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THE GEOKINETICS IN SITU SHALE OIL RECOVERY PROJECT

Third Annual Report for 1979

By
David L. Hutchinson

May 1980
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MASTER

Geokinetics Inc.
Concord, California

U. S. DEPARTMENT OF ENERGY

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THE GEOKINETICS IN SITU SHALE OIL
RECOVERY PROJECT

THIRD ANNUAL REPORT
YEAR 1979

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C.L.L.

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SUMMARY

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

This Third Annual Report covers work completed during the year 1979. During 1979, five retorts were blasted. Four of these were small retorts ($\approx 7,000$ tons), designed to collect data for improving the blast method. The fifth retort was a prototype of a full-sized retort measuring approximately 200 feet on each side. Two retorts, blasted the previous year, were burned, and a third retort was ignited near the end of the year. A total of 5,170 barrels of oil was produced during the year.

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

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

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

Prior to 1979, 18 retorts had been blasted and 10 retorts had been burned. This work has established the technical viability of the basic process, as follows:

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

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

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

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

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

(6) Recovery of in place oil of up to 50 percent has been achieved.

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

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

During 1979, Retorts #20, #21, #22, #23 and #24 were blasted and Retorts #10 and #17 were burned. Retort #18 was ignited and underway by the end of the year. The weather data system was operational and collected a full year's data; retort water and shallow groundwater were characterized and a series of wells surrounding spent retorts provided data on the quality of water around spent retorts. Off gases from the retorts were characterized and data on sulfur and ammonia emissions were collected.

Retorts #20, #21 and #22 were small retorts ($\approx$ 7,000 tons) designed to improve the blast pattern to be used on a major scale up to Retort #24 (9,400 tons). Powder factors, blasthole separations and time delays were varied to establish the optimum design in a three blast series. Retort #23 was a separate experiment to test a new blasting concept to improve fragmentation in the lower portion of the retort. Retort #24 is a prototype of a full size retort, measuring 217 feet by 230 feet.

Retort #10 (730 tons), Retort #17 (13,000 tons) and Retort #18 (19,000 tons) were burned during the year. Retort #10 used hot inert gas ignition to achieve an initial separation of the retorting and burning fronts. Retort #17 scaled up the cross section and length of the retort substantially from prior tests and resulted in recovery of 50 percent of in place oil. Retort #18 was ignited late in the year.

The Environmental Program concentrated on meteorology, characterization of emissions from operating retorts, hydrologic studies, vegetation studies, revegetation of spent retorts and wildlife studies. Work began to secure a PSD permit and a permit for a deep waste water injection well.

FIGURE 2. GEOKINETICS FIELD SITE AT KAMP KEROGEN, SHOWING LOCATION OF RETORTS #1 THROUGH #19

FIGURE 3
GEOKINETICS INC. FIELD SITE

FIGURE 4

PLAN AND SECTION OF A HORIZONTAL IN SITU RETORT

Retort Number	Date Blasted	Thickness of Shale Blasted	Overburden Thickness	Width	Length	Cross-Sectional Area ft ²	Tons of Broken Shale	Date Ignited	Barrels of Oil Recovered
1	7/75	10 ft.	0 ft.	10 ft.	50 ft.	100	330	9/76	56
2	7/75	3	10	10	30	30	60	3/76	28
3	1/76	10	17	20	40	200	530	7/76	82
4	2/76	10	16	20	40	200	530	2/77	146
5	2/76	11	19	20	81	220	1200	5/77	354
6	Drilled - Not Blasted								
7	11/76	10	15	20	50	200	670	-	-
8	11/76	23	22	20	83	460	2600	-	-
9	12/76	22	22	40	83	880	4900	9/77	1007
10	12/76	11	14	20	50	220	730	1/79	445
11	3/77	12	14	20	45	240	720	4/77	272
12	3/77	11	31	30	50	330	1100	-	-
13	6/77	11	31	30	50	330	1100	-	-
14	6/77	12	29	40	70	480	2200	2/78	384
15	7/77	20	31	50	75	1000	5000	5/78	1003
16	8/77	20	41	62	87	1200	7200	8/78	2067
17	5/78	17	26	72	156	1200	13000	6/79	3700
18	7/78	17	27	108	156	1800	19000	11/79	Burn Underway
19	12/78	30	50	126	182	3800	46000	-	-
20	4/79	24	36	40	100	960	6100	-	-
21	6/79	23	35	40	100	920	6100	-	-
22	6/79	23	34	50	100	1150	7700	-	-
23	9/79	24	36	50	100	1200	8000	-	-
24	11/79	28	45	217	230	6100	94000	-	-

FIGURE 5. SUMMARY OF DATA ON RETORTS #1 THROUGH #24 (to December 31, 1979)

Days	N ₂	O ₂	CO ₂	CO	CH ₄	H ₂	Propane	Propene	ISO-Butane	N-Butane	1-Butene	Trans-2-Butene	CIS-2-Butene	1:3 Butadiene	ISO-Pentane	N-Pentane	1-Pentene	Ethene	Ethane
1-10	52.3	1.6	27.1	8.0	2.1	7.6	.173	.163	.018	.057	.063	.014	.010	.010	.016	.046	.022	.28	.37
11-20	57.0	2.3	22.1	7.3	2.0	8.3	.129	.115	.020	.060	.054	.012	.007	.007	.017	.048	.022	.21	.37
21-30	54.4	1.4	26.6	8.3	1.6	7.0	.117	.085	.062	.052	.042	.010	.007	.003	.012	.040	.015	.20	.30
31-40	55.7	1.3	26.0	7.8	1.6	6.8	.130	.099	.018	.053	.044	.010	.006	.003	.014	.039	.011	.04	.29
41-50	55.9	1.6	26.4	8.1	1.5	7.9	.136	.103	.019	.061	.052	.013	.009	.003	.008	.043	.011	.11	.34
51-60	57.2	1.3	24.3	7.2	1.5	7.5	.162	.108	.021	.064	.051	.011	.008	.003	.009	.048	.014	.10	.34
61-70	58.1	1.2	24.4	6.4	1.6	7.3	.155	.092	.021	.061	.045	.012	.008	.002	.009	.048	.005	.08	.33
71-80	56.0	1.3	27.0	5.6	1.8	7.0	.169	.095	.031	.085	.062	.014	.012	.003	.016	.072	.024	.07	.32
81-90	58.6	1.5	25.5	5.5	1.5	6.5	.151	.098	.033	.090	.067	.015	.009	.003	.022	.077	.021	.07	.29
91-100	54.7	1.3	26.5	7.1	1.5	7.6	.155	.108	.019	.056	.046	.013	.010	.001	.023	.100	.358	.07	.29
101-110	54.4	2.5	26.2	5.6	1.9	8.1	.188	.101	.026	.067	.042	.010	.009	.000	.022	.115	.279	.05	.35
111-120	56.0	1.9	26.0	8.9	1.5	7.6	.126	.064	.016	.046	.033	.004	.000	.000	.011	.038	.007	.06	.27
121-130	55.1	2.4	24.1	5.8	1.7	9.9	.172	.108	.019	.056	.041	.010	.010	.000	.015	.046	.009	.07	.30
131-140	55.7	1.5	24.5	6.9	1.8	8.7	.156	.085	.037	.063	.045	.011	.007	.001	.017	.041	.007	.08	.33
141-150	57.0	1.5	24.1	6.0	2.0	8.5	.170	.090	.029	.059	.039	.012	.006	.000	.017	.040	.010	.12	.39
151-160	58.3	2.0	23.5	5.3	1.9	8.1	.167	.095	.026	.060	.041	.010	.006	.000	.014	.048	.061	.08	.34
161-170	57.9	1.6	24.3	5.5	1.9	8.5	.178	.102	.025	.060	.041	.012	.004	.000	.016	.098	.236	.09	.35
Avg.	56.1	1.7	25.2	6.8	1.7	7.8	.155	.101	.026	.062	.048	.011	.008	.002	.015	.058	.065	.11	.33

FIGURE 6. ANALYSIS OF RETORT #17 OFF GAS, SHOWING CHANGE IN CHARACTERISTICS DURING RETORTING.
TEN DAY AVERAGED TABULATIONS, UNITS IN VOLUME PERCENT.

