. Costomiris and Jen Sheng Tzeng.

q. Construction and Operation of Geokinetics In Situ Retort #26, by Edward G. Costomiris, Doran Meade and Robert J. Hadfield.

r. Report on Burning The Geokinetics Experimental Retorts #27 and #28, by Robert J. Hadfield, James M. Lekas, Edward G. Costomiris and Kenneth B. Henderson.

2. Retort Drilling and Blasting Reports

a. Preliminary Field Experiments to Determine Fragmentation Characteristics of Oil Shale, Geokinetics Experimental Site 2-14-22, Uintah County, Utah. September 3, 1975, by Daniel P. Zerga.

b. Drilling and Blasting of Retorts #3, #4 and #5, Kamp Kerogen, Utah, by Daniel P. Zerga.

c. Developing The LOFRECO Blasting Technology, Retorts #1 to #24, by Daniel P. Zerga and Mitchell A. Lekas.

d. Blasting of The Geokinetics In Situ Retorts #26 and #27, by Keith Britton.

e. Blasting of the Geokinetics In Situ Retort #28, by Keith Britton.

f. Principles of Blast Design Developed for In Situ Retorts of the Geokinetics Surface Uplift Type, by Keith Britton. Proceedings of the 13th Oil Shale Symposium, Colorado School of Mines, 1980.

g. Limitations of Commercial Explosives and Blasting Caps and Their Effect on In Situ Blast Design, by Keith Britton. Proceedings of the 18th Oil Shale Symposium, Colorado School of Mines, 1985.

h. Raising Overburden for the Geokinetics LOFRECO Process, by Keith Britton and John Edl, Jr. Fragmentation by Blasting. First Edition. W. L. Fourney, R. R. Boady, L. S. Costin, Editors. Published by the Society for Experimental Mechanics, 1985.

i. Surface Uplift Blasting for Shale Oil Production, by Keith Britton. Mechanics of Oil Shale, K. P. Chong and John Ward Smith, Editors. Published by Elsevier Applied Sciences Publishers. 1984.

3. Retort Post Blast Drilling and Fragmentation Evaluation Reports

a. Reentry Drilling on Retorts #3, #4 and #5, by Daniel P. Zerga.

b. Reentry Drilling of Retorts #7, #8, #9, #10, #11, and #12, by Michael G. Leidich.

c. Reentry Drilling of Retorts #13, #14, #15 and #16, by Michael G. Leidich.

d. Retort #18 Fragmentation Analysis Based on Post Blast Core Data and Drill Logs of Instrumentation Holes, by Michael G. Leidich.

e. Reentry Drilling on Retort #17, by Michael G. Leidich.

f. Post Blast Investigations of Retort #17 based on The Drilling Logs of the Instrumentation Holes, by Michael G. Leidich.

g. Retort #19 Fragmentation Analysis based on Post Blast Core Data and Instrumentation Hole Drill Logs, by Michael G. Leidich.

4. Environmental Reports

a. Vegetation, Ecoclimatic and Soils Factors, 1978 - 1979, at the LOFRECO Field Research Site, Geokinetics Inc., Uintah County, Utah, by ERO Associates. (Annual Report, 1981)

b. Results of Geokinetics Shale Oil and Altamont Crude Analysis, by Dr. H. V. Hanson. (Annual Report, 1981)

c. Geokinetics Water Quality Studies Progress Report, by David L. Hutchinson. (First Quarterly Report, 1979)

d. Oil Analysis Report, Retort #16, by Chromaspec Labs, Inc. (First Quarterly Report, 1979)

e. Well Level Monitoring Investigation, by Hilding K. L. Spradlin. (Second Quarterly Report, 1979)

f. Ecoclimatic Studies, by Dr. Erik R. Olgerson. (Second Quarterly Report, 1979)

g. Wildlife Studies for The Hollberg Oil Shale Project, Uintah County, Utah, by Dr. Robert E. Stoecker. (Second Quarterly Report, 1979)

h. Socio-Economic Impacts of Geokinetics Inc. Activity, by David L. Hutchinson. (Second Quarterly Report, 1979)

i. Geokinetics Chloride in Water, and Geokinetics Boron in Water, Analysis Methods, by Lawrence L. Morriss. (Second Quarterly Report, 1979)

j. Meteorological and Climatological Investigation; a Review of the January - June 1979 Investigative Period, by Hilding K. L. Spradlin. (Third Quarterly Report, 1979)

k. Soil Investigations on The Geokinetics Oil Shale Group LOFRECO Site, Uintah County, Utah. Soil Studies, Soil Inventory Studies, Mapping and Description by Dr. Woodrow Nielson and Dr. Erik R. Olgeirson. (Third Quarterly Report, 1979)

l. Soil Investigations on The Geokinetics Oil Shale Group LOFRECO Site, Uintah County, Utah. Soil Studies, Physical and Chemical Analysis, Native and Retort Soils, by Dr. Erik R. Olgeirson. (Third Quarterly Report, 1979)

m. Herbaceous Productivity Studies on The Geokinetics Shale Group Field Research Site, Uintah County, Utah, by Dr. Erik R. Olgeirson. (Third Quarterly Report, 1979)

n. Results of Retort #18, Shale Oil Chromatographic Analysis by Geokinetics Analytical Laboratory, by Lawrence L. Morriss. (First Quarterly Report, 1980)

o. Evaporation Pond Water Investigation, by Lawrence L. Morriss. (Second Quarterly Report, 1980)

p. Final Environmental Research Report: Vegetation, Ecoclimatic and Soils Factors, 1978 - 1979. LOFRECO Field Research Site, Geokinetics Inc., Uintah County, Utah, by Dr. Erik R. Olgeirson. (Second Quarterly Report, 1980)

q. Native Groundwater Analysis Results, by Hilding K. L. Spradlin. (Third Quarterly Report, 1980)

r. Retort #24 Post-Blast Pre-Burn Water Sample Analysis, by Hilding K. L. Spradlin. (Third Quarterly Report, 1980)

s. Retort #24 Water Monitoring Program, by Hilding K. L. Spradlin. (Third Quarterly Report, 1980)

t. Meteorological and Climatological Investigation: Review of July - December 1979. Investigative Period, by Hilding K. L. Spradlin and David Lundberg. (Third Quarterly Report, 1980)

u. Forest Service Revegetation Survey. Progress Report - 1980 by Linda Kenny and William L. Sharrer. (First Quarterly Report, 1981)

v. Irrigation Experiments with Produced Waters from the Retorting of Oil Shale, by David L. Hutchinson. (First Quarterly Report, 1981)

w. Enviromental Research Record: 1982 Summary, by David Lundberg. (First Quarterly Report, 1983)

x. Summary Report of Research Findings on Geokinetics Retort #24, by Bland Z. Richardson and Eugene E. Farmer. U. S. Department of Agriculture, Forest Service Intermountain Research Station, Logan, Utah. November, 1985.

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DOE/LC/10787-1797 DEVELOPING THE GEOKINETICS/DEPARTMENT OF ENERGY HORIZONTIAL IN SITU RETORTING PROCESS DOE