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ENVIRONMENTAL ANALYSIS OF THE EASTERN SHALE HYDRORETORTING DATA BASE

By
R. C. Rex, Jr.
P. A. Lynch

May 1984

Work Performed Under Contract No.: DE-AC20-83LC11039

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

By
Hycrude Corporation
Chicago, Illinois

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EXECUTIVE SUMMARY

HYTORT® is a process utilizing non-catalytic hydrogenation of the kerogen in oil shale for the production of a middle distillate synthetic crude oil. The retorting of oil shale in a hydrogen-rich atmosphere at elevated pressures, termed hydrotretorting, enables attainment of the maximum possible oil yields from oil shales. With the Eastern U.S. Devonian oil shales, which are relatively deficient in hydrogen, HYTORT processing can more than double the oil recovery compared to conventional, thermal retorting processes.

The promising results of early experimental work led to a DOE contract in 1979 for the technical and economic verification of the HYTORT process. Upon subsequent completion of the DOE program, a development agreement was entered into between HYCRUDE Corporation and Phillips Petroleum Company in 1980. The HYTORT Feasibility Study (involving HYCRUDE, Phillips Petroleum Company, IGT, and Bechtel Group, Inc.) was conducted to provide the necessary process chemistry and process physics information for the development of a preliminary demonstration module design and a preliminary commercial plant design and economics. The feasibility study, completed in May 1983, verified the technical and economic feasibility of the HYTORT process. The process chemistry portion of the feasibility study, primarily conducted in a continuous bench-scale unit to investigate the effects of operating parameters on oil yield, provided the extensive data base utilized in the present study.

The purpose of this study is to perform a preliminary environmental analysis of certain chemical aspects of Eastern shale hydrotretorting utilizing the data from the twenty-one (21) bench scale

unit runs conducted during the HYTORT Feasibility Study. The report contained herein primarily addresses the potential types and quantities of pollutants emanating directly from the hydrotreating of oil shale (i.e., the retort proper). The following areas are discussed in detail:

- Nitrogen distribution
- Sulfur distribution
- Gas trace constituents
- Sour water constituents
- Shale leachates.

The results of the analysis have not identified any potential pollutants or quantities which cannot be brought to conformance with currently promulgated environmental standards using existing technology.

Additional analysis of the process chemistry portion of the HYTORT data base, coupled with the process and mechanical design information, can provide a methodology for dealing with the identified environmental concerns as they pertain to a commercial facility. Section 5.0 of the report delineates the areas which should be addressed in a continuing analysis of environmental concerns. The suggested program divides naturally into three phases, of which Phase 1 has been completed:

- Phase 1 - Environmental Analysis of the Eastern Shale Hydrotreating Data Base
- Phase 2 - Generic (non-site-specific) Environmental Analysis
- Phase 3 - Site-Specific Environmental Analysis.

Phase 2 details the anticipated emissions from all areas of a commercial HYTORT facility operating on a typical Eastern shale using the results of this Phase 1 effort and the HYTORT data base. Phase 3 utilizes this information to assess the effects of plant emissions on chosen sites in the context of applicable laws and regulations.

1.0 INTRODUCTION

This study is a preliminary environmental analysis of the most recently available data for the HYTORT oil shale retorting process. In the HYTORT process, synthetic crude oil and hydrocarbon gases are produced by retorting oil shale in a countercurrent moving bed reactor in the presence of hydrogen at elevated pressure.

Figure 1 is a schematic diagram of a conceptual commercial HYTORT reactor. It is a countercurrent moving bed reactor which consists of three distinct zones: shale preheating, shale retorting, and shale cooling. In the preheat zone, oil shale is heated to 700°F - 750°F by contact with a hydrogen-rich recycled gas which has been heated in an indirect fired heater outside the retort. In the retorting zone, the maximum bed temperature is 950°F - 1000°F, and in the cooling zone, the sensible heat of the spent shale is recovered by contact with cool hydrogen-rich recycled gas. The product gas from the preheating and retorting zones is combined and sent through gas clean-up equipment. Excess hydrocarbon gas is used to help meet overall plant fuel requirements, while the remaining "recycle gas" is returned to the reactor. Preliminary conceptual plant designs include facilities for the removal of hydrogen sulfide, ammonia, and other potential pollutants from the product gas and sour water produced during oil shale retorting.

In order to obtain a preliminary conceptual commercial plant design which realistically evaluated process economics, it was necessary to study both process chemistry and process physics for the particular oil shale (Indiana New Albany) which was the subject of the study. This was accomplished by the recently completed HYTORT Feasibility Study. The process physics was studied in a newly constructed six foot diameter Cold

Figure 1. Commercial HYTORT Reactor Configuration

Flow Model (CFM) and the concept of the three zone reactor shown in Figure 1 was verified.

Previous data on HYTORT process chemistry (References 1 and 2) was used as the starting point for optimization of the hydrotorting process for Indiana New Albany shale. A 250 lb/hr Bench Scale Unit (BSU) was used to optimize process operating conditions.

A total of twenty-one BSU tests on Indiana New Albany shale were made during the course of the Feasibility Study. These tests investigated the effects of varying process operating conditions over a wide range. The resulting data base is the foundation for this preliminary environmental study. The distribution of sulfur and nitrogen is evaluated over the range of operating conditions. On some of the runs an Environmental Sampling Train was operated and the results of these tests are presented and discussed. An EPA leachate test was performed on the spent shale from the run which most closely duplicates process conditions utilized in the conceptual commercial plant designs. Data on trace contaminants in the sour water is also presented and discussed.

Although it is realized that data obtained in a 250 lb/hr bench scale unit primarily defines the retorting area of a commercial scale plant, it is important to identify and quantify the potential liquid, solid, and gaseous by-products formed during hydrotorting. In turn, this data provides the retorting area design for inclusion into commercial plant designs which allow a realistic assessment of the environmental concerns associated with HYTORT processing.

Environmental protection for oil shale retorting will depend upon a number of factors such as a complete understanding of the existing environment which may be impacted by individual oil shale retorting plants.

It is also necessary to determine the quantity and quality of liquid, solid, and gaseous by-products so that disturbance of the environment, if any, can be predicted and prevented or mitigated.

Environmental regulations and the BSU are discussed in Section 2.0 and Section 3.0 to provide a reference framework for the subsequent analysis of the HYTORT data base contained in Section 4.0. Section 4.0 provides a comprehensive analysis of the BSU portion of the HYTORT Feasibility Study data base to identify potential pollutants from the hydrotretorting of a specific Indiana New Albany shale. When assessing the results contained in Section 4.0 it is important to remember that hydrotretorting of Eastern shales requires significantly less raw shale per unit of oil produced compared to thermal retorting of the Eastern shales due to the increased oil yields obtained by hydrotretorting. In fact, results of hydrotretorting on Indiana New Albany shale indicate that hydrotretorting utilizes 40 percent to 50 percent less raw shale per unit of oil than conventional thermal retorting. This not only impacts land use, but mitigates overall environmental concerns through the reduction of potential pollutants from process areas and reduction of potential leachates from spent shale. This aspect of hydrotretorting casts a much more favorable light on the development of an Eastern oil shale industry utilizing hydrotretorting rather than conventional thermal retorting.

The final section deals with methods for addressing environmental concerns by taking advantage of the existing wealth of information contained in the HYTORT Feasibility Study data base. Using this "Phase 1" study as the basis for a continuing effort, Section 5.0 outlines a program to provide a definitive assessment of environmental concerns which must be addressed by an Eastern oil shale industry. The suggested

program briefly indicates items which should be addressed to obtain a comprehensive environmental analysis. The work divides naturally into two phases; Phase 2 - Generic (non-site-specific) Environmental Analysis, and Phase 3 - Site-Specific Environmental Analysis.