FIGURE 7
RETORT NUMBER 18
REVISED SURFACE FACILITIES LAYOUT

FIGURE 8

STATISTICAL CHARACTERIZATION OF RETORT WATER, BASED ON n=11, UNLESS OTHERWISE NOTED.
ALL CONCENTRATIONS EXPRESSED AS mg/l, UNLESS OTHERWISE NOTED

n-Size	Parameter	Mean	Standard Deviation	Variance	High	Low
	Alkalinity as CaCO_3	17,836.36	4,373.39	17,387,768	30,300	15,000
	Hardness as CaCO_3	153.72	85.75	6,684.20	303	28
	pH units	8.56	0.34	0.10	9.08	8.14
	Conductivity $\mu\text{mhos.cm}^{-1}$	34,035.91	10,968.05	109,362,003	64,800	24,600
	COD	3,682.36	650.57	384,764	4,420	2,000
	Ammonia as $\text{NH}_3\text{-N}$	1,270.68	779.52	552,415	2,400	65.2
	Bicarbonate as HCO_3	17,174.91	7,152.98	46,513.803	36,996	11,346
	Carbonate as CO_3	2,825.45	1,567.70	2,234,261	4,560	0
	Chloride as Cl	3,016.36	4,292.25	16,748,550	15,000	800
	Cyanide as CN	13.31	9.55	82.89	25.3	0.94
	Nitrate as $\text{NO}_3\text{-N}$	34.16	28.15	720.25	76	2.5
	Nitrite as $\text{NO}_2\text{-N}$	1.33	1.13	1.17	3.6	0.18
	Phenol	11.56	11.84	127.50	26.48	0.10
	Phosphate-total	2.1	1.22	1.34	3.82	0.50
	Phosphate-ortho	1.07	0.80	0.58	2.26	0.02
	Sulfate as SO_4	609.09	361.71	118,942	1,020	184
	Sulfide as S	447.36	280.72	71,641.55	816	34.8
	Oil & Grease	103	202.00	37,095.68	697.8	7.9
	Surfactants as MBAS	23.20	34.39	1,075.35	110	0
	Total Dissolved Solids	22,144.64	7,133.03	46,254,620	23,500	16,052
	Gross Alpha $\pm 3.5\text{pCi.l}^{-1}$	8.29	4.21	16.13	14	3.8
	Gross Beta $\pm 5.0\text{pCi.l}^{-1}$	26.45	6.74	41.34	38	21
5	Antimony as Sb	0.011	0.003	0.000006	0.015	0.008
	Arsenic as As	2.55	3.92	13.96	13.485	0.21
	Barium as Ba	0.54	0.18	0.03	0.82	0.30
5	Beryllium as Be	0.009	0.006	0.00003	0.016	0
5	Bismuth as Bi	0.059	0.017	0.0002	0.088	0.046
	Bromide as Br	0.18	0.10	0.01	0.4	0.1
	Boron as B	60.55	67.63	4,157.52	175	0.51
	Cadmium as Cd	0.084	0.088	0.007	0.2	0.001

FIGURE 8

STATISTICAL CHARACTERIZATION OF RETORT WATER, BASED ON n=11, UNLESS OTHERWISE NOTED
 ALL CONCENTRATIONS EXPRESSED AS mg/l, UNLESS OTHERWISE NOTED

n-Size	Parameter	Mean	Standard Deviation	Variance	High	Low
5	Calcium as Ca	32.58	33.25	1,005.19	101.7	0.12
	Chromium as Cr	0.078	0.039	0.001	0.144	0.046
	Cobalt as Co	0.56	0.30	0.08	1.272	0.246
	Copper as Cu	0.209	0.167	0.025	0.504	0.026
	Fluoride as F	35.15	6.47	38.10	44.3	25.0
	Germanium as Ge	0.044	0.096	0.008	0.28	0
	Iron as Fe	13.99	25.46	589.10	88.20	1.54
	Lead as Pb	0.642	0.924	0.776	2.24	0.015
	Lithium as Li	0.179	0.117	0.012	0.378	0.070
	Magnesium as Mg	17.49	7.75	54.56	26.4	6.86
	Manganese as Mn	0.937	1.876	3.20	4.74	0.038
	Mercury as Hg $\mu\text{g.l}^{-1}$	3.78	11.35	117.18	38	0
	Molybdenum as Mo	11.91	8.74	69.49	24.4	2.05
	Nickel as Ni	1.62	2.06	3.85	5.21	0.067
	Potassium as K	121.43	21.16	407.10	147.8	99.2
	Selenium as Se	0.215	0.470	0.20	1.238	0
	Silica as SiO ₂	17.95	4.15	15.65	25	13.5
	Silver as Ag	0.135	0.123	0.014	0.316	0.004
	Sodium as Na	9,392	2,951.0	7,916,720	17,800	7,281
	Strontium as Sr	0.002	0.003	0.000008	0.007	0
	Tin as Sn	0.168	0.454	0.187	1.5	0
	Vanadium as V	0.43	0.25	0.056	0.82	0.12
	Zinc as Zn	0.095	0.067	0.004	0.242	0.03

-11a-

FIGURE 9
SOIL MAP

(SOILS DISTRIBUTION AT THE GEOKINETICS FIELD SITE)

SECTION 2. T14S. R22E, UINTAH COUNTY, UTAH

LEGEND

- LR GRAVELLY LOAM
- JR LOAM ● TEST PIT
- HAVRE SILT LOAM
- LUHON LOAM
- ROCK OUTCROP

GEOKINETICS INC.

KG

0 500' 1000'
SCALE

DRILLING BLASTHOLES

LOADING IRECO SLURRY EXPLOSIVE IN BLASTHOLE

RETORT #18 IN OPERATION

PUMPING SHALE OIL

OIL STORAGE TANKS

WAREHOUSE AND SHOP

KAMP KEROGEN - 1979

II DRILLING TECHNIQUES

1. Blasthole Drilling

In 1979, blasthole drilling for Retorts #20, #21, #22, #23 and #24 was completed at the Kamp Kerogen test site.

Retort #20 was drilled with the Chicago Pneumatic Crawler 650 (CP-650) rotary drill and Kenclaw bits that proved successful in 1978. No difficulties were encountered in drilling the six-inch diameter blastholes. The blastholes were drilled in the spring of the year, however, and substantial amounts of groundwater occurred in some blastholes.

Retorts #21, #22 and #23 were drilled by Roberts Drilling of Vernal, Utah, using a Drill Tec D40 air rotary rig.

Retort #24 blastholes were drilled by Geokinetics using the CP-650 drill rig and by Roberts Drilling using their Drill Tec D40 drill rig. Conventional drag bits were tested with the CP-650 and worked effectively while sharp. The drag bits dulled quickly, however, and Kenclaw bits proved to be more cost-effective. Drilling rates for the CP-650 averaged 60 feet per hour and Roberts Drilling averaged 41 feet per hour.

2. Re-Entry Drilling

Before a retort can be burned, air holes, production wells, and instrument holes must be drilled and cased. The drilling and casing of these holes present unique drilling problems since the retort zone has been fractured with explosives. New re-entry drilling techniques, as well as previously tested methods, were used during 1979. The latest procedures are described in this report.

The air holes provide the air flow to the retorting zone, to sustain the fire front in a burning retort, and to remove the off gases.

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

Instrument holes are used to monitor the temperatures and pressures within the retort. These holes are placed throughout and peripheral to the retort zone. The holes outside the retort are used to detect any thermal fronts extending beyond the retort boundary during a burn. All instrumentation holes are logged during drilling to obtain indications of the degree of retort fragmentation achieved during blasting.

Observation holes are used to monitor fluid levels in the retort and to collect gas samples. Holes drilled during post-blast coring programs are frequently used as observation wells.

Re-entry air holes were drilled with a Chicago Pneumatic CP-650 air-rotary drill rig. The cased portion of each hole was drilled with an eight inch bit and cased with 6-5/8 inch steel pipe. The open hole below the casing was then drilled with a 6-1/8 inch bit to the bottom of the retort zone. A casing driver was used, as needed, whenever the eight inch hole caved and the casing could not be properly set. In this procedure the casing was set in the hole as deep as possible, the 6-1/8 inch bit was inserted through the casing and drilled a short distance, and the casing then driven down behind the bit. This procedure was repeated until the casing reached the predetermined depth. Generally, there is about five feet of open hole left between the casing and the bottom of the air hole.

A new method of drilling and installing production wells was developed during 1979 and proved to be more successful than earlier techniques. The CP-650 drill rig was used to drill large holes ranging from 8 to 12 inches. The holes were cased with 6-5/8 inch O.D. (outside diameter) thinwall steel casing which was perforated at the bottom fifteen feet. "Poor-boy" packers were placed above the perforations. The well annulus was then stemmed using gravel in the rubble zone with cuttings and soil used nearer the surface. Pipes were installed to trickle water through the gravel packing in order to cool the production well when the burn front reaches the well. Another new technique is to drill the production wells five feet deeper than the rubblized zone to collect excess rubble and sediment at the bottom of the well. This serves as a built-in trap which reduces or eliminates the need for cleaning out a production well. Production has been more consistent with this type of well.

Instrumentation holes were drilled with the GD 3200 air trac and 750 scfm compressor. The holes were drilled with a three inch bit using foam for circulation and cased with one inch steel pipe. The holes near the center axis of a retort were used as both pressure and temperature monitoring wells, which required two separate one inch pipes. The pressure monitoring pipes had 10-15 feet of perforations at the bottom of the hole. Instrumentation holes adjacent to air-in holes also had double pipes in this manner to monitor both pressure and temperature.

