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INSTRUMENTATION AND OPERATIONAL PLAN
FOR GEOKINETICS RETORT NO. 22

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ABSTRACT

Sandia National Laboratories support of the Department of Energy's in situ oil shale program includes instrumentation and technical evaluation of designated field experiments. This report outlines the general plan for the instrumentation and technical direction of a horizontal in situ retorting experiment to be conducted at the Geokinetics, Inc. field site in Uintah County, Utah. Bed preparation has been accomplished by Geokinetics by blasting the retort zone with explosives emplaced in wells drilled from the surface. Retorting will be a joint Geokinetics Sandia effort--Geokinetics will operate the surface processing equipment; Sandia will provide the instrumentation and technical direction with emphasis on the acquisition of data to provide an in depth understanding of the intra-retort dynamics.

Downhole instrumentation will consist of ~300 thermocouples and 28 combustion gas sampling ports to monitor the movement of the reaction front during the retorting process. Surface instrumentation will provide measurements of flow rates, gas composition, liquid products and other process parameters to monitor the overall operation of the process. The operational plan includes provision for data interpretation and real time material balance calculations in the field, including an evaluation of the effect on processing rates and oil yield due to the use of recycled combusted off gases and changes in rate of injection of inlet gases.

I. INTRODUCTION

Sandia National Laboratories support for the Department of Energy's Fossil Fuels Extraction Programs includes participation in field experiments related to the development of underground coal gasification and in situ extraction of oil from shale. The scope of activities includes predictive modeling, instrumentation of field experiments, diagnostic and formation assessment measurements, interpretation of experiment data, and technical evaluation of the experiments. Significant contributions to these programs are the development of instruments to more adequately interrogate the experiments and the development of advanced modeling techniques.

This report outlines the general test plan for the instrumentation and technical direction of an in situ oil shale retorting experiment to be conducted at the Geokinetics, Inc. (GKI) field site approximately 70 miles south of Vernal, Utah. This experiment is being conducted as a joint GKI-Sandia venture. Bed preparation (rubblization) and operation of the surface processing equipment during the experiment will be done by GKI; Sandia will be responsible for the technical direction, instrumentation, data acquisition, and overall evaluation. Emphasis will be placed on instrumentation and data acquisition in sufficient detail to acquire an in-depth understanding of the retorting process such that oil production and overall efficiency of future in situ projects may be maximized.

II. BACKGROUND

The Geokinetics, Inc. in situ oil shale recovery program is an industry-government cooperative venture, governed by DOE Agreement No. DE-FC20-78LC10787, to develop a true in situ process for recovering shale oil by progressing a retorting front horizontally through the

bed.⁽¹⁾ The oil shale at the GKI project site is in the mahogany zone, is about 30 feet (9 m) thick, and has an average grade of ~23 gal/ton. Overburden ranges from essentially zero to a maximum of ~60 feet (18 m) at this site.⁽²⁾

The GKI LOFRECO (low front end cost) true in situ process for extracting oil from oil shale is designed to retort relatively thin shale beds under shallow overburden.^(1,2) In this process the shale is fractured by means of explosives placed in boreholes drilled from the surface. After a specified volume has been fractured, injection wells are drilled at one end of the fractured zone, and off-gas and liquid recovery wells at the other. The oil shale is ignited at the injection wells and an oxidant (air or air plus recycle gas) is continually injected to establish and maintain the combustion front. The burn front moves in a horizontal direction through the fractured rock, heating the oil shale ahead of the combustion front, decomposing kerogen which produces oil that drains to the bottom of the retort where it is recovered through oil production wells (Figure 1). The residual coke left in the retorted oil shale is utilized as fuel.

Through 1979, bed preparation via blasting has been executed on 23 retort sites, of which 12 have been retorted. These retorts have been of various sizes, ranging from 40 to 156 feet (12 to 48 m) in length and 10 to 108 feet (3 to 33 m) in width, with the retort zone thickness ranging from 10 to 23 feet (3 to 7 m). The overburden has ranged from essentially zero to ~45 feet (14 m). The retort geometries for recent burns were similar to that shown in Figure 1.