2.0 ENVIRONMENTAL REGULATIONS

Federal, state, and local pollution control laws will provide the guidelines for substances which have potential environmental impact. The collection and organization of information from a wide range of retorting activities into a coherent data base provides the information necessary to identify these materials associated with oil shale retorting that are regulated by pollution control laws.

The Federal pollution control laws which concern air and water quality and the disposal of solid and hazardous wastes are outlined in Tables 1 through 5.

The Clean Air Act of 1977 requires compliance with the National Ambient Air Quality Standards shown in Table 2. Of particular interest to the oil shale industry in general will be sulfur dioxide, carbon monoxide, hydrocarbons, and NO_x . Both primary and secondary standard levels are shown with required averaging time periods. The Clean Air Act also requires the prevention of significant deterioration as shown in Table 3 for particulate matter and for sulfur dioxide.

It should be noted that when utilizing the HYTORT process for shale retorting, no sulfur dioxide or NO_x formation is experienced in the retort because there is no combustion of shale or gas. Any heat required is supplied to the process by indirectly heated recycle gas, thereby eliminating the presence of combustion products in the retort off-gases. However, a portion of the sulfur and nitrogen which is present in the feed shale does end up in the product gas and sour water and must be removed from the gas prior to combustion and from the water prior to recycle or discharge. The distribution of sulfur and nitrogen in residue shale, oil, and product gas is therefore examined in detail. The amounts of these

components in the sour water produced in the BSU is also examined.

Although the composition of sour water in a commercial scale plant will be different due to process conditions and the addition of effluent streams from ancillary process areas, the BSU data provides identification of nitrogen and sulfur compounds, and trace constituents formed during hydroretorting of Eastern oil shale. This will provide an indication of environmental concerns which must be addressed in a commercial facility.

The quality of water discharged from the process is regulated by both the Clean Water Act Amendment of 1977 and the Safe Drinking Water Act of 1974. The trace constituents of the sour water produced during the BSU tests are identified in Section 4.4 of this report.

Solid wastes from the process (i.e., spent shale from the retort) must meet limits set by the Resource Conservation and Recovery Act of 1976 and may also be affected by EPA regulations. An EPA leachate test was performed on the spent shale from the BSU test which was made at the most economical operating conditions. The leachate test results are presented in Section 4.5.

The legislation of individual states generally parallels Federal legislation in form and substance and the Federal government retains an oversight reviewing role for those state delegated programs.

Although the HYTORT Feasibility Study utilized a New Albany shale from Indiana as a feedstock, the potential pollutants identified in this study would be expected to be found when other Eastern oil shales are hydroretorted; however, the levels of these constituents may vary significantly depending on the particular feed shale. Likewise, the absence of a particular pollutant based on the data used in this study does not ensure that it will not be formed when other Eastern shales are hydroretorted.

The data in this study are evaluated in light of general Federal regulations. An environmental study for a particular plant site is beyond the scope of this report.

Table 1. Federal Air Pollution Control Regulations

Clean Air Act Amendments of 1977

(PL-95-95)

1. Employ Best Available Control Technology (BACT).
2. Assure compliance with National Ambient Air Quality Standards (NAAQS).
3. Comply with Prevention of Significant Deterioration (PSD) requirements.
4. Do not significantly degrade visibility in mandatory Class 1 areas.
5. Comply with baseline data monitoring requirements as specified by EPA.

Table 2. National Ambient Air Quality Standards^{1,2}

<u>Pollutant</u>	<u>Averaging Time</u>	<u>Primary Standard</u>	<u>Secondary Standard</u>
SO ₂	Annual	80	60
	24 hour	365	---
	3 hour	---	1300
NOx	Annual	100	100
CO	8 hour	10,000	10,000
HC (non-CH ₄) ³	3 hour	160	160

1. Allowable levels - milograms/cubic meter.
2. Volume 40 of the Federal Register (40 CFR 50).
3. Not a standard - a guide to show achievement of the ozone standard.

Table 3. Prevention of Significant Deterioration of Air Quality Standards¹

<u>Pollutant</u>	<u>Class I</u>	<u>Class II</u>	<u>Class III</u>
<u>Particulate Matter</u>			
Annual geometric mean	5	19	37
24-hour maximum	10	37	75
<u>Sulfur Dioxide</u>			
Annual arithmetic mean	2	20	40
24 hour maximum	5	91	182
3 hour maximum	25	512	700

1. Maximum allowable increases (micrograms per cubic meter).

Table 4. Federal Water Pollution Control Regulations

Clean Water Act Amendments of 1977

(PL-95-217)

1. Provides mechanism for establishing water quality stream standards.
2. Requires a National Pollution Discharge Elimination System (NPDES) permit to be issued in all cases where water is to be discharged into a navigable stream.
3. Provides control practices for non-point source runoff.

Safe Drinking Water Act of 1974

1. Provides underground injection control (UIC) regulations which govern injection or reinjection of any fluids.
2. Specifies monitoring and mitigation measures to prevent pollution of the groundwater system.

Table 5. Federal Solid and Hazardous Wastes Control Regulations

(PL-94-580)

1. Requires permits for safe disposal to be obtained from U.S. EPA or state. May cover processed shale, spent catalysts, process wastes and sewage wastes.

U.S. EPA (40 CFR 261.7 as modified, 1982)

1. Exempts many substances from hazardous waste regulation until special provisions can be developed, specifically substances that are:
 - a) being beneficially used or re-used or legitimately recycled or reclaimed.
 - b) being accumulated, stored, or physically, chemically, or biologically treated prior to beneficial use or re-use or legitimate recycling or reclamation.

3.0 BENCH SCALE UNIT

The objective of the BSU test program was to further study the basic process chemistry of oil shale hydroretorting and the effects of selected process variables on the behavior of a specific Indiana New Albany shale in a countercurrent moving-bed retort.

During the course of the test program, twenty-one runs were made which achieved steady-state operation. The entire test program was subdivided into three phases:

- Phase I - Investigated effects of heat-up rate and maximum bed temperature.
- Phase II - Investigated the effects of maximum temperature at two levels of shale residence time.
- Phase III - Investigated the combined effects on oil yield and quality of the following variables: four different pressure levels, high shale mass flux, shale residence time at temperature, and shale preheat.

Phases I and II were statistically designed. The Phase I test matrix consisted of eight runs. Four of the runs were performed to investigate the effects of two levels of shale heatup rate and two levels of maximum bed temperature. The remaining four runs were replicates of the first four runs, which provided an estimate of experimental error. This estimate of experimental error includes the errors inherent in the equipment and the methodology used in performing the test program. Statistical analysis of any experimental program assumes the following: 1) the measured experimental error will remain constant for the length of the test program, 2) the variables being studied have a normal distribution, and 3) the variables are independent. Phase II also consisted of three runs while

Phase III was comprised of the remaining ten runs. Table 6 shows the twenty-one BSU tests which were performed during the feasibility study.

The variable identification for Table 6 is as follows:

- LETID - Letter identification of run for plotting
- RUNID - Run identification number
- TPRESS - Total Pressure - psia
- MAXT - Maximum bed temperature - degrees Fahrenheit
- TOTREST - Total shale residence time - minutes
- PRHT - Preheat identification
- TOCS - Total organic carbon conversion - weight percent

3.1 Equipment

Figure 2 is a flow diagram of the BSU, which consists primarily of a reactor with associated equipment for feeding and measuring the flow rates of feed shale and feed gas, and for collecting and measuring the flow rates of residue shale, liquid products, and product gas. The maximum capacity of the unit is 250 pounds per hour of raw shale feed. The shale-gas contacting occurs in a truly continuous, countercurrent manner.