It was noted last year that the casing in temperature monitoring holes has been failing as the burn front passed during a burn. In order to test a possible method of preventing thermocouple well burnout, one-half of the Retort #10 thermowells were stemmed with drill cuttings, the standard procedure used on previous retorts. The rest of the thermowells were stemmed with 100 mesh quartz sand. After the burn was completed, the average lifespan of both types of thermocouple wells was computed based on the length of time each thermocouple well remained operable after 800°F temperatures were reached. Thermowells stemmed with drill cuttings lasted an average of 7.9 days after 800°F temperatures were attained. The comparable "lifespan" of thermowells stemmed with silica sand was 11.4 days, an increase of 44 percent.

Several types of stemming materials were used in Retort #17 thermocouple wells in an attempt to find a solution to the problem. All holes with less than five feet of cave material in the annulus were stemmed with the special materials listed below. Success was calculated by the number of vertical positions in each hole still open 15 days after the temperature reached 1000°F. The results were as follows:

<u>Thermocouple Row #</u>	<u>Stemming Material</u>	<u>Success Rate</u>
2	Drill cuttings	34 percent
3	100 mesh quartz sand w/ceramic paint*	59 percent
4	Silica flour (except holes 15 & 16)	0 percent
5	Flour and sand mixture (except holes 21 & 22)	25 percent
6	Quartz sand (except holes 27, 28 & 29)	38 percent

* The outside of these well casings were coated with a heat-resistant ceramic paint.

While the quartz sand/ceramic paint combination showed the highest survival rate, the success rate was not significant enough to warrant the time and expense of applying the paint. Quartz sand was the preferred stemming material.

One major problem experienced in drilling instrumentation holes was that the holes caved often, trapping drill bits and making the setting of casings difficult. When this happened, the casing had to be driven or forced down the hole, which increased the chance of damaging the casing.

In an attempt to eliminate this problem, the GD 3200 air trac drill was equipped to use an Atlas-Copo ODEX drilling system. The ODEX system inserts a three-inch retractable casing behind an eccentric drill bit as the hole is drilled. When the hole is completed, the drill bit is pulled up through the casing. The retractable casing keeps the hole open while one inch thermocouple pipe is installed. The ODEX casing would then be retracted and reused on other holes.

Unfortunately, the system was not successful. Difficulties were encountered in withdrawing the drill bit and when inserting or retracting the ODEX casing. Instrument holes were drilled without the ODEX system.

III RETORT FRAGMENTATION

After a retort blast pattern has been drilled, the blastholes are systematically prepared for firing by following certain procedures:

- (1) Clear the borehole of cuttings and water by blowing with compressed air.
- (2) Load the hole to the desired height with explosive, primer and delayed blasting cap.
- (3) Stem the hole with drill cuttings and/or pea gravel.
- (4) Connect surface wiring between holes to attain the desired firing sequence.
- (5) Run lead wires to a protected area where detonation will be initiated.

Six distinct blasting patterns have been tested to date:

Pattern A was tested in Retorts #3, #5, #7, #8 and #9. This pattern was effective in breaking the rock, but was complicated to drill, load and fire.

Pattern B was a modification of Pattern A. The pattern was tested in Retort #4. This pattern was also effective in breaking the rock, but was expensive to drill.

Pattern C was a new design that was tested in Retort #10. It was effective in fragmenting the shale.

Pattern D was a new design. It was tested in Retorts #11, #12, #13, #20, #21 and #22. This pattern was much easier to drill and load, and had a relatively simple firing system.

Pattern E was a modification of Pattern C. The pattern was simple to drill, load and fire, and was effective in rock breaking. This was adopted as the most desirable pattern to develop. It was tested and improved with Retorts #14, #15, #16, #17, #18, #19 and #24. A patent is in the process of issuance for this pattern (the Walking W).

Pattern F was a modification of Pattern D. It utilized a springing and decking approach to improve bottom breakage, which involves additional difficult steps in the preparation and execution of the blast. The pattern was tested in Retort #23.

Retorts #20, #21, #22, #23 and #24 were designed, drilled and blasted during 1979. Retorts #20, #21 and #22 were all scaled-up versions of Retort #11 utilizing Pattern D. Retort #23 was a new concept in retort blast design. Retort #24 is the largest retort blast to date, and is a scale-up of Pattern E. Retort #24 is the size of a prototype retort in a commercial operation.

Retort #20 was blasted on April 6, 1979, using 7,460 pounds of IRECO site-mix slurry explosives. Slurry explosives were used mainly because of the large number of wet blastholes. The retort is 100 feet long by 40 feet wide, averaging 23.6 feet of retortable shale and 34.5 feet of overburden. Maximum uplift resulting from the blast was 3.1 feet, with the greatest heave occurring along the south side of the retort. Although the blast did go as planned, scatter in the delays was high because blasting caps did not perform to specifications. It was decided that scatter would be carefully monitored on other blasts to determine the extent and predictability of scatter with various blasting caps.

Retort #21 was very nearly a duplication of Retort #20. Average retort thickness increased to 25.3 feet and average overburden decreased to 33.3 feet. The length and width remained the same. The only design changes were an increased powder factor, which was achieved by larger blasthole diameters, and altered delays between sequentially fired rows. The retort was blasted on June 27, 1979, using 9,616 pounds of IRECO slurry explosives. Maximum surface uplift resulting from the blast was 6.9 feet, with an average uplift of 4.6 feet.

Retort #22 was a scale-up of Retort #20. Retort length increased from 100 feet to 125 feet, and width increased from 40 feet to 50 feet. The spacing between blastholes was increased, but retort thickness and overburden remained the same. Retort #22 was blasted on June 27, 1979, using 10,351 pounds of IRECO slurry explosives. Maximum surface uplift was 4.2 feet, with an average uplift of 2.5 feet. Although fairly even, heave was considered marginal and could indicate a lack of propping.

For Retort #23, the Retort #22 design was modified to incorporate a new concept of deck loading bottom point charges. The blastholes were sprung to create a cavity at the bottom.

Point charges, to be delayed for relatively long periods of time in order to improve retort bottom breakage, were added at the bottom of the blastholes. The column charges were to fire first, followed by the point charges, after an appropriate delay. Stemming material between the column and point charges consisted of clay and pea gravel.

Retort #23 was blasted on September 28, 1979, using 15,176 pounds of IRECO slurry explosives and Atlas Powder Aquagel, which was used for the point charges. Apparently the delay systems did not work as planned, and the point charges may have fired at the same time as the column charges. Retort surface uplift averaged 3.5 feet. The blast system designed for Retort #23 was quite complex, and execution of the blast was difficult.

Retort #24 was originally intended to be a scaled-up version of Retort #19, with improvements incorporating the work completed on Retorts #20, #21, #22 and #23. However, after analysis of the post-blast cores from Retort #19 and discussions regarding design improvements, the following modifications were made:

- (1) The initiation round was moved from the air-in end of the retort (where the overburden was the most shallow) to the air-out end where the overburden was deepest.

- (2) The shape of the "W" pattern was modified.
- (3) Three oil drainage channels, instead of two, were designed into the blast.
- (4) Changes were made in the delay sequence.
- (5) Blasthole diameters were increased.
- (6) Powder factors were increased.

Retort #24 is 229 feet long by 217 feet wide, compared to the dimensions of Retort #19 which were 182 feet long by 126 feet wide. Average retort thickness remained approximately the same at 28 feet for Retort #24. Average overburden decreased slightly to 45 feet for Retort #24, compared to 50 feet for Retort #19.

Retort #24 was blasted on November 15, 1979, using 136,667 pounds of IRECO slurry explosives. Maximum surface uplift was 12.3 feet, with an average uplift of 4.5 feet. The blast went as planned, with good lateral movement along "W" rows, indicating the likelihood of good breakage within the retort. There was some surface breakage at the air-out end as a result of excessive heave from the initiation round. Retort fragmentation is much better for Retort #24 than Retort #19; most likely due to the considerable increase in powder factor.

The blasting of four retorts in 1979 led to significant progress and improvement in a number of areas:

(1) Increased Spacing Between Blastholes and Increased Blasthole Diameters. The spacing between blastholes reached an all time maximum distance on Retort #24. Fragmentation appears to be good, indicating that even greater increases may be possible. Blasthole diameters in the initiation round of Retort #24 were almost double the blasthole diameters used on Retort #19 in 1978. Drilling rates for both sizes remained nearly equal for the CP-650. Coupled with increased spacing, this indicates a considerable savings in drilling costs.

(2) Overall Increase in Retort Size. Retort #24 was created using approximately the same number of blastholes as was used on Retort #19. Due to the increase in spacing and blasthole diameters, however, an overall retort volume increase of about 100 percent was accomplished.

(3) Optimization of Powder Factor Calculations and Delay Systems. Analysis of fragmentation and heave data from past retorts has allowed empirical improvement in the application of powder factor calculations and delay systems. Data obtained by Sandia Laboratories has been essential in achieving these successful optimizations.