The horizontal in situ process, as employed by GKI, wherein the porosity and permeability necessary for retorting is introduced by overburden uplift during blasting, has been successful in the production

of shale oil, as shown in Table 1.⁽²⁾ Recovery, based on the quantity of oil in the shale, has been on the order of 40-50% of Fisher Assay. This has demonstrated the oil production capability of this method, although gas losses through the overburden have been a problem.

Future efforts in the LOFRECO program will concentrate on regions with increased overburden thickness, together with gaining a greater understanding of the blasting and retort processes so as to maximize oil production per ton of shale. To this end, GKI will be retorting full scale modules of commercial retorts during 1980 via a pragmatic approach; Sandia will conduct a small retort (GKI Retort #22) as a scientific test module.

III. EXPERIMENT OBJECTIVES

The overall objective of burning GKI Retort 22 is to increase the understanding of the horizontal in situ retorting process, which, in turn, should lead to increased efficiency and greater oil yield. Specific technical objectives are to:

1. Determine spatial distribution of the retort and correlate this with the results of the post-blast formation assessment.
2. Quantify gas losses and their effect on over-all yield, e.g., percent injected air versus percent produced gas lost.
3. Determine intra-retort dynamics and local retorting efficiency, e.g., block versus packed bed, oil versus char combustion.
4. Determine effect of variations in injected gas compositions and rates on retorting efficiency and rates. Specifically, the effects of the addition of combusted recycle gas will be examined.
5. Determine the usefulness of point variation in the injected gas rate and/or composition for obtaining or maintaining spatial control of the combustion front.

A secondary set of objectives, relating to the determination of the viability of various analytical and instrumentation techniques are to:

1. By comparison with independent measurements, determine the usefulness of retort off-gas analyses (e.g., material balance, alkene/alkane ratios) as retort diagnostics.
2. Determine relative merits of various thermocouple materials in the retort environment.
3. Investigate the viability of the inverted thermocouple concept in an oil shale retort.
4. Determine the reliability of intra-retort gas sampling as a test diagnostic.
5. Utilize a data acquisition system for real time analyses of measured data.
6. Provide measurements for comparison of analytical models with test results, thereby determining the usefulness of the models as predictive tools.

Specific objectives may be modified as the experiment progresses, but the over-all purpose, to obtain in-depth scientific information, will be adhered to.

IV. BED PREPARATION

The rubble bed for Retort 22 was created by GKI in July 1979, by the detonation of slurry explosive in blast holes drilled from the surface. The uplift of the overburden induced by the explosives allows vertical and horizontal motion of the shale during the fracturing sequence and provides a rubblized zone. Measurements of the surface uplift versus time and the residual surface heave were made by Sandia. GKI performed pre- and postshot surface level surveys which also provided the residual surface uplift. Surface heave contours are

shown in Figure 2. Estimated void volume based on surface heave is $\approx 10\%$. Both the transient motion and residual heave measurements showed that the surface uplift was nearly uniform over the entire blast zones. Further, the maximum and residual surface uplift was less than recorded during the blasting of nearby retorts. (This was in accordance with the blast design.) As a result, gas losses through the overburden during retorting may be less, permitting more accurate retort material balance calculations.

V. FORMATION ASSESSMENT

Five post-blast cores were extracted by GKI at the locations and orientations shown in Figure 3. These cores have been analyzed by the GKI geologist. The core analyses will be coupled with other formation assessment measurements for use in the selection of downhole instrument locations and process parameters. Additional cores will be taken during the drilling of instrument wells to provide data regarding the degree of rubblization at particular instrument locations. Cores will also be used to determine the vertical distribution of shale grade and mineral content in the vicinity of the retort.