A pressurized raw shale feed hopper is filled with sufficient shale for the entire run. The shale is fed by a screw feeder, where it enters the top of the reactor and is preheated by countercurrent contact with the hot product gases formed during retorting. The residue spent shale is discharged from the bottom of the reactor into a pressurized residue receiver by a second screw feeder. The residue shale is cooled by countercurrent contact with cold hydrogen feed gas.

The reactor itself consists of a cold pressure shell (24 inches in internal diameter and 23 feet in length) containing an internal reactor

Table 6. Bench Scale Unit Test Program

HYTORT FEASIBILITY STUDY
BENCH SCALE UNIT TEST PROGRAM

LETID	RUNID	TPRESS	MAXT	TOTREST	PRHT ¹	TOCC
A	8201	1039	995	57	0	85.44
B	8202	1012	1000	57	0	85.28
C	8205	1009	1260	59	0	87.96
D	8206	1014	1250	60	0	84.95
E	8207	1011	1000	58	0	84.48
F	8209	1021	1220	59	0	86.53
G	8211	1011	1240	57	0	87.05
H	8212	1024	1000	59	0	80.73
I	8213	1003	850	30	0	67.86
J	8214	1001	1000	31	0	82.57
K	8215	1018	850	62	0	74.30
L	8218	1018	961	46	1	84.86
M	8219	610	965	47	1	78.82
N	8220	816	980	47	1	79.92
O	8221	609	1121	46	1	80.19
P	8222	816	960	47	1	79.33
Q	8223	1017	1020	21	1	50.98
R	8224	1003	1035	21	1	75.27
S	8225	1017	974	28	1	77.81
T	8301	415	1048	47	1	69.84
U	8302	423	1050	49	1	70.41

N=21

1. Preheat identification: 0 = without shale preheating
1 = with shale preheating

Figure 2. Bench Scale Unit

tube (Incoloy 800, 4 inches ips, Schedule 40) which is heated by a seven-zoned Kanthal electric heater. Each heater is 31 inches long and has an internal diameter of about 7 inches. The temperature of each zone is controlled individually by separate temperature controllers. The space between the reactor outer wall and the electric heater is packed with refractory fiber insulation. The pressure between the heated reactor tube and the cold pressure vessel shell is controlled by a pressure-balancing system which keeps the pressures inside and outside of the reactor nearly equal to avoid rupturing the reactor tube when hot. The pressure balancing system works by bleeding nitrogen either into or out of the insulated space to equalize the pressures.

Feed gas enters the bottom of the reactor above the residue shale discharge screw through a dip tube. The exiting product gas also leaves through a dip tube which extends down into the top of the reactor. The product gas dip tube contains a sintered metal bayonet filter that is positioned at the bottom of the second heating zone.

The feed shale drops down yet another, larger dip tube which keeps the heavy liquids in the exit gas from condensing on the feed shale at the feed screw outlet and plugging the reactor tube.

A small purge flow of feed gas is continuously passed into the top of the reactor during tests to make up for the volume of shale which diminishes in the feed hopper during the course of the run and to prevent product gas from entering the feed hopper.

Both the reactor pressure and the bed pressure drop are continuously recorded, as are all reactor tube temperatures. A total of 32 thermocouples are attached to the outer tube wall along with six internal thermocouples. Four of the internal thermocouples were removed during the course of the feasibility study to increase the reliability of operation by allowing for the freer flow of

shale through the reactor tube. During steady-state operations, the wall thermocouple readings and the internal thermocouple readings were essentially equal. The internal thermocouples are enclosed in a 3/8-inch outside diameter thermowell and measure temperatures in the bed below the heated zones. The refractory fiber insulation which is wrapped around the reactor eliminates thermocouple radiation errors.

The flow rates of the hydrogen feed gas, the purge gas, and helium tracer gas are recorded continuously and are measured by orifice meters calibrated against the exit gas meter before each run. Mass flow meters are connected in series with each of the orifice meters and to individual electronic digital displays which input to board-mounted mass flow totalizers. The duplication of orifice meters and mass flow meters for each input gas stream provides checks on the gas flows to the BSU.

Both of the screw feeders are calibrated and the shale is fed to the reactor by setting the screw speed to the desired value. The rate of residue shale discharge is controlled automatically to maintain a constant shale bed level. The bed level is sensed by a nuclear-type gauge, the electrical signal output of which is converted to a pneumatic signal which is sent to the bed level recording controller. During operation, the bed level can be maintained within a few inches of the desired level. The full-scale range of the recording controller corresponds to a bed level variation of about three inches. The differential pressure across the bed is measured using a differential pressure cell and is recorded continuously. This provides a second check on the bed height.

Both feed and residue shale are weighed on a large trip beam scale with an arm balance, which is accurate to 0.1 pound. The raw shale consumed during the run is calculated by weighing the shale initially

charged to the feed hopper and that present at the end of a run. Feed and residue shale rates are calculated by dividing these weights by the measured shale feeding time. The residue receiver has a sample container inside for obtaining a residue shale sample during steady-state operation of the retort.

The exit gas volume is measured by two conventional iron-case-type direct-reading meters installed in series. An aliquot sample of the exit gas is taken by feeding a portion of it at a constant rate into a ten cubic foot water-sealed gas holder during the steady-state portion of each run. "Spot" samples are also taken throughout each steady-state test period. The exit-gas specific gravity is monitored continuously by a recording gravitometer. Board-mounted infrared analyzers provide analyses of selected gases. In addition, a process-type gas chromatograph is available to provide on-line analyses of additional gases.

An internal, 1-1/2-foot long, sintered stainless steel bayonet filter was installed prior to these tests to prevent solids elutriation. Although the filter mean pore size was 165 microns, some fine dust was carried out of the reactor. Although the exit gas usually is quite hot, some of the heavy liquids condense and are carried from the reactor along with some fine dust.

The exit gas is cooled in a single-stage condenser. The condensed liquids are then collected in a knockout pot. The pot is drained and the liquid is weighed at approximately 20-minute intervals during the steady-state portion of each run to obtain product rates. Steady-state is defined as a condition wherein the temperature profile in the shale bed is uniform; feed gas, purge gas, and exit gas flow rates are constant; reactor pressure is stable; and the shale feed rate and bed height remain essentially constant.

The reactor is filled with silica sand prior to each run to establish a stable temperature profile prior to the run, thereby avoiding rapid heating of the initial shale feed. This also prevents a varying bed height at the start of a run and subsequent problems with tar formation, and subjects all feed shale for a particular run to essentially the same time-temperature history.

The fine silica sand used in these tests is also weighed on the large trip beam scale. Liquid products from the runs are weighed on a small trip beam balance scale having 0.01 pound as the smallest division.

3.2 Equipment Modifications

Before Phase I testing began, modifications were made to the BSU to improve the quality of data gathered. Prior to the HYTORT Feasibility Study, numerous hydroretorting experiments were performed in the BSU. The importance of good overall material and elemental balances was emphasized from the start of the program. Accurate individual and elemental material balances aid in the formulation of commercial process designs and in elemental distribution studies required for environmental data analysis. Additionally, the carbon balance and the subsequent hydrogen consumption are particularly important in the examination of the economic feasibility of the HYTORT process.

It was recognized that three basic types of uncertainties (as distinct from systematic errors) associated with elemental balance closures have to be dealt with: uncertainties in flow measurement, uncertainties in sampling, and uncertainties in analyses. Based on BSU hydroretorting tests performed previously, an error propagation analysis was made which resulted in the addition of equipment which would reduce uncertainties in flow measurement and sampling as well as sample analysis.