(4) New Explosive Type and Improved Loading Procedures. Due to water encountered in blastholes it became necessary to switch to a water-resistant slurry explosive. In 1979 all retorts were loaded with IRECO site-mix slurry explosives. The slurry is pumped directly into the

blastholes from a mix truck. The system is quicker, cleaner and more accurate than earlier hand-loading techniques.

(5) Instrumentation. Sandia Laboratories has continued to monitor retort blasts with high speed photography of surface motion and various types of in-place instruments. Precision of data recovery and analysis has improved with each retort blasted. For the blast of Retort #24, 37 film targets were laid out in four separate rows, to be filmed by high speed cameras from all four sides. Fifteen optical "time of arrival" devices were employed. These devices consisted of lengths of Ensign Bickford Nonel shock tube leading up out of the explosive column and exposed on the surface for optical (camera) data collection. Nine conventional TOA's (time of arrival gauges) and three sliphers (a type of TOA) were taped to boosters and lowered into the explosive. Cables attached to these instruments ran up out of the blastholes to Sandia's instrumentation trailer where high speed data collection is made during the blast. In addition to the above instrumentation, Sandia used three PDT's (Pressure Differential Transducers) designed to record the opening of fractures during the blast. These PDT's and four accelerometers, each with both horizontal and lateral components, were grouted in place down the center line of the retort.

The Sandia contribution to a fuller understanding of retort blast phenomena has played a significant role in optimizing retort blast design.

IV RETORTING EQUIPMENT

Three retorts were ignited in 1979. Retorts #10 and #17 were burned completely, and Retort #18 continued to burn into 1980.

1. Retort #10

Surface equipment was constructed and moved to the Retort #10 location during the autumn of 1978.

(1) Power System. Electrical power for the operation of retort equipment was drawn from the Kamp Kerogen power grid. The distribution system provided 440-V three phase, 220-V single phase and 110-V single phase electric power to the retort through buried conductor cables.

(2) Blowers. Air to the retort was supplied using a Sutorbilt blower rated at 1000 scfm at 4 psi powered by a 25 HP, 440-Volt, three-phase motor. Vacuum pressure was maintained with a centrifical fan capable of 1400 scfm at 14 inches of water column, powered by a 10 HP Dayton motor.

(3) Surface Piping and the Hot Gas Generator (HGG). The HGG consisted of a steel tank with a rounded bottom and a conical top laid on its side. It measured seven feet in length with a diameter of five feet. The horizontal HGG was oriented with the cone toward the air-in well head. The inlet gas exited the HGG at the tip of the cone and passed through a six inch thinwall steel pipe to the air-in well. Propane was burned in the generator to provide hot inert gas.

(4) Mist Extraction. Suspended liquids in the off gas were collected in a series of three steel cylinders, each four feet high with a diameter of 2.8 feet. The first two containers used baffled chambers which forced the gas from side to side. The third container was a tower type with tangential plates welded to the inner surface.

(5) Afterburner. Retort off gas was oxidized to carbon dioxide and water in a steel vessel to eliminate odor and smoke from the off gas. The vessel, which was used earlier on Retort #15, had a diameter of four feet and a total effective length of eight feet. Off gas was introduced through the bottom and burned in the main chamber.

(6) Oil Production Equipment. Retort #10 was designed for two production wells. PW-1 and PW-2 were located 42 feet from the air injection well along the retort center axis.

The well casing on PW-1 was two inch steel pipe perforated in the lower 10 feet. A 1-7/8 inch diameter working barrel pump with a two foot stroke capacity was hung in the oil collection sump on one inch pipe. PW-2 utilized a three inch diameter steel casing, perforated in the lower 15 feet. A two inch diameter working barrel pump with an 18 inch stroke capacity was hung on two inch pipe.

Both pumps were activated by 7/16 inch sucker rods and Jensen walking beam pump jacks which had a 10 inch stroke.

(7) Instrumentation. Orifice runs were used to measure gas flow rates. These orifice runs measured 10 feet in length with six inches inside diameter and were incorporated into the air-in and air-out piping. The air-in orifice run was located between the air-in blower and hot gas generator. The air-out orifice run was located between the air-out well head and the demisters. Manometers were used to measure pressure differential in inches of water which was converted to flow rate in cubic feet per minute (scfm).

A total of 25 thermocouple wells were drilled vertically to the bottom of the retort zone and cased with one inch pipe. Sixteen of these were capped and stemmed with silica sand. One thermocouple well was placed one foot downstream from the air-in well and used to monitor ignition temperatures.

A 3/16 inch diameter Inconel sheathed chromel-alumel thermocouple was placed in each thermocouple well. Each thermocouple was marked and read at five foot intervals in the ten foot retort zone and in the 20 feet of overburden above. Readout was made by a West Type K meter which converted milliamps to degrees Fahrenheit.

Retort pressure was monitored at three pressure wells which were drilled to the retort bottom and cased with one inch pipe perforated on the lower seven feet.

2. Retort #17

(1) Power System. Electrical power for the operation of the retort equipment was supplied from the Kamp Kerogen power grid.

(2) Blowers. Two Sutorbilt positive displacement blowers, each capable of 1100 scfm at 2 psig, were used to supply inlet gas to the combustion front in the retort. Three air-out blowers were used to control retort pressure and draw off gas from the retort. The air-out blowers were a centrifugal fan type, two of which were rated at 1400 scfm at 14 inches of water column. The other air-out blower was rated at 3000 scfm at 1.5 psig.

(3) Surface Piping. The recycle experiment required an extensive surface piping system. Six inch and 10 inch diameter thinwall steel pipe was used to construct the air-in manifold, the air-out manifold, and to recycle gas from the afterburner back to the air-in wells.

The recycle system was constructed of 10 inch diameter pipe which connected the afterburner recycle outlet to the air-in manifold via a cooling unit. This unit cooled the recycle gas from about 600°F to less than 140°F.

(4) Mist Extraction. The mist extraction equipment on Retort #17 consisted of three steel cylindrical containers (measuring three feet

in diameter by four feet high) arranged in sequence. The off gas entered each container on the lower side and exited at the upper side 180° from the point of entry.

All three of the mist collectors gravity drained into a collection sump directly below. The mist oil and production oil were combined in a 200 barrel tank where it was stored prior to transfer to the tank battery for dewatering and shipping.

(5) Afterburner. The afterburner consisted of a refractory-lined steel vessel that received and combusted raw process gas and then vented the products of combustion to the atmosphere through a stack.

The overall dimensions of the afterburner were 13 feet long and 14 feet tall. Process gas entered through 10 inch pipes into a horizontal chamber six feet in diameter and eight feet long. This chamber connected to a vertical chamber five feet in diameter and ten feet tall. The four foot stack was at the top of the vertical chamber.

Inert gas used during periods of recycle gas injection was drawn out of the afterburner via a ten inch pipe located below the stack in the vertical chamber.

(6) Oil Production Equipment. Six production wells were equipped with two inch working barrel pumps. The oil was pumped to a 200 barrel storage tank, and from there to the tank battery where it was dewatered and stored for shipping.

(7) Instrumentation. Orifice runs were used to measure the quantity of air and recycle gas injected into the retort and the flow of off gas out of the retort. Differential pressure "U" Tube manometers were used for readout.

Thermocouples were used to monitor the thermal characteristics in the retort. A total of 42 thermowells were drilled to the bottom of the retort zone. A movable thermocouple in each thermowell was read at six foot intervals over a 30 foot vertical distance.

Retort pressures were measured at five locations parallel to the retort axis. Pressures were read through pressure monitoring wells which were drilled to the retort bottom. These wells were cased with 3/4 inch black pipe which was perforated in the lower 15 feet.

Gas samples were taken on a daily basis from a sample point before the demisters. Once a week a gas sample was collected from each of the retort pressure wells. Detailed analyses of these samples were obtained using a Hewlett-Packard Model 5830 gas chromatograph. The gas analysis results showing changes in characteristics during the retorting are included as Figure 6.

Immediate oxygen and combustibles in the off gas were determined using a Fyrite oxygen analyzer and a Bacarach portable combustible meter. These readings were taken daily at the sampling port before the demisters.

A Hydril Net Oil Computer (NOC) was used to measure and distinguish the volumes of oil and water produced from the retort. A turbine meter measured the total fluid volume, while a capacitance probe differentiated the oil and water. The NOC displayed the volume of each fluid in number of barrels.

In the first quarter of 1979, two test probes were installed in two Retort #17 pressure pipes by Lawrence Berkeley Laboratories personnel. The probes exposed various alloys to the retort environment in an effort to determine which is the most resistant to the corrosive environment of a burning retort. This will aid in the selection of a durable material from which down-the-hole process equipment can be made.

3. Retort #18

The surface equipment layout for Retort #18 is shown in Figure 7.

(1) Power System. Electrical power for the retort is supplied by the Kamp Kerogen power grid.