Airflow pressure tests and krypton 85 tracer tests will be conducted. Tests with the Sandia downhole injection/detection system (Figure 4) will be made in the process and observation wells (Figure 3). These measurements should provide information regarding the vertical distribution of the active void volume. Tracer tests utilizing the LETC ^{85}Kr tracer system will be conducted to ascertain estimates of the lateral uniformity of the airflow versus the distance along the retort and active void volume prior to (cold flow) and during (hot flow) retorting. These estimates of active void volume will be used for selection of instrument locations and specification of process parameters (e.g., flow rates).

Geophysical (e.g., gamma-gamma density, neutron porosity) logs will be made in and around the rubblized zone. This will provide comparative measurements of the degree of fracturing as well as baseline data regarding the relative merits of evaluating rubble in oil shale with these techniques.

VI. INSTRUMENTATION PLAN

The instrumentation plan is designed to meet specific, as well as over-all, experiment objectives as discussed in Section III. The general plan, as presented herein, will be used for procurement of hardware and definition of the data acquisition requirements. The final design layout, (e.g., specific levels of thermocouple and gas sampling ports) may be adjusted as appropriate in response to the results of the formation assessment. The plan is presented in two categories; in-formation (downhole) and surface instrumentation.

A. Downhole Instrumentation

Downhole instrumentation consisting of thermocouples and ports for pressure and gas sampling measurements will be emplaced in 26 vertical wells and one slant well ($\approx 30^\circ$), as depicted in Figure 5 and listed in Tables 2 and 3. The thermocouples will be spaced through the retorting zone and for a distance up into the overburden (Figure 6). Each well will have either six or ten 1/8 inch diameter 310 stainless steel sheathed, high temperature ($\approx 2000^\circ\text{F}$ maximum) thermocouples, spaced at either 3-feet (1 m) or 6-feet (2 m) intervals, depending on the particular well location. In addition, either two or three low temperature sheathed ($\approx 500^\circ\text{F}$ maximum) thermocouples will be placed in the overburden to determine the thermal effects near the surface. The base of the retort zone dips approximately 15 feet (4.5 m) through the total retort length; hence, the thermocouple strings will be shifted downward approximately 3 feet (1 m) per 25

feet (4.5 m) of retort length. The shifting of the thermocouple levels along the retort coupled with a nominal three foot spacing insures complete coverage of the retort zone while providing constant levels with respect to the base of the zone, simplifying analyses.

As shown in Figures 5 and 6, inverted thermocouple strings will be emplaced in three wells. Each string will have eight thermocouples; which, together with a string of six thermocouples emplaced from the surface, will provide more complete vertical coverage of the retort zone in these wells. The inverted thermocouple strings will be terminated at transmitters emplaced below the retort zone. The thermal signals will be transmitted to dual receivers located in wells outside the retort (Figure 5). The receivers will be hard-wired to the data acquisition system. The inverted thermocouple system used will be an improved version of equipment successfully tested in the Hoe Creek III Underground Coal Gasification test (3) and will be the first application of this technology in oil shale retorting. The improvements to the system will allow resistance diagnostics to be made on the thermocouples.

Intra-retort pressure and gas sampling ports will be emplaced in 14 wells, (Figure 5). Two 1/2 inch diameter pipes will be installed in each of these wells, with one sample port in each pipe at the levels listed in Table 3. The pipes will be terminated at the surface with pressure transducers and valves to permit "grab samples" of in-formation gasses. In eleven wells, the two sample ports will be at two discrete levels within the retort zone; in three wells one of the sample ports will be in the overburden for use in investigating the nature of gas losses.

B. Surface Instrumentation

The surface instrumentation will permit measurement and analyses of the process and reaction parameters, e.g., injection and production

gas flow rates, gas compositions, and oil and water production. A sketch of the surface layout, modeled after GKI Retort 17, is shown in Figure 7. The final process and instrumentation drawing (P&ID) will be coordinated with GKI.