The addition of mass flow meters (in series with orifice meters), a second product gas meter (in series with the first meter), and a helium tracer system improved gas flow measurements.

Product sampling and analysis equipment was also added to improve accuracy after the error propagation analysis was performed:

- Sampling train for sulfur and nitrogen species
- "Cold Finger" for product gas freeze-out sample
- Steady-state product shale sampler
- On-line infrared gas analyzer
- On-line gas chromatograph
- Flash gas measurement system.

Additional equipment installed to improve operation of the unit included a closed-loop bed level control system, electronic feed and discharge screw RPM indicators, a multipoint digital pressure gauge (0.1% accuracy), and an electronic temperature profiler.

In an attempt to improve oxygen balances, a new laboratory analytical method was developed for measuring reactable organic oxygen in the shale (Reference 3).

After the installation of equipment designed to improve the accuracy of measurements and reliability of BSU operation, two blank runs were conducted before the hydrotreating tests of Phase 1 were begun. The purpose of the first blank run was to determine the accuracy of the metered gas flows into and out of the reactor system. The run was made with an empty reactor at reaction temperature and pressure with hydrogen flow. It was determined that gas flows were measured with an accuracy of $\pm 1\%$.

In the second blank test, gravel was fed to the reactor to simulate shale movement without the heat effects which result from chemical reactions. Temperature controllers were set to obtain a nearly linear temperature profile in the reactor. The results of this test indicated that solids flow rates could be measured with an accuracy of $\pm 0.25\%$ over the course of a run. After completion of the second blank run, Phase I tests were begun.

3.3 Material Balance Closures

Table 7 shows the unadjusted elemental and overall material balances for the individual BSU runs performed during the Feasibility Study. The average overall material balance is quite good (98.7%).

An important statistical consideration was to force closure of all BSU material balances in a consistent manner for all runs. The method must be selected prior to beginning the test program to remove all bias from the statistical analysis.

In closing the material balances, it was decided that adjustment of the shale analyses was inadvisable for the following reasons:

- (1) It was not possible to assess the feed shale sampling error.

All BSU runs utilized shale from a 19-ton sample of Indiana New Albany shale. Although several samples of the 19-ton raw shale pile were originally obtained and analyzed, they were not prepared by riffing the entire 19 tons of shale.

Therefore, the variation between these samples as analyzed does not represent the variation which would be expected if multiple riffled samples were obtained of the feed for an individual BSU run.

Table 7. Unadjusted Elemental and Overall Material Balances¹
for Individual Bench Scale Unit Runs

-----Elemental Balances -----

<u>Run</u>	<u>Carbon</u>	<u>Hydrogen</u>	<u>Oxygen</u>	<u>Sulfur</u>	<u>Nitrogen</u>	<u>Overall Balance</u>
8201	93.5	101.3	103.7	97.1	94.1	97.8
8202	89.8	101.9	105.6	98.7	83.5	98.7
8205	96.1	99.0	104.6	97.7	88.0	99.7
8206	93.7	101.3	104.7	110.9	83.2	99.8
8207	96.2	100.2	107.9	101.5	94.8	99.7
8209	98.2	99.2	105.3	95.0	95.9	98.1
8211	94.6	100.9	107.4	107.0	83.5	99.1
8212	99.9	100.6	113.4	96.0	92.7	101.0
8213	96.8	100.4	102.4	97.6	94.1	100.4
8214	98.5	99.2	104.7	101.9	92.3	100.7
8215	92.6	99.1	99.2	107.4	89.1	97.2
8218	97.4	100.7	95.7	118.9	95.4	98.7
8219	96.7	99.8	99.3	98.7	92.7	96.9
8220	99.0	99.7	99.8	105.8	94.6	97.4
8221	99.1	98.9	97.6	85.4	90.1	97.1
8222	98.1	98.0	99.3	100.1	92.9	99.7
8223	93.3	98.4	103.0	108.4	91.1	98.4
8224	94.0	97.1	102.5	100.7	123.9	98.3
8225	101.0	97.1	102.5	106.7	92.0	98.8
8301	96.4	97.8	113.4	111.5	91.2	98.5
8302	95.9	99.9	114.0	90.3	89.5	97.0
Average	96.2	99.5	104.1	101.8	92.6	98.7

1. Reported percentages were calculated in the following manner:
(mass out/mass in) x 100.

- (2) There would be no logical basis for choosing whether the raw shale or the spent shale analysis (or both) should be altered. Since both raw and spent shale analytical techniques are identical, there is no reason to believe that a raw shale analysis should be altered while a spent shale analysis remains unchanged, or vice versa.
- (3) Since raw shale flow (which is the basis for the material balance) is essentially constant during the run, a change in the analysis of the shale will shift the pounds per hour of each component entering the reactor. Any change that would result in reducing feed shale carbon while leaving spent shale carbon unchanged (or which would reduce spent shale carbon while leaving feed shale carbon unchanged) would increase the calculated carbon conversion. Enhancement of the carbon conversion in this manner would not be conservative with respect to the development of commercial plant designs and costs.

Therefore, the first step of the material balance procedure is to adjust the spent shale discharge rate, without altering the reported analytical analysis, utilizing mineral matter as a tie component. This has a very minor affect, showing good agreement between observed and calculated spent shale rates. Table 8 shows the observed and calculated spent shale rates for each run.

What then remains is to balance the carbon, oxygen, nitrogen, and sulfur, and to calculate the resultant hydrogen consumption.

The results of the error propagation analysis discussed above indicated that there was relatively small sampling and analytical error for the hydrocarbon gases produced. It was therefore decided

that the adjustment to close the carbon balance would be made by increasing or decreasing the total amount of oil.

The oxygen is then balanced by adjusting the total reported water production. The adjustment is taken in water produced chemically. The raw shale moisture is assumed correct as reported, therefore, product water from shale moisture is never adjusted.

The sulfur balance is closed by adjusting the hydrogen sulfide, while the nitrogen balance is closed by adjusting ammonia production.

The total hydrogen content of the products (spent shale, sour water including ammonia and hydrogen sulfide, oil and hydrocarbon gases) and the feed components (except for free hydrogen) is calculated. The difference between these two Figures is the total calculated hydrogen consumption which is used for design purposes.

These systematically closed material balances provided the basis for the sulfur and nitrogen distribution studies contained in the following section and was utilized in preparing the final commercial plant process designs. Many different methods of closure were proposed during the HYTORT Feasibility Study prior to selection of the method utilized and delineated herein. It was generally agreed that the closure method selected provided adjustments that were consistent with HYCRUDE's knowledge of the process, equipment, and analytical techniques. Additionally, selection of plausible alternate material balance schemes should not grossly affect the sulfur and nitrogen distributions reported.