(2) Blowers. Air is injected using two Peerless centrifugal blowers rated at 3000 scfm at 1.5 pounds of static pressure. Vacuum pressure to the air-out wells is supplied by two Peerless blowers of the same type.

(3) Surface Piping. The air-in blowers are connected to the air-in wells with 10 inch diameter thinwall steel pipe. Retort off gas passes from the air-out wells to the mist elimination system and the afterburner through a manifold built from 10 inch steel pipes.

(4) Mist Eliminator. Retort off gas is recovered at the air-out wells and passed through an Austin-Western mist eliminator to remove oil and water mist entrained in the gas stream.

(5) Afterburner. The afterburner was designed to combust retort off gas to CO_2 and H_2O . The cylindrical steel structure stands 20 feet high with a diameter of eight feet.

(6) Oil Production Equipment. Retort #18 has four production wells. Two production wells are located along the retort axis in line with air-in well AI-1, and the other two production wells are in line with AI-3. The production wells are 96 feet and 144 feet from the respective air-in wells.

Two inch diameter working barrel pumps with an 18 inch stroke capacity are hung on two inch pipe and activated by 7/16 inch sucker rods. Recovered fluids are pumped to a 32 barrel separator tank for gauging.

(7) Instrumentation. Readings on all instrumentation are taken daily. Production of oil and water is measured three times daily.

Nine orifice runs are used to measure gas flow into and out of the retort. Three measure air-in and six measure air-out. The orifice runs are 10 feet in length. Pressure differential readout is made using U-Tube manometers.

A total of 56 thermocouple wells were drilled to the bottom of the retort zone and cased with one inch diameter steel pipe. Three of the wells were used only to monitor ignition temperatures. In each of the other 53 thermocouple wells, four chromel-alumel thermocouples were placed so that temperatures at four levels could be recorded.

Thermocouple data acquisition was accomplished with an automated data recording system built by WestAq. Corporation. Retort #18 is the first retort where such a system has been used. This data recording system uses stationary thermocouples which allows the continuation of readings after the well would have plugged and prevented the use of a sliding thermocouple.

Each of the four thermocouples in each thermocouple well is wired into a central panel in the retort instrument shed. A data processor accesses each thermocouple individually and records the retort number, date, time, thermocouple location and temperature in degrees Fahrenheit. The data is recorded on magnetic tape and may be printed on paper tape, as well as displayed digitally. The processor can be programmed to record data automatically at prescribed intervals and can be manually accessed to look at data from any or all thermocouples. The system will also record pressure transducer data and has the channel capacity for two retorts.

Retort pressures are measured at four points along the retort length. One inch diameter steel pipe extend into the retort zone and are perforated the bottom 15 feet. Static pressures are read using U-Tube type manometers.

Gas samples have been taken daily from a sample point in the 10 inch diameter air-out manifold pipe before the demister. The samples are collected in gas sample bombs for analysis at the GKI analytical laboratory using a Hewlett-Packard 5830A gas chromatograph.

V RETORTING EXPERIMENTS

Three retorts were ignited during 1979. Retorts #10 and #17 were ignited and completely burned. Retort #18 was ignited late in the year and continued burning into 1980.

Retort Parameters

Retort #	Date Ignited	Blast Method	Thickness of Shale Blasted	Over-Burden Thickness	Cross-Section ₂ Area(ft ²)	Tons of Broken Shale	Bbls. of Oil Re-covered
10	1/79	C	11 ft.	14 ft.	220	730	364
17	6/79	E	17 ft.	26 ft.	1,200	13,000	3,775
18	11/79	E	17 ft.	27 ft.	1,800	19,000	1,187*

* Oil production as of December 31, 1979.

1. Retort #10

The experimental objective of Retort #10 was to test the feasibility of creating a separation of the retorting and combustion thermal fronts. The retorting front is indicated by temperatures of 800°F; the combustion front is a zone in which oxygen is being consumed after hydrocarbons have been released, as indicated by temperatures in excess of 2000°F. The anticipated result is more efficient resource recovery in the form of increased oil yield due to decreased combustion of oil.

The primary piece of process equipment was a propane-fired burner (described under Retort Process Equipment) capable of producing 400 scfm of hot inert gas, with less than three percent oxygen by volume, at a temperature of 1300°F.

The procedure called for the injection of hot gas into the retort at 200 scfm and bottom hole temperatures in excess of 900°F until the third row of thermocouples (12 feet downstream from the air-in well) reached a temperature of 800°F. At that time the burner would be shut down and injection of air (21 percent oxygen by volume) would begin at 200 scfm to start combustion of the hot char in the air-in well bore vicinity. With this procedure an initial front separation of 12 feet would be created, and the respective rates of thermal front advances could be determined by monitoring the retort thermocouples.

The retort burn was initiated on January 29, 1979, by igniting the hot gas generator and injecting the gas into the retort. Air-in flow rates

were decreased to 150 scfm and downhole temperatures of 1000°F were achieved.

Significant temperatures were registered at the first row of thermocouples three days after ignition. The retorting thermal front (800°F) advanced slowly, and high temperatures began moving into the overburden. The retorting front had reached the third row of thermocouples by the 25th day of the burn. At that time, the inert hot gas generator was shut down and injection of air commenced at 200 scfm. This was intended to create a combustion front at the air-in well, which it did. Thermocouple data indicated that an initial thermal front separation of 12 feet was accomplished.

The combustion front advanced rapidly to within two to three feet of the retorting front and remained close behind the retorting front for the duration of the burn. It had originally been planned to initiate subsequent inert hot gas phases as needed to maintain significant thermal front separation, but, due to problems with the inert hot gas generator, this could not be done.

The overall resource recovery from Retort #10 was 69 percent of the total oil in place in the blast zone; the best for any retort to date.

It has been noted that high temperatures extended into the overburden during the initial stages of Retort #10. In order to further study this phenomenon, temperatures were measured daily at three five-foot intervals above the intended retort zone. The data from this study indicate that retorting temperatures extended into the overburden throughout the retort. In fact, temperatures of 1000°F were recorded at the highest level in several locations. The overburden is low-grade oil shale.

Carbon monoxide concentrations at the retort surface were measured weekly using a MiniCo Model 1 carbon monoxide indicator. The highest concentration recorded was four parts per million (ppm), and the average concentration over the duration of the burn was 0.3 ppm. The primary reason for these low concentrations was the vacuum pressure applied to the retort. Retort pressures were maintained at levels close to zero inches of water column. This was the most significant factor in reducing Retort #10 fugitive emissions.

2. Retort #17

Retort #17 was basically a scale-up from Retort #16. The primary experimental objective of Retort #17 was to test the effects of recycle gas (reinjecting, inert, combusted off gas) and increased superficial gas velocity on retort behavior. Other investigators have reported that a decreased oxygen content in the inlet (air-in) gas, has a beneficial effect on the rate of oil recovery and overall resource recovery. Furthermore, the optimum oxygen content for the inlet gas is reportedly 14 percent by volume. Retort #17 provided an opportunity to attempt to apply these findings to an operating in situ retort.

The experimental procedure called for drawing combusted off gas from the afterburner and mixing it with ambient air at a ratio of 2:1 and

injecting it into the retort through the air-in wells. The addition of the inert diluent to the ambient air decreased the oxygen content of the inlet gas to 14 percent by volume. The superficial gas velocity was then increased by one-third more than a comparable combustion run while keeping the oxygen flux constant.

Retort #17 was ignited on June 7, 1979. The retort was not operated continuously with recycle until elapsed day 58 due to difficulties with the equipment designed to cool the recycle gas. Recycle was used through elapsed day 79, with the oxygen content of the inert gas averaging 15.5 percent during this period. No significant effects on retort operation were attributed to the injection of recycle gas. However, data on production, fire front advance rate and off gas composition is being further evaluated.

Superficial gas velocity (scfm per square foot of retort cross-section) was varied during the course of the burn such that there were two distinct phases. The first 104 days of the burn constituted Phase I, a period of high air-in rate (averaging 1160 scfm). Phase II, was a period of low air-in rate (averaging 650 scfm) during the last 82 days of the burn. The retort burned for a total of 186 days ending December 10, 1979.

Overall oil production during the two phases totaled 3,775 barrels, or 50 percent recovery of in place oil and 56 percent of the volume swept. The average daily production rate for the entire burn was 20 barrels per day. There was a notable difference between the daily production rates for the two phases. Production rates averaged 30 barrels of oil per day during Phase I and eight barrels of oil per day during Phase II. Since the burn front advanced more rapidly in Phase I, oil production rates per 100 square feet (ft^2) of retort cross-section should also be considered. Phase I averaged 2.4 barrels per 100 ft^2 per day, Phase II averaged 0.57 barrels per 100 ft^2 per day. These figures also indicate a direct relationship between superficial gas velocity and daily production rates.

3. Retort #18

Retort #18 is a scale-up of Retort #17 and the largest retort ignited to date. The retort measures 156 feet long by 108 feet wide, with 19,000 tons of shale. This represents 20 percent of a full-sized retort.