The insertion gas flow system will provide the capability of delivering either air or a mixture of air and combusted recycle gas to the injection wells. Flow measurements will be made in the recycle lines upstream of the blowers, and in the combined gas injection lines between the blowers and each injection well. The flow section provides for measurement of the differential pressure, absolute pressure and gas temperature. The production gas flow will be measured in the same manner with flow sections in the lines between each gas production well and the demist equipment and in the total gas production line downstream of the demist system.

Combined on-line and grab-sample ports will be installed in the flow lines to each injection well and in the production flow line downstream of the demist system. These lines will permit analysis of the air-recycle mix in the inlet stream and the production gases. This will allow on-line real time analysis of the retort gasses, with the grab sample as backup. The on-line sample ports will be connected to a gas chromatograph which, in turn, is linked directly to the data acquisition system.

The oil-water collection system, as used by GKI, will be installed for this retort. The interface of this system with the data acquisition system will be by manual entry, with the possible exception of the oil-water flow measurement.

VII. DATA ACQUISITION SYSTEM

The data acquisition system, housed in a Candia instrumentation trailer, will include a field cable termination board, zone

boxes, signal conditioners, and a central data collection and storage system. The central data collection system will consist of a primary system utilizing a Modcomp computer and associated peripheral equipment, with data loggers for backup data collection. The primary data to be acquired will consist of thermal measurements from ≈ 300 thermocouples, pressure from ≈ 36 pressure transducers, computed flow measurements, and gas analyses from the on-line gas chromatograph. Additional retort information, such as oil-water production and gas analyses from the 26 "grab-sample" gas ports on the instrument wells, will be added to the central data acquisition and storage system manually.

The primary data acquisition-storage system will permit sampling all or a portion of the temperature and pressure points at variable rates. Gas analyses from the on-line gas chromatograph will be sampled at a variable rate with a typical frequency of one hour. These include the species O_2 , N_2 , Ar, CO, CO_2 , CH_4 , C_2H_4 , C_2H_6 , C_3H_6 , C_3H_8 , C_4 , and C_5 .

The computer system will provide a range of data listing and plotting capabilities. These will include time histories of data, well thermal profiles, and pressure and temperature contours at discrete times.

In addition to raw data, certain computed quantities, such as those that would result from material and energy balances, will be stored in the system. The status of all thermocouples will be monitored through loop resistance diagnostics. A display of the current functional thermocouples will be available at all times. All user programs pertaining to data acquisition, manual data entry, plotting, listing, analysis, etc. will be organized into a tutorial system that will be user oriented (e.g., simple and convenient).

VIII. OPERATIONAL PLAN

The guidelines for the conduct of the retort attempts to address the experiment objectives as closely as is possible consistent with the site facilities. The preliminary plans are also sufficiently flexible to be adjusted as deemed advisable through the retorting period. The operational plan outlined herein assumes individual control of the two injection flow rates and the capability to inject various percentages of a combined off-gas/air mixture. The rubble zone of Retort 22 has a cross-sectional area of approximately 1150 ft². A blower system with the capability to inject at superficial gas velocities up to 1.5 ft/minute (e.g., 1800 scfm, ~900 scfm in each well) is assumed to be available.

The proposed operating conditions, based on the above assumed airflow capabilities and estimates of associated retorting rates, are presented in outline form in Table 4. In general, the plan is for ignition and establishment of combustion, burning with air injection until the flame front has proceeded about one-third of the way along the retort, addition of recycle gas through the middle third of the retort, and air only injection through the remainder of the retort. Modifications to the general plan may be addressed, based on gas losses, retorting rates, material and energy calculations, etc.

FIGURE 1. PLAN AND ELEVATION VIEWS OF A TYPICAL HORIZONTAL IN SITU RETORT.

FIGURE 2. PLAN VIEW OF GKI RETORT 22 SHOWING POST-BLAST
SURFACE HEAVE CONTOURS.