Table 8. Observed and Calculated Spent Shale Rates

<u>Run</u>	<u>Spent Shale Rate (lbs/hr)</u>		<u>Difference</u> ¹
	<u>Observed</u>	<u>Calculated</u>	
8201	63.2	64.9	2.7
8202	63.9	64.5	0.9
8205	63.7	63.7	0.0
8206	58.3	58.7	0.7
8207	63.3	63.4	0.2
8209	62.2	64.0	2.9
8211	61.0	62.3	2.1
8212	62.9	62.8	-0.2
8213	69.0	68.3	-1.0
8214	65.7	65.3	-0.6
8215	65.9	68.0	3.2
8218	66.4	67.1	1.0
8219	63.8	66.3	3.9
8220	64.7	67.3	4.0
8221	62.7	65.0	3.7
8222	65.5	65.2	-0.4
8223	210.1	213.7	1.7
8224	188.8	191.7	1.5
8225	157.4	159.1	1.1
8301	62.6	64.5	3.0
8302	60.0	62.9	4.8

Average (of absolute value) - 1.9

1. Reported value calculated in the following manner:

$$[(\text{calculated} - \text{observed})/\text{observed}] \times 100$$

4.0 ANALYSIS OF THE DATA BASE

Using the results from the twenty-one (21) BSU runs, a data base consisting of sixty-nine (69) parameters per BSU run was developed. Along with the run identifiers and operating parameters such as pressure, temperature, and shale residence time, the data base includes all solids, gas, and liquid flowrates and compositions. This comprehensive data base allows for the examination of specific variables or, as was often done, the examination of "secondary" calculated variables as a function of the various operating parameters. These "secondary" variables include percentages calculated for component distribution and the weights of potential pollutants generated per pound of dry raw shale.

The data base was assembled and placed in a computer file for analysis using SAS (Statistical Analysis System). SAS was developed by SAS Institute Inc., of Cary, North Carolina, and is available for telephone access through many computing companies in the United States. SAS is capable of arithmetic operations on the data set and generation of the results in a secondary data set for analysis. SAS contains procedures for sorting, plotting, and a myriad of statistical calculations along with the capability of report generation.

Once the data base was input to a computer file, SAS programs were written to ascertain that the data set was free of errors. These programs examined stream compositions for addition to 100 percent and mass balance by comparing the total input and output stream weights. After correction of data set errors, the data was re-checked to certify correctness. Analysis of the Eastern shale data base to

identify applicability of the data base in addressing environmental concerns was begun after validation of the data set.

4.1 Sulfur Distribution

A detailed discussion of the sulfur distribution in the hydroretorting product streams and identification of possible environmental concerns is given in this section. In general, the results indicate that the conversion of sulfur in the raw shale to oil and gas is fairly constant for all operating conditions. The weight percentage of conversion ranges from 47 to 59 percent with 4 to 6 percent of the raw shale sulfur going to the product oil, and the remainder to hydrogen sulfide. The maximum hydrogen sulfide production indicated was 0.025 pounds per pound of dry raw shale (50 pounds per ton of dry raw shale). The average value for commercial plant design conditions was in the area of 0.021 pounds per pound of dry raw shale (42 pounds per ton of dry raw shale).

The total conversion of raw shale sulfur to the product oil and gas in hydroretorting is less than conversions experienced in conventional thermal retorting technologies which include direct combustion. Additionally, since hydroretorting does not involve combustion, the product gases from the HYTORT retort do not exhibit a sulfur dioxide component. The range of hydrogen sulfide concentration in the untreated recycle gas for the commercial design envisaged in the HYTORT Feasibility Study is 300 grains per 100 SCF to 350 grains per 100 SCF. The currently available technology is capable of attaining adequate removal of the pollutant at these concentrations.

4.1.1 Analysis

To examine the sulfur distribution in the hydroretorting product

streams, the following data was generated (see Tables 9 and 10):

- Weight percent of sulfur to product oil and gas
- Weight percent of sulfur to hydrogen sulfide
- Weight percent of sulfur to oil
- Pounds of hydrogen sulfide produced per pound of dry raw shale.

In essence, this method of analysis assumes that the sulfur in the raw shale which is not contained in the oil or spent shale will be contained in the retort product gas in the form of hydrogen sulfide. This is a useful approximation for the study of general trends, and in fact, has almost no effect on the analysis since less than 1 percent of the raw shale sulfur ends up in trace constituents (see Section 4.3). Although BSU runs do produce a sour water stream, it is recognized that the particular composition of this stream is, to some extent, an artifact of the test equipment and operating temperatures. Therefore, the hydrogen sulfide content of the sour water was added to the retort product gas for the analysis presented in this section. This is equivalent to an analysis of potential pollutants from the retort proper, independent of the downstream process conditions. A separate analysis delineating the trace constituents identified in the BSU sour water is presented in Section 4.4.

The four (4) dependent variables identified above were plotted as a function of the following (see Tables 9 and 11):

- Total organic carbon conversion
- Maximum bed temperature
- Total shale residence time
- Ratio of hydrogen to shale
- Total pressure
- Hydrogen partial pressure.

Table 9. Sulfur Distribution Variable Identification

<u>Variable</u>	<u>Description</u>
LETID	Letter identification of run for plotting
RUNID	Run identification number
PS	Sulfur to products - weight percent
PSH2S	Sulfur to hydrogen sulfide - weight percent
PSOIL	Sulfur to oil - weight percent
LBH2S	Hydrogen sulfide production - pounds per pound of dry raw shale
TOCC	Total organic carbon conversion - weight percent
MAXT	Maximum bed temperature - degrees Farenheit
TOTREST	Total shale residence time - minutes
H2DRS	Ratio of hydrogen to shale - SCF per pound dry raw shale
TPRESS	Total pressure - psia
H2PRES	Hydrogen partial pressure - psia

Table 10. Sulfur Distribution Data

SULFUR CONVERTED TO PRODUCTS,
HYDROGEN SULFIDE, AND OIL - WT PCT
AND S TO H₂S - LBS PER LB DRS

LETID	RUNID	PS	PSH ₂ S	PSOIL	LBH ₂ S
A	8201	48.1239	44.8717	3.25215	0.0209875
B	8202	49.6742	44.8844	4.78985	0.0197052
C	8205	50.6731	46.4776	4.19554	0.0218375
D	8206	48.4626	44.1208	4.34182	0.0196045
E	8207	51.1665	46.1934	4.97307	0.0205745
F	8209	53.5494	49.2904	4.25905	0.0223207
G	8211	47.4124	43.0716	4.34073	0.0183600
H	8212	58.1056	53.1335	4.97202	0.0216888
I	8213	54.1989	50.0620	4.13690	0.0226701
J	8214	54.0018	48.6680	5.33375	0.0206420
K	8215	47.3136	42.6249	4.68870	0.0171727
L	8218	54.7347	48.9347	5.80000	0.0201829
M	8219	56.0145	50.7745	5.24006	0.0207798
N	8220	51.0339	45.4185	5.61543	0.0181051
O	8221	59.6623	54.7236	4.93869	0.0248393
P	8222	52.4685	47.0847	5.38377	0.0197202
Q	8223	46.4869	43.4744	3.01252	0.0190862
R	8224	51.0646	46.3281	4.73648	0.0186647
S	8225	50.7012	45.3519	5.34930	0.0201997
T	8301	48.6711	44.3548	4.31637	0.0185297
U	8302	53.3978	49.2989	4.09883	0.0221674

N=21

Table 11. Bench Scale Unit Run Data

EASTERN SHALE DATA BASE

LETID	RUNID	TOCC	MAXT	TOTREST	H2DRS	TPRESS	H2PRES
A	8201	85.44	995	57	17.2	1039	896
B	8202	85.28	1000	57	17.6	1012	897
C	8205	87.96	1260	59	16.7	1009	861
D	8206	84.95	1250	60	16.6	1014	839
E	8207	84.48	1000	58	17.4	1011	891
F	8209	86.53	1220	59	17.2	1021	880
G	8211	87.05	1240	57	15.9	1011	875
H	8212	80.73	1000	59	17.8	1024	895
I	8213	67.86	850	30	16.7	1003	892
J	8214	82.57	1000	31	16.5	1001	875
K	8215	74.30	850	62	16.2	1018	904
L	8218	84.86	961	46	15.7	1018	888
M	8219	78.82	965	47	16.0	610	548
N	8220	79.92	980	47	15.9	816	704
O	8221	80.19	1121	46	16.1	609	533
P	8222	79.33	960	47	16.3	816	722
Q	8223	50.98	1020	21	18.7	1017	941
R	8224	75.27	1035	21	19.3	1003	914
S	8225	77.81	974	28	16.2	1017	908
T	8301	69.84	1048	47	16.7	415	366
U	8302	70.41	1050	49	17.0	423	371

N=21

Plots were made for every combination of the two variable sets. Additionally, each plot was further divided into two sub-plots; one showing only the BSU runs conducted without shale preheating (Phases I and II), and one showing only the BSU runs utilizing preheat (Phase III). The concept of shale preheating was adopted about half-way through the feasibility study, and found to provide a dramatic increase in the oil yield. Therefore, an examination of each data subset is warranted. This procedure generated seventy-two (72) plots, all of which are contained in Section 7.2 of the Appendix to this study. As an example of the graphical analysis, Figures 3 through 6 contain a series of graphs depicting the four dependent variables as a function of total organic carbon conversion for the entire series of BSU runs.