Ignition was accomplished on November 12, 1979, using charcoal at each of the three air-in holes. By the third day of the burn, temperatures at the first row of thermocouples had reached 1000°F. The fire front had advanced to the full retort cross-section by early December and was producing an average of 32 barrels of oil per day by the end on 1979.

Oil recovery from Retort #18 was 1,187 barrels at the end of 1979. The retort continued burning into 1980.

Retort off-gas samples were taken daily from the 10 inch air-out manifold and analyzed at the GKI analytical laboratory using a Hewlett-Packard 5830A gas chromatograph. Gas analysis results have been reported monthly.

VI ENVIRONMENTAL RESEARCH

1. Program History

The goals of GKI's Environmental Program, in broad form, are to:

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

The Environmental Research Program description was restructured late in 1979 and consists of a two-part document. The "Program Outline" describes the Environmental Research Program goals and objectives and a second section, the "Research Record," describes the actual research conducted, modifications thereto, and conclusions therefrom. Environmental research and activities fall into four major categories: Atmospheric Resources, Hydrological Resources, Ecological Resources, and Cultural-Economic Resources.

2. Atmospheric Resource Research

(1) Meteorology. In the summer of 1979, the following modifications were made to the existing monitoring and data collection network:

(a) The 100-foot electrical weather station (A-04) was converted from the paper chart data recording system to a new solar-powered unit using a magnetic tape cassette for data recording; and

(b) A 30-foot mobile weather station (A-07) was installed to provide site specific data for future diffusion modeling near the new retort area #2 located in the north central part of the research site.

These new systems are more reliable and less expensive than earlier systems. Data reduction is computerized, thereby realizing a major savings in labor costs. Reduction of data from these stations is currently being provided by WestAq Associates of Grand Valley, Colorado.

All data collected during the first half of both 1978 and 1979 has been analyzed and reported in the quarterly reports to DOE for the first and third quarters of 1979, respectively. The data has been applied to developing a quantifiable description of the existing microclimate of the research site. Vertical temperature profiles have indicated that nighttime inversionary periods are present a high percentage of the time. The new meteorological data collection and recording systems will aid in determining if the number of inversions, and their relative strengths, are being accurately assessed. During winter, prevailing winds are predominantly from the southeast, with an average wind speed of seven miles per hour. Southwesterly winds averaging 17 miles per hour predominate in the spring. Net evaporation for the first six months of 1979 was recorded to be 28.6 inches, of which 92 percent occurred during the second quarter. The recorded (uncorrected) precipitation for the same period was 4.8 inches, with 66 percent recorded during the second quarter. Rain accounted for 0.7 inches and snow totaled 40.1 inches. The maximum and minimum temperatures recorded for the first six months of 1979 were 95° Fahrenheit and minus (-)17° Fahrenheit, respectively.

(2) Air Quality. Three separate air quality investigations have been conducted at the research site to date:

(a) An in-house investigation of process and stack gases commencing with Retort #16 in 1978 and continuing with Retorts #10, #17, and #18 in 1979;

(b) A comprehensive study of process gases, stack gases, and fugitive emissions conducted by the Monsanto Research Corporation on Retort #17 for a ten-day period in July, 1979; and

(c) A one-year qualitative baseline record of visibility attained through air clarity photomonitoring from September, 1978 to September, 1979.

Three types of analyses are carried out on process gas as part of the in-house investigation. The first is by gas chromatography. The following constituents are measured using a Hewlett-Packard 5830A gas chromatograph:

Hydrogen	Propane	Trans-Butene	1-Pentene
Oxygen	Propene	CIS-Butene	Methane
Nitrogen	ISO-Butane	1:3 Butadiene	Ethene
Carbon Monoxide	N-Butane	ISO-Pentane	Ethane
Carbon Dioxide	Butene-1	Pentane	Carbonyl Sulfide

Chromatographic analyses was done on gas samples collected daily from the air-out line and weekly on a suite of samples collected from various points along the axis of the retort. Results were reported monthly in volume percent for each constituent.

The second analytical method involves the determination of hydrogen sulfide (H₂S). A sample of H₂S is collected at least twice a

week from the air-out manifold. A sodium hydroxide solution (NaOH), through which off gas is bubbled at a controlled flow rate, is used to scrub out the H₂S. A wet-test meter is then utilized to measure the volume of gas used and temperature of the gas. The sulfide in the solution is finally measured by one of three methods: sulfide ion sensing electrode, the iodine titrimetric method, or the potentiometric-argentometric titration method. After the concentration of H₂S in the retort off gas is determined, using the flow rate of the off gas, the calculated conversion of H₂S to sulfur dioxide (SO₂) is made to determine the number of pounds of SO₂ produced per day.

The third analytical method is very similar to the second, except that ammonia is scrubbed from the off gas using sulfuric acid. The ammonia is then measured and the production of nitrogen oxides (NO_x) is calculated based on combustion of the ammonia. The result can then be reported in pounds per day of nitrogen (NO), which is actual gas emitted from the stack, or nitrogen dioxide (NO₂), which is what the NO becomes upon exposure to sunlight and air.

Stack gas is also analyzed for particulates, ozone, carbon monoxide (CO) and hydrocarbons.

Emission rates to date for any one pollutant have neither approached or exceeded 100 tons per year. The pollutants with significant concentrations appear to be SO₂, NO_x, CO, and hydrocarbons.

Retort #10. During the 100 days that Retort #10 burned, about 31 million cubic feet of off gas was produced. The off gas was burned in a gas incinerator which emitted a total of 68 million cubic feet of exhaust gas. Retort #10 emitted a total of 1,115 pounds of NO_x; 2,036 pounds of SO₂; and 4.4 pounds of particulate matter. Concentrations of CO and hydrocarbons averaged 477 parts per million (ppm) and 23 ppm, respectively.

NO_x and SO₂ emissions from the stack were very low. The emissions measured were lower than actual emissions due to the stack and sampling device design. (Samples were collected from the stack wall rather than the cross-section of the stack.) Actual emissions, as determined by calculations, were still low. Particulate emissions from Retort #10 were high because propane was added to the stack to enhance combustion. The propane was burned in limited oxygen, which lead to incomplete combustion of the propane and the formation of fine carbon soot. This fine soot was very nearly the entire contribution of particulates. Carbon monoxide emitted from the stack was typically 1,400 ppm, providing an additional indication of incomplete combustion of the retort off gas.

Retort #17. Total emissions from Retort #17 were calculated to be 48,925 pounds of SO₂ and 34,890 pounds of NO_x. The arithmetic mean of the H₂S concentration through the retort burn was 2,079 ppm, and the arithmetic mean of the ammonia concentration (throughout the burn) was 1,101 ppm. Hydrocarbons and CO levels were typically found to be less than 5 ppm under smooth retort and afterburner operating conditions. Particulates were typically less than 0.05 micrograms per cubic meter

($\mu\text{g}/\text{m}^3$). Ozone was found to be less than 0.001 ppm, or about the same as atmospheric background.

The SO_2 loading (pounds of SO_2 per mscf) was found to decrease with increased air-in flows. The sulfur loading increased with respect to time throughout the retort burn; increased travel through the burned retort resulted in increased sulfur emissions. The number of pounds of NO_2 per mscf increased as air-in flows increased. The pounds of NO_2 per mscf appeared to increase with respect to time during the retort burn. However, the correlation for this parameter was not as good, indicating the need for additional study. (An explanation for this phenomena is that ammonia is more soluble than H_2S . As air flow increases, residence time decreases and ammonia is swept out of the retort rather than being dissolved in water and entrained in the off gas mist.)

Retort #18. Trends noted with Retort #17 are being monitored during the burn of Retort #18. Noting and confirming such trends will aid in the planning of off gas management for future retorts and will contribute to accurate projections of future off gas production.

The following table summarizes GKI emissions for 1979:

GKI EMISSIONS, 1979

	SO_2	NO_x as NO_2	Carbon Monoxide ppm	Hydro- Carbons ppm	Parti- culates $\mu\text{g}/\text{m}^3$	Ozone ppm
Total lbs/yr	58,870	36,490				
Average Concentration			< 5	< 5	< 0.05	< 0.001

3. Hydrologic Resource Research

The objectives of GKI hydrologic programs are to:

(1) Generate reliable background data on the chemical characteristics of the groundwater in the areas which may become associated with the retorting process;

(2) Produce and evaluate data on the chemical characteristics of waters generated by in situ retorting of oil shale;

(3) Determine and quantify the effects and their extent that in situ retorting might have upon ground and surface waters;

(4) Assess the degree of probability that contaminants emitted or left in place by retorting may be transported by natural hydrologic processes to areas beyond those of immediate development; and

(5) Develop cost-effective and environmentally sound means of disposing of waters produced by in situ retorting.

Since the beginning of the GKI Environmental Program in 1977, three separate well level studies, a native groundwater quality study, two retort water quality studies, a dye trace study and numerous short-term hydrologic studies have been conducted at the research site.