FIGURE 3. PLAN VIEW OF GKI RETORT 22 SHOWING LOCATION OF CORE WELLS AND RETORT PROCESS AND OBSERVATION WELLS.

SAMPLE TRACER DATA

RAW TRACER DATA
showing effect of flow in recovery
wellbore

REDUCED TRACER DATA
(with wellbore effect removed)
showing flow entry points

DQWNHOLE TRACER SYSTEM is used to study flow through coal and oil shale seams in situ. A pulse of Kr^{85} is introduced in the injection well at the top of the seam, and the arrival of that pulse in the recovery well is measured at four or more locations. Data can provide information on the number of flow paths and their location, size, and character (fracture, rubble, etc.) as well as a flow log of the recovery well.

FIGURE 4. SKETCH DEPICTING OPERATION OF DOWNHOLE TRACER SYSTEM.

FIGURE 5. PLAN VIEW OF INSTRUMENT WELL LOCATIONS, GKI RETORT 22.

FIGURE 6. ELEVATION VIEW OF INSTRUMENT WELLS. ELEVATIONS ARE M.S.L.

FIGURE 7. SKETCH OF SURFACE INSTRUMENTATION, GKI RETORT 22.

Table 1
Summary of Data on GKI Retorts 1 through 24 (to 12/31/79)

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	-	-
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	3775
18	7/78	17	27	108	156	1800	19000	11/79	-
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	125	1150	7700	-	-
23	9/79	24	36	50	125	1200	8000	-	-
24	11/79	28	45	217	230	6076	94000	-	-

Table 2

Downhole Thermocouple Locations. The Z Coordinate in Each Well Is The Distance In Feet Above 6640 Feet M.S.L. Underlined Depths Denote Low Temperature Thermocouples.

WELL	X	Y	Z															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	5.0	-6.25		23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0	47.0	50.0				<u>60.0</u>	<u>70.0</u>
2	5.0	6.25		23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0	47.0	50.0				<u>60.0</u>	<u>70.0</u>
3	17.5	-17.5		23.0		29.0		35.0		41.0		47.0		53.0			<u>60.0</u>	<u>70.0</u>
4	17.5	0			26.0		32.0		38.0		44.0		50.0		56.0		<u>60.0</u>	<u>70.0</u>
4I	17.5	0	20.0	23.0	26.0	29.0	32.0	35.0	36.5	39.5								
5	17.5	17.5		23.0		29.0		35.0		41.0		47.0		53.0			<u>60.0</u>	<u>70.0</u>
6	30.0	-25.0		20.0		26.0		32.0		38.0		44.0		50.0			<u>60.0</u>	<u>70.0</u>
7	28.5	-12.5		20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0		47.0		53.0		<u>60.0</u>	<u>70.0</u>
8	32.5	-12.5				26.0		32.0		38.0		44.0		50.0		56.0	<u>60.0</u>	<u>70.0</u>
8I	32.5	-12.5	17.0	20.0	23.0	26.0	29.0		35.0	36.5	39.5							
9	30.0	10.0		20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0		47.0		53.0		<u>60.0</u>	<u>70.0</u>
10	30.0	25.0		20.0		26.0		32.0		38.0		44.0		50.0			<u>60.0</u>	<u>70.0</u>
11	42.5	-32.0		20.0		26.0		32.0		38.0		44.0		<u>50.0</u>			<u>60.0</u>	<u>70.0</u>
12	42.5	-16.0		20.0		26.0		32.0		38.0		44.0		50.0			<u>60.0</u>	<u>70.0</u>
13	42.5	0.0		20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0		47.0		53.0		<u>60.0</u>	<u>70.0</u>
14	42.5	20.0		20.0		26.0		32.0		38.0		44.0		50.0			<u>60.0</u>	<u>70.0</u>
15	55.0	-19.5			20.0		26.0		32.0		38.0		44.0		50.0		<u>60.0</u>	<u>70.0</u>
16	55.0	-10.0			20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0		47.0		53.0	<u>60.0</u>	<u>70.0</u>
17	54.0	5.0			20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0		47.0		53.0	<u>60.0</u>	<u>70.0</u>
18	58.0	5.0						29.0		35.0	38.0	41.0		47.0		53.0	<u>60.0</u>	<u>70.0</u>
18I	58.0	5.0	14.0	17.0	20.0	23.0	26.0		32.0	35.0	36.5							
19	55.0	17.5			20.0		26.0		32.0		38.0		44.0		50.0		<u>60.0</u>	<u>70.0</u>
20	55.0	30.0			20.0		26.0		32.0		38.0		44.0		50.0		<u>60.0</u>	<u>70.0</u>
21	80.0	-24.0		17.0		23.0		29.0		35.0		41.0	44.0		<u>50.0</u>		<u>60.0</u>	<u>70.0</u>
22	80.0	-12.5		17.0	20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0		<u>50.0</u>		<u>60.0</u>	<u>70.0</u>