The results of the sulfur distribution analysis are summarized in Table 12 below.

Table 12. Results of Sulfur Distribution Analysis

	<u>Design</u>	<u>Range</u>
Total sulfur converted (weight percent)	55	47 - 59
Sulfur to hydrogen sulfide (weight percent)	50	43 - 55
Sulfur to oil (weight percent)	5	4 - 6
Sulfur to spent shale (weight percent)	45	41 - 53
Hydrogen sulfide production (lb/lb DRS)	0.021	0.017 - 0.025
(lb/ton DRS)	42	34 - 50

The design values represent the sulfur distribution and production experienced with the specific New Albany rock unit utilized in the HYTORT Feasibility Study at the operating conditions envisaged for a commercial HYTORT plant. Commercial plant operating conditions were determined through preliminary economic trade-off studies based on the results of BSU runs. As such, the table provides a good indication of sulfur distribution under the commercial plant operating conditions specified in the HYTORT Feasibility Study. Additionally, the ranges serve as an indication of possible extremes which may occur during periods of abnormal operating conditions.

Examination of the graphs indicate that the point Q representing run 8223 is an outlier. The overall carbon conversion for run 8223 was only 51 percent, much lower than the 75 percent to 85 percent range normally experienced with hydroretorting. The detailed run results show that the time-temperature history of the shale through the BSU was not adequate (the required hydroretorting temperatures were not maintained for a sufficient time period) for complete conversion of the carbon content. In run 8224 (point R), which is a duplicate of run 8223, the temperature profile was corrected and a 75 percent total organic carbon conversion was obtained. The existence of these two runs does support the relative consistency of sulfur conversion throughout the operating range being considered for commercial operation. Whereas the total organic carbon conversion increased 24 percent, the sulfur conversion only increased 4.5 percent (51 - 46.5). The sulfur conversion to products seems to take place at lower temperatures than those required for oil shale retorting. Additionally, the sulfur conversion was not affected by the shale

residence times within the range of residence times studied.

4.1.2 Environmental Concerns

The fact that hydroretorting does not require a combustion zone eliminates the sulfur dioxide emissions often experienced in thermal retorting. However, the retort gases do contain hydrogen sulfide which must be removed prior to use as recycle gas. At the commercial plant design conditions identified for the Indiana New Albany shale utilized in the HYTORT Feasibility Study, the hydrogen sulfide gas loading in the untreated product gas stream will be in the range of 300 grains per 100 SCF to 350 grains per 100 SCF. Current technology is capable of reducing the hydrogen sulfide content of the synthesis gas to a level where stack emissions from process areas utilizing the synthesis gas will not exceed the values promulgated by the various environmental agencies. Additionally, the consistency of hydrogen sulfide production over a wide range of operating variables will allow the gas cleaning plants to operate smoothly near design loading conditions during any operational upsets which may occur in the shale retort.

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PSH2S*TOCC SYMBOL IS VALUE OF LETID

Figure 3. Sulfur Converted to Gas versus Total Organic Carbon Conversion

SULFUR CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF $PSOIL \cdot TOCC$ SYMBOL IS VALUE OF LETID

Figure 4. Sulfur Converted to Oil versus Total Organic Carbon Conversion

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PS*TOCC SYMBOL IS VALUE OF LETID

Figure 5. Sulfur Conversion versus Total Organic Carbon Conversion

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF LBH2S*TOCC SYMBOL IS VALUE OF LETID

Figure 6. Hydrogen Sulfide Production versus Total Organic Carbon Conversion

4.2 Nitrogen Distribution

A detailed discussion of the nitrogen distribution in the hydrotreating product streams and identification of possible environmental concerns is given in this section. The plotted results indicate that the retorting temperature has an effect on the nitrogen conversion. In the BSU runs without shale preheating the nitrogen conversion increases linearly by approximately 10 weight percent per every 100°F increase in retorting temperature within the 850°F to 1250°F temperature range studied. Although the same behavior may be postulated for runs utilizing raw shale preheating, it is not possible to validate this behavior because the shale preheating runs were conducted within a narrow temperature range (960°F - 1050°F). In general, about 7.5 percent of the nitrogen conversion increase goes to the production of ammonia with the remaining 2.5 percent increase going to oil. Using the envisaged commercial design point operating in the 950°F to 975°F retorting temperature range, the expected nitrogen conversion will be 70 weight percent with 20 percent of the nitrogen being converted to ammonia and the remaining 50 percent going to the oil. Ammonia production at the design point will be approximately 0.013 pounds per pound of dry raw shale (2.6 pounds per ton).

A commercial plant with onsite oil upgrading facilities should be considered as the most difficult situation when addressing the concept of ammonia removal from the synthesis gas stream. Removal of nitrogen from the raw shale oil in an on-site oil upgrading facility for subsequent treatment in existing refineries can generate up to 2.5 times the amount of ammonia present in the retort gas effluent. The

selected ammonia removal system must be capable of handling the additional source of ammonia and the large swings in ammonia concentration during periods when the oil upgrading facility is off line. A second alternative would be to have separate ammonia scrubbing systems for each area of the plant. The ammonia concentration in the untreated recycle gas for a commercial plant based on the HYTORT Feasibility Study designs is expected to be in the area of 20 grains per 100 SCF. If the ammonia from an upgrading facility is added to the recycle gas, the ammonia concentration will rise to a maximum concentration of 70 grains per 100 SCF. In either event, the currently available technology is capable of removing and recovering the ammonia concentrations present in the recycle gas streams.

4.2.1 Analysis

To examine the nitrogen distribution in the hydrotreating product streams, the following data was generated (see Tables 13 and 14):

- Weight percent of nitrogen to oil and gas
- Weight percent of nitrogen to ammonia
- Weight percent of nitrogen to oil
- Pounds of ammonia produced per pound of dry raw shale.

This method of analysis assumes that all nitrogen in the product gas is in the form of ammonia. This is a useful approximation for the study of general trends, and in fact, has almost no effect on the analysis since less than 1 percent of the raw shale nitrogen ends up in trace constituents (see Section 4.3). Although BSU runs do produce a sour water stream, it is recognized that the particular composition

of this stream is, to some extent, an artifact of the test equipment and operating temperatures. Therefore, the ammonia content of the sour water was added to the retort product gas for the analysis presented in this section. This is equivalent to an analysis of potential pollutants from the retort proper, independent of the downstream process conditions. A separate analysis of the BSU sour water trace constituents is presented in Section 4.4.