All three well level monitoring programs were conducted during an 18-month period from January, 1978 through June, 1979. The programs were subjected to a comprehensive evaluation at the end of that period. A detailed description of the three studies, including a compilation of data and a discussion of the results, was included in the second DOE quarterly report for 1979.

Water levels in the Series 1 wells, the Series 2 wells and the Supplemental Series wells were monitored. The Series 1 wells, located around blasted, operational and spent retorts, confirmed that rubblization does improve horizontal communication and may be effecting vertical communication. The Series 2 wells, in contrast, are located away from any retorts and suggested that there is perched water above the mahogany oil shale bed, in cracks and fissures, but not communicating freely either horizontally or vertically. The Supplemental wells strengthened the findings of the Series 2 wells by indicating that there is very little horizontal communication of waters throughout the entire section since the heads of many of the wells are above surface elevations of other wells a short distance away. All three studies confirmed that the water table does vary seasonally, but even during wet periods this variance is not statistically significant.

GKI water quality data obtained in 1978 and early 1979 was evaluated with the objective of developing preliminary characterizations of native groundwater and retort water at the field site. The results were included in the first DOE quarterly report for 1979. Both retort water and native groundwater at the site were found to be of poor quality, though statistical testing indicated that further study was needed. The results indicated, with a high degree of statistical certainty, that GKI retort water is of significantly poorer quality than native groundwater as determined for tests of hardness, ammonia, cyanide, sulfide, molybdenum and potassium. The statistical characterization of retort water is shown in Figure 8. Additional native groundwater samples will be collected in 1980.

A dye trace study utilizing the Series 2 wells was conducted during the first half of 1979 to assess the communication of native groundwaters. Dye was injected into the center well and water samples were taken from adjacent wells twice a week for nearly five months to assess movement

to other wells. The study was finally terminated in May, 1979 after it was determined that no dye had ever intercepted an adjacent well.

An on-going hydrologic study is the quarterly sampling of six wells adjacent to Retort #15 to assess time-related changes of water contained in the retort after the burn. This study began in October, 1978, and will continue through 1980.

Samples were collected monthly from the evaporation pond used for retort water disposal and analyzed to assess changes in the concentration of its constituents over time. Water and ice samples were taken from the evaporation pond in January, 1979 to determine if freezing of the effluent water produced a significant decrease in contaminant concentrations in the ice. The analyses indicated that contaminant concentrations in the ice may be as much as 10 times lower than the concentrations found in the pond water. These results were included as part of the first DOE quarterly report for 1979.

Work began in 1979 to assess the feasibility of disposing of retort water through deep well injection. This investigation continued into 1980, and preparations are underway to apply for an "Underground Injection Control" (UIC) permit which is needed to construct and operate a disposal well.

The GKI analytical laboratory developed several improved methods of analysis for retort water and local groundwater samples during 1979. Improved analysis methods for chloride in water and boron in water were published as part of the first DOE quarterly report for 1979. GKI is cooperating with DOE/LETC in developing methods of analysis for oil shale associated waters.

A 100 barrel sample of Retort #17 water was sent to DOE/LETC for use in efforts there to characterize oil shale retorting effluent waters. Retort effluent water generated at the field site was also studied by Monsanto during their two-week study.

4. Ecological Resource Research

(1) Vegetation. Vegetation baseline studies were begun in 1978 under the guidance of Dr. E. R. Olgeirson (ERO Associates, Conifer, Colorado), a plant ecologist hired as a consultant to assist in the studies. The baseline work included vegetation mapping, as well as on-going floristics, phytosociology, herbaceous productivity and eco-climatological studies. Vegetation mapping was produced from aerial photographs of the site and ground-truthed in the process of baseline studies. Four major vegetation types were identified; north facing pinyon-juniper woodland, south facing pinyon-juniper woodland, sagebrush-saltbush lowland and sagebrush-grass upland.

The purpose of the floristics study has been to collect, identify and catalog the plant species occurring on the site, including any rare, threatened or endangered species. Floristic information consists of a

list of all species of vascular plants occurring on the site. A preliminary list was published in 1978, with positive identification and final reporting to be accomplished in 1980.

In order to conduct phytosociological, herb productivity and eco-climatological baseline studies, eight vegetation study plots were established, two plots in each major vegetation type. These sampling sites were paired so that each vegetation type could be examined in remote areas as well as areas proximate to development operations. The phytosociological study is being conducted to quantify and describe in detail the structural and compositional characteristics of the major vegetation types occurring on the section. The purpose of the herbaceous productivity study is to develop estimates of annual herb productivity on the project site. Eco-climatological studies are conducted to obtain microclimate data from the environmental zone that has the greatest influence on plant distribution and growth. The information yielded by these studies will be applied to planning and evaluating the revegetation of disturbed sites and will be useful in distinguishing between the effects of changes caused by development versus those resulting from natural trends and cycles.

The results of the 1978 portion of the ecoclimate study were received from Dr. Olgeirson in June, 1979, and published as part of the second DOE quarterly for 1979. The results of the 1978 portion of the herbaceous productivity study were also reported on during the year and were included in the third DOE quarterly report for 1979. The report concluded that in 1978 the productivity of the herbaceous layer of vegetation on the site was relatively low. It was found that areas which are of greatest importance to herbivores are those which have a substantial component of the following three fractions: (1) western wheatgrass, (2) perennial grasses and (3) blue grama grass. Annual forbes and annual grasses are an important component of the herbaceous standing crop, particularly in sagebrush bottomland sites.

The low rainfall received during the summer of 1978 had a direct influence on the herbaceous growth measured and resulted in decreased growth among the fractions sampled. Preliminary analysis of phytosociological studies conducted in May, 1979 revealed some significant increases in the herb layer as compared with 1978 samplings, probably the result of higher moisture in the spring of 1979.

A comprehensive report of the two-year baseline vegetation studies is expected from Dr. Olgeirson in 1980.

A one-year qualitative baseline record of vegetation coverage in the vicinity of the project site to supplement the quantitative studies described above was completed in 1979. Vegetation panorama photomonitoring was conducted every fourth week from a platform located one mile north of Kamp Kerogen (Environmental Research Station #2), which provided an unobstructed 360° view of the area. The entire year's data, in the form of slides, is on file at the field site.

(2) Wildlife. A one-year wildlife baseline study was begun in May, 1978 and completed in May, 1979. These studies were conducted under

the direction of Dr. Robert E. Stoecker, Research Ecologist (Stoecker-Keammerer & Associates, Boulder, Colorado). Quantitative studies amenable to future monitoring programs were conducted on mule deer (pellet group counts and big sagebrush production-utilization studies) small mammals (live trapping), and birds (spring and summer transect counts). The research design used was systematic sampling in selected strata (pinyon-juniper woodland and sagebrush draws).

A detailed description of these studies and the results obtained was included in the second DOE quarterly report for 1979. The most significant findings of the baseline wildlife studies were:

(a) No threatened or endangered wildlife species were encountered on or near the study area (Section 2, plus a one-mile surrounding zone).

(b) No critical habitats or wildlife of special scientific interest or unusual occurrence were identified.

(c) Mule deer and elk occur on the study area. Deer were not very common during the period of field investigations but were present most of the year. Only occasional signs of elk were observed, which suggested a rare and probably sporadic occurrence.

(3) Land. GKI began conducting soils studies early in 1978 and in 1979 the original objectives were assessed and revised to provide a more concise, reasonable and relevant basis for land studies. The objectives of GKI land studies are to:

(a) Characterize and describe the distribution of soils on the project site;

(b) Assess the impact of project operations upon local soils and implement measures to mitigate unacceptable impacts; and

(c) Assess the impact of project operations upon the local geomorphology and implement measures to mitigate adverse impacts such as erosional enhancement, drainage, modification, etc.

The first objective was achieved through a soils inventory study. Preliminary identification of soil units was made using aerial photography. The four soil types, thus identified, were verified in the field using standard Soil Conservation Service (SCS) techniques. A map showing the distribution of soils at the field site is included as Figure 9. The complete soils inventory studies report was published as part of the third DOE quarterly report for 1979.

The second objective was addressed by a study in which soil analyses were performed on native soils and on retort soils before and after the completion of the retorting process. This study indicated that there was no apparent differences between native soils and retort soils, and that retorting does not appear to have any serious deleterious effects upon soils and their revegetation potential. A detailed report on this study was included as part of the third DOE quarterly report for 1979.

The third objective was addressed in the Landscape and Erosion Control Plan prepared by E. R. Olgeirson Associates. This manual presented guidelines to be used in the course of development activities and recommendations for maximizing reclamation efforts.

(4) Reclamation. GKI reclamation objectives are to:

- (a) Return the land concurrently with process operations, or within a reasonable amount of time thereafter, to a stable ecological condition compatible with past, present and probable future local land uses;
- (b) Minimize or prevent present and future on-site or off-site environmental degradation caused by Geokinetics' operations to the ecologic and hydrologic regimes; and
- (c) Minimize or prevent future hazards to public safety and welfare.