Table 2 (cont.).

	<u>X</u>	<u>Y</u>	<u>Z</u>															
WELL			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
23	80.0	20.0		17.0	20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0		<u>50.0</u>		<u>60.0</u>	<u>70.0</u>
24	92.5	-8.5		14.0		20.0		26.0		32.0		38.0		44.0		<u>50.0</u>	<u>60.0</u>	<u>70.0</u>
25	92.5	8.5		14.0		20.0		26.0		32.0		38.0		44.0		<u>50.0</u>	<u>60.0</u>	<u>70.0</u>
26	-15.5	0.0		26		32		38		44		50						

TS-1 Slant (30°) Well

100.3 -4.0 @ z = 82.5 [Y = -4.0 for all points, X = 100.3 - $\frac{1}{\sqrt{3}}$ (82.5 - z)]

x		62.5	64.2	66.0	67.7	69.4	71.2	72.9	74.6	76.4	78.1		81.6			87.3	93.1
z		17.0	20.0	23.0	26.0	29.0	32.0	35.0	38.0	41.0	44.0		<u>50.0</u>			<u>60.0</u>	<u>70.0</u>

Thermocouple totals

High Temp 220

Low Temp 63

Table 3

Gas Sample Port Locations

The position in each well is the
distance in feet above 6640 M.S.L.

Well	Coordinates				
	X	Y	Z1	Z2	Z3
3	17.5	-17.5	29.0	41.0	
5	17.5	23.0	23.0	29.0	
7	28.5	-12.5	29.0	38.0	
9	30.0	10.0		38.0	60.0
11	42.5	-32.0	26.0	38.0	
12	42.5	-16.0	26.0	38.0	
14	42.5	20.0	26.0	38.0	
16	55.0	-10.0	26.0	38.0	
17	54.0	5.0	26.0	38.0	
20	55.0	30.0	26.0	38.0	
22	80.0	-12.5		35.0	50.0
23	80.0	20.0		35.0	50.0
24	92.5	- 8.5	20.0	32.0	
25	92.5	8.5	20.0	32.0	

Total = 28 ports in 14 wells

Table 4. Operation Plan

Day of Test	Test Conditions
0	Ignition by propane burner.
0 - 5	Ignition phase air injection (200-400 scfm/per well)
~5 - 25	Steady air burn. Injection rates dependent upon vertical cross section taking flow. Once true flow cross section is estimated, the flow rate will provide for SGV of 1.5 ft/min. Will probably be in the range 1200-1800 scfm total injection.
~25 - 60	Recycle test. After the combustion-front has progressed past the first thermocouple well doublet, recycle gas will be introduced. The target should be to maintain same SGV as with airburn but reduced with O ₂ mole fraction to the range 11-14%.
~60 - 90	Terminal phase once combustion front with recycle has passed second thermocouple well doublet. Air-only injection will be resumed. The injection rates will be determined as a function of gas loss rate, active vertical flow cross section and modeling calculations to maximize yield.

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