The four (4) dependent variables identified above were plotted as a function of the following (see Tables 13 and 15):

- Total organic carbon conversion
- Maximum bed temperature
- Total shale residence time
- Ratio of hydrogen to shale
- Total pressure
- Hydrogen partial pressure.

Plots were made for every combination of the two variable sets. Additionally, each plot was further divided into two sub-plots; one showing only the BSU runs conducted without shale preheating, and one showing only the BSU runs utilizing preheat. The concept of shale preheating was adopted about half-way through the feasibility study. Shale preheating provides a dramatic increase in the oil yield, thereby warranting a separate examination of each data subset. This procedure generated seventy-two (72) plots, all of which are contained in Section 7.3 of the Appendix to this study. As an example of the graphical analysis, Figures 7 through 10 contain a series of graphs depicting the four dependent variables as a function of total organic carbon conversion for the entire series of BSU runs.

Table 13. Nitrogen Distribution Variable Identification

<u>Variable</u>	<u>Description</u>
LETID	Letter identification of run for plotting
RUNID	Run identification number
PN	Nitrogen to products - weight percent
PNNH ₃	Nitrogen to ammonia - weight percent
PNOIL	Nitrogen to oil - weight percent
LBNH ₃	Ammonia production - pounds per pound of dry raw shale
TOCC	Total organic carbon conversion - weight percent
MAXT	Maximum bed temperature - degrees Farenheit
TOTREST	Total shale residence time - minutes
H ₂ DRS	Ratio of hydrogen to shale - SCF per pound dry raw shale
TPRESS	Total pressure - psia
H ₂ PRES	Hydrogen partial pressure - psia

Table 14. Nitrogen Distribution Data

NITROGEN CONVERTED TO PRODUCTS,
AMMONIA, AND OIL - WT PCT
AND N2 TO NH3 - LBS PER LB DRS

LETID	RUNID	PN	PNNH3	PNOIL	LBNH3
A	8201	77.5386	38.8643	38.6743	0.00174050
B	8202	85.7026	42.6981	43.0045	0.00237731
C	8205	92.6691	49.5429	43.1262	0.00257852
D	8206	96.2766	52.0113	44.2654	0.00258108
E	8207	83.8054	32.9831	50.8223	0.00163680
F	8209	91.9166	46.5578	45.3588	0.00225410
G	8211	96.4340	54.9903	41.4436	0.00279548
H	8212	78.0436	35.6158	42.4279	0.00193988
I	8213	55.6227	14.6385	40.9842	0.00076188
J	8214	70.5553	21.0631	49.4922	0.00109625
K	8215	65.2685	22.9585	42.3099	0.00116712
L	8218	75.7261	20.8384	54.8878	0.00103411
M	8219	67.7231	19.6892	48.0339	0.00100092
N	8220	71.5818	21.4440	50.1378	0.00109013
O	8221	76.2286	26.0185	50.2100	0.00132267
P	8222	76.1287	25.6238	50.5049	0.00130261
Q	8223	41.9405	13.0064	28.9342	0.00067693
R	8224	70.2606	25.3825	44.8782	0.00122889
S	8225	70.6686	21.9435	48.7251	0.00122175
T	8301	56.3563	20.2641	36.0922	0.00115278
U	8302	57.2363	19.5449	37.6914	0.00108821

N=21

Table 15. Bench Scale Unit Run Data

EASTERN SHALE DATA BASE

LETID	RUNID	TOCC	MAXT	TOTREST	H2DRS	TPRESS	H2PRES
A	8201	85.44	995	57	17.2	1039	896
B	8202	85.28	1000	57	17.6	1012	897
C	8205	87.96	1260	59	16.7	1009	861
D	8206	84.95	1250	60	16.6	1014	839
E	8207	84.48	1000	58	17.4	1011	891
F	8209	86.53	1220	59	17.2	1021	880
G	8211	87.05	1240	57	15.9	1011	875
H	8212	80.73	1000	59	17.8	1024	895
I	8213	67.86	850	30	16.7	1003	892
J	8214	82.57	1000	31	16.5	1001	875
K	8215	74.30	850	62	16.2	1018	904
L	8218	84.86	961	46	15.7	1018	888
M	8219	78.82	965	47	16.0	610	548
N	8220	79.92	980	47	15.9	816	704
O	8221	80.19	1121	46	16.1	609	533
P	8222	79.33	960	47	16.3	816	722
Q	8223	50.98	1020	21	18.7	1017	941
R	8224	75.27	1035	21	19.3	1003	914
S	8225	77.81	974	28	16.2	1017	908
T	8301	69.84	1048	47	16.7	415	366
U	8302	70.41	1050	49	17.0	423	371

N=21

The results of the nitrogen distribution analysis are summarized in Table 16 below:

Table 16. Results of Nitrogen Distribution Analysis

	<u>Design</u>	<u>Range</u>
Total nitrogen converted (weight percent)	70	55 - 96
Nitrogen to ammonia (weight percent)	20	14 - 55
Nitrogen to oil (weight percent)	50	36 - 54
Nitrogen to spent shale (weight percent)	30	4 - 45
Ammonia production (lb/lb DRS)	0.0013	0.0008 - 0.0028
(lb/ton DRS)	2.6	1.6 - 5.6

The design values represent the nitrogen distribution and production experienced with the specific New Albany rock unit utilized in the HYTORT Feasibility Study at the operating conditions envisaged for a commercial HYTORT plant. The table provides a good indication of nitrogen distribution under the commercial plant operating conditions specified in the HYTORT Feasibility Study.

The plot of nitrogen converted to product oil and gas versus the total organic carbon conversion is shown in Figure 7. The graph depicts a well-defined relationship between the two variables, with nitrogen conversion ranging from 55 weight percent at 70 percent organic carbon conversion to 95 percent at total organic carbon conversion levels around 85 percent. Examination of the operating variables affecting carbon conversion is required to determine the operating variables affecting nitrogen conversion. The operating

variables of interest are temperature, pressure, and total shale residence time.

Cursory examination of the plots of nitrogen conversion versus pressure, temperature, and total residence time seems to indicate that all variables have an effect on nitrogen conversion. However, closer examination reveals that temperature is the primary variable.

Although nitrogen conversion at total shale residence times around 60 minutes seems to increase (Figure 11), the increasing shale residence time is not the cause. Examination of these higher nitrogen conversion points (C, D, F, and G - the F observation is hidden in Figure 11) shows that they are all from the series of runs conducted at 1250°F. Without these points, all that can be said about total shale residence time is that it may have a slight effect in the observed nitrogen conversion. The same analysis and reasoning holds for the plot of nitrogen converted versus total pressure shown in Figure 12. Again, points C and D (and hidden observations F and G directly under C and D) constitute the series of runs conducted at 1250°F. The resulting plot does not support the existence of any effect between nitrogen conversion and pressure.

Figures 13 through 15 depict nitrogen conversion as a function of maximum bed temperature. Plots showing only BSU runs with shale preheating (Figure 15) and BSU runs without shale preheating (Figure 14) are included in this series. Figure 13, in which all the BSU run points are contained, indicates a relatively straight line relationship between the variables. The outliers are run Q, in which the temperature profile required for complete hydrotreating was not achieved, and runs T and U, conducted at 400 psia (the lowest

operating pressure studied), whose material balances are not as good as prior BSU runs. Examination of Figure 14, which plots only the runs without shale preheating, reveals a very definite straight line relationship between nitrogen conversion and maximum bed temperature. Over the 400°F range from 850°F to 1250°F, the nitrogen conversion (weight percent) increases by approximately 10 percentage points for every 100°F rise in maximum bed temperature. Figure 15, containing only the BSU runs with shale preheating, shows that these runs were conducted over the relatively narrow temperature range from 960°F to 1050°F. Although these points lie within the expected values defined by the non-preheated runs, it is not possible to substantiate any conclusions about the shale preheating runs outside the 960°F to 1050°F range studied. On the other hand, there is no reason to suspect any radical difference in the behavior of nitrogen conversion between the BSU runs with shale preheating and those without shale preheating.