Guidelines for minimizing environmental surface degradation and achieving rehabilitation of land affected by project operations have been presented in the Landscape and Erosion Control Plan prepared by E. R. Olgeirson Associates. This plan makes recommendations for minimizing erosion and other landscape degradation during development.

The testing of recommended revegetation procedures began in late 1979 with the planning of two test areas; a one-fourth acre test area on and around Retort #9, and a one-half acre test area on and around Retort #14 and Retort #15. The surface of those areas was roughed and the prescribed seed mix applied, after which the seed was covered. Evaluation of these revegetation tests will be ongoing and will begin in the spring of 1980.

Also, Retort #1 was reclaimed during 1979. This very small retort area contained a trench several feet deep, which was filled in.

5. Cultural-Economic Resource Research

(1) Historical. Studies have been conducted to assess potential impacts to, and avoid or mitigate description or destruction of, historical resources that may exist on the project site. No significant archeological sites were found to occur in the section. Confirmation was received from the Utah Division of State History that GKI had fulfilled all requirements of Utah State antiquities regulations. In-house policies were formulated to protect historical resources that may be discovered in the future.

(2) Socio-Economic Impacts. The present and projected future impacts of GKI's operations upon the socio-economic fabric of the Uintah Basin were examined and a summary report of findings was published in the second DOE quarterly report for 1979. It was determined that GKI's operations will have minimal adverse impact upon the Uintah Basin, and, in fact, will probably have a net positive impact. Communication is maintained with local government planning agencies to ensure that adverse impacts are avoided.

Policies for mitigating internal impacts upon employees resulting from living and working at a remote, isolated field camp were developed in 1979.

(3) Permits. Permits to build the new warehouse/shop facility and to operate the Kamp Kerogen sanitary landfill were obtained in 1979. Various other permits were updated as necessary, and efforts were made toward obtaining Utah State approval for the evaporation pond and the Kamp water supply and wastewater disposal systems. In addition, work began on applications for the Underground Injection Control (UIC) permit to allow retort water disposal through deep-well injection. It was also noted that GKI emissions of SO₂ for 1980 would exceed 100 tons, thus necessitating a Prevention of Significant Deterioration of Air Quality (PSD) permit. Preparation of an application for the PSD permit began in 1979.

In addition to the research described above, GKI assisted in the preparation of an updated Environmental Assessment Report (EAR) published in December, 1979. This document addresses potential future impacts of the project.

VII OIL PRODUCTION, SHIPPING AND REFINING

During 1979, Retorts #10 and #17 were completely burned and Retort #18 was ignited in November. These retorts resulted in a total production of 5,170 barrels of shale oil for 1979. During the year, 1,550 barrels were sold to the Plateau refinery at Roosevelt, Utah, and 99 barrels were disposed of on site during tank cleaning operations. At the end of 1979, 2,124 barrels of shale oil were in storage at Kamp Kerogen and 4,106 barrels were in storage at Rifle, Colorado, in DOE tanks. A total of approximately 10,500 barrels have been produced to date.

As production increased during 1979, it became necessary to expand the tank battery. A 3,000 barrel oil storage tank (on loan from DOE) was erected and plumbed into the existing facilities. Those facilities consist of a 400 barrel wash tank, two 400 barrel storage tanks, a lined evaporation pond and a tank truck loading dock. All of the oil tanks and related pipelines are steam heated.

Oil pumped from the retorts is first measured and sampled, then transferred to a heated and insulated 200 barrel holding tank. From the holding tank it is pumped through a 1,600 foot long heated buried pipeline to the tank battery. At the wash tank, the emulsion is mixed with an emulsion breaker and heated to 180°F. The clean oil, with water less than one percent, flows over the top of the tank into the storage tank, and water flows out of the bottom to the evaporation pond. The process is continuous and the dumping of the water is controlled by a float-actuated valve in the wash tank.

Oil that was sold to the Plateau refinery in Roosevelt ranged in price from \$22.50 per barrel in June, 1979 to \$28.25 per barrel, FOB Kamp Kerogen, in October, 1979.

Shale oil blending tests were conducted at the Plateau Roosevelt refinery in 1979. Shale oil was blended with Altamont crude, the refinery's normal feedstock, in concentrations of 0.1 to 1.0 percent shale oil by volume. The distillation, API gravity, pour point, flash point, Naptha and Cat Gas were not affected by the shale oil. The diesel from the crude unit, however, changed from water white to yellow and a fine grayish-brown precipitate formed. Plateau tested eleven additives in an attempt to eliminate the precipitate and achieved the best results when Tretolite Tolad T-362 was added to the diesel at a ratio of 1 to 6,500.

The GKI analytical laboratory conducted several shale oil blending and distillation experiments in 1979, as reported in the third and fourth DOE quarterly reports. In one test, mixtures of Retort #17 shale oil and Bluebell crude from Altamont were distilled under nitrogen. The mixtures contained 0.5%, 1%, 2%, 5%, and 10% shale oil by volume. Fractions were collected at 200°F - 300°F, 300°F - 400°F, 400°F - 500°F, 500°F - 550°F, and 550° - 600°F. The fractions collected were stored in the dark under inert atmosphere for five days. At the end of five days, the fractions were examined for cloudiness, color and the presence of any precipitate or deposit on the walls of the glass container. The samples were then left out in the light for another five days at room temperature, then

examined again for changes in the conditions listed above. The fractions were then filtered through a fine membrane filter to remove any precipitate. The filters were reweighed and, from the amount of precipitate collected on the filter from each fraction, the percentage of the precipitate contained was calculated.

The amount of the precipitate decreased with the increase of the shale oil in the mixture for the 400°F - 500°F distillation fraction. The other fractions (200°F - 300°F and 300°F - 400°F) showed a decrease from 0.5% to 1%, a general increase at 5%, then a decline at 10%. The data indicated that the greatest precipitation problem exists with the 0.5% shale oil mixture, and that less precipitation takes place at 1% - 2% than at less than 1%.

Other efforts were initiated to develop methods for eliminating the precipitate and to determine the cause of incompatibility when shale oil is blended with Altamont-Bluebell crude. A sample of shale oil was sent to the University of Utah to be tested by gradient elution chromatography. That analysis had not been completed at the end of 1979. Shale oil samples were provided to DOE/LETC and various other parties for research purposes.

Chromatographic analyses of shale oil recovered from Retorts #17 and #18 were performed by the GKI analytical laboratory late in 1979. The results were reported in the fourth DOE quarterly report.

VIII FIELD SITE CONSTRUCTION AND IMPROVEMENTS

The Geokinetics project site is located 70 miles from Vernal, Utah, the nearest town. Roughly half of this distance is unpaved road which is difficult to travel in the winter and spring. There is no electrical power line or telephone line in the area. Because of the remote location of the site, and its poor accessibility over the dirt roads, a field camp (Kamp Kerogen) was established to support the project and provide living quarters for the field crew and their families, as well as visitors and contractor personnel. The maintenance and operation of this camp is vital to the success of the operation.

The initial camp was established in the spring of 1975 and consisted of tents, with outdoor cooking and eating facilities. The camp has grown as the project progressed and increased in size. During the winter of 1975-1976, three trailers were moved in to serve as living quarters, office, shop and warehouse. Additional trailers were moved in during 1976 and 1977. In 1977, two buildings were constructed for shops and warehouse. A recreational hall with television, a pool table, a ping-pong table and hot water showers was also built. A radio-telephone communications link was established with the outside world.

In 1978, a major expansion of Kamp Kerogen took place with the objective of providing a field camp suitable for family living. A water well was drilled to a depth of nearly 1,400 feet so that water would no longer need to be hauled in to the project site. A central water system and a central septic system were constructed, providing Kamp Kerogen with the luxury of running water. Additional mobile homes were added to the camp so that each family had its own home, while bachelors either shared a large trailer or were provided a smaller trailer.

By the end of 1979, two dozen trailers housed nearly 50 residents of the remote village, including wives and children. A natural gas distribution system was constructed, and the camp was converted from propane to natural gas from the Mountain Fuel pipeline. Improved radio-telephone equipment was also installed.

Another major improvement in 1979 was the construction of a 4,800 square foot warehouse and shop facility. This building houses some offices and the supply warehouse, as well as automotive, machine, carpentry and electrical shops. The original shop and warehouse buildings are being used for supplemental shop, storage and recreational uses.

Electrical power for Kamp Kerogen and the experimental retorts is supplied by diesel-powered electric generators. Generating capabilities were increased in 1979, and at the end of the year a 200 KW generator was in use with a 150 KW unit available as back-up.

A reliable source of electricity is necessary for the 24-hour operation of laboratory and retorting equipment, as well as for the living quarters,

shops and offices. It became apparent in 1979 that existing generating facilities would not be sufficient during 1980. GKI is working closely with DOE/LETC to obtain the use of several larger generators.