Plots of nitrogen converted to ammonia and nitrogen converted to oil as a function of maximum bed temperature are shown in Figures 16 and 17. These plots indicate that about 7.5 percent of the 10 percent increase in nitrogen conversion per 100°F rise in temperature results in increased ammonia production. The remaining 2.5 percent increase in nitrogen converted goes to the product oil.

It should be noted that the majority of the nitrogen converted to gaseous products ends up as ammonia. Most of the ammonia is condensed with sour water and product oil. As previously indicated, this ammonia has been included in the above analysis. The remainder of the concentrations of ammonia and other nitrogen containing gaseous

products were determined for select runs in the acid scrub of the environmental sampling train. Therefore, the ammonia concentrations shown in the environmental sampling train results presented in Section 4.3, Table 17, do not indicate the temperature dependence of ammonia concentration observed in this analysis of effluents emanating from this retort proper.

4.2.2 Environmental Concerns

As was indicated in the preceeding section, an ammonia production of 2.6 pounds per ton dry raw shale is expected when hydroretorting the Indiana New Albany shale in a commercial plant. This level of ammonia production results in an ammonia gas loading of approximately 20 grains per 100 SCF of untreated recycle gas. This gas loading is on the low end of the scale when dealing with ammonia recovery processes from gas streams. In a commercial process, about 95% of the ammonia will be knocked out of the gas in the oil condensers prior to the light oil scrubbers. Because of ammonia's high solubility in water, the sour water stream from the oil condensers will contain the produced ammonia. The sour water in turn will be distilled for re-use and the concentrated off-gases can either be utilized in by-product production or incinerated.

At these levels of nitrogen production, it should be possible to design the equipment for adequate ammonia removal during operational upsets in the retort. Additionally, the high capacity of the shale to absorb heat from the recycle gas will serve to mitigate the severity of temperature swings due to operational upsets. As an example, abnormally high hot gas temperatures to the retorting zone should be detected long before the high temperatures have any noticeable effect

on the massive heat sink provided by the shale bed. Another aspect of the HYTORT process is that heating of the recycle gas is accomplished indirectly through fired heaters, thus placing a limitation on the maximum hot gas temperature achievable. This is in contrast to direct combustion processes where localized high temperature regions may exist within the retort.

A second area of ammonia production is from the oil upgrading facilities. This off-gas stream could conceivably add up to 50 grains per 100 SCF to the gas concentration of the recycle gas. However, a total concentration of only 70 grains per 100 SCF would result, which is well within the operable concentration range of present ammonia removal and recovery systems.

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PN*TOCC SYMBOL IS VALUE OF LETID

Figure 7. Nitrogen Conversion versus Total Organic Carbon Conversion

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF $PNNH_3 \cdot TOCC$ SYMBOL IS VALUE OF LETID

Figure 8. Nitrogen to Ammonia versus Total Organic Carbon Conversion

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PNOIL*TOCC SYMBOL IS VALUE OF LETID

Figure 9. Nitrogen to Oil versus Total Organic Carbon Conversion

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF $\text{LBNH}_3 \cdot \text{TOCC}$ SYMBOL IS VALUE OF LETID

Figure 10. Ammonia Production versus Total Organic Carbon Conversion

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF PN*TOTREST SYMBOL IS VALUE OF LETID

Figure 11. Nitrogen Conversion versus Total Shale Residence Time

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL PRESSURE

PLOT OF PN*TPRESS SYMBOL IS VALUE OF LETID

Figure 12. Nitrogen Conversion versus Total Pressure

NITROGEN CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF PN*MAXT SYMBOL IS VALUE OF LETID

Figure 13. Nitrogen Conversion versus Maximum Bed Temperature

NITROGEN CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=0

PLOT OF PN*MAXT SYMBOL IS VALUE OF LETID

Figure 14. Nitrogen Conversion versus Maximum Bed Temperature
For BSU Runs Without Preheat

NITROGEN CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=1

PLOT OF PN*MAXT SYMBOL IS VALUE OF LETID

Figure 15. Nitrogen Conversion versus Maximum Bed Temperature
For BSU Runs With Preheat

NITROGEN CONVERTED TO AMMONIA VERSUS MAXIMUM BED TEMPERATURE

PLOT OF PNNH3*MAXT SYMBOL IS VALUE OF LETID.

Figure 16. Nitrogen to Ammonia versus Maximum Bed Temperature

NITROGEN CONVERTED TO OIL VERSUS MAXIMUM BED TEMPERATURE

PLOT OF PNOIL*MAXT SYMBOL IS VALUE OF LETID

Figure 17. Nitrogen to Oil versus Maximum Bed Temperature

4.3 Gas Trace Constituents

During the HYTORT Feasibility Study six (6) of the twenty-one (21) runs were conducted with an environmental sampling train (EST) to determine trace constituents present in the gas phase downstream of the oil condenser and knockout pot. The EST consists of a series of sample bombs containing scrubbing solutions for the recovery of various species. High removal efficiencies are obtained by utilizing three (3) bombs containing the same scrubbant in series. The exit gas flowrate from the EST is measured to allow calculation of gas loadings. The EST used in the six BSU runs consisted of a basic scrubbing solution (6N NaOH) and an acidic scrubbing solution (3N HCl) for recovery of the following species:

- Base Scrub - Sulfide ($S^{=}$)
 Cyanide (CN^{-})
 Thiocyanate (CSN^{-})
 Sulfates ($SO_4^{=}$)
- Acid Scrub - Ammonia Nitrogen
 Phenols (Phenol C_6H_5OH)
 Nitrite (NO_2^{-})
 Nitrate (NO_3^{-})
 Organic Nitrogen

An additional analysis utilizing a Tracor gas chromatograph yielded concentrations of the following compounds:

- Hydrogen sulfide (H_2S)
Carbonyl sulfide (COS)
Methyl mercaptan (CH_4S)
Dimethyl sulfide (C_2H_4S)
Ethylene mercaptan ($C_2H_6S_2$)

These trace constituent analyses provide for preliminary identification of compounds which may have an adverse effect on various downstream processes. To more completely address the environmental aspects, an organic scrub (such as methylene chloride) should be added to the EST. The HYTORT Feasibility Study was unable to address the aspect of organic trace constituents in detail due to termination of the program before the final two (2) BSU runs which were to be conducted at design conditions.

4.3.1 Analysis

The EST results are shown in Table 17. Table 18 contains the average reported value for each trace constituent with the range of reported values. Results from the Tracor gas chromatograph analysis for sulfur-containing compounds is shown in Table 17. Although in some cases the reported results vary by as much as a factor of ten, these analyses serve a useful purpose in determining the presence of various trace constituents and identify possible concentrations of the constituents.

4.3.2 Environmental Concerns

The results provided an indication of the hydrogen sulfide and ammonia concentrations to be handled by downstream processing and identified trace constituents which may inhibit the removal of the potential pollutants. The results of analyses from the EST and gas chromatography were analyzed during the HYTORT Feasibility Study conceptual commercial plant design. The trace constituent concentrations obtained from the EST were deemed to be within the allowable limits for downstream processing by currently available technology. However, the EST did not adequately address the entire scope of process and environmental concerns.

An environmental report entitled "Problem Definition and Recommended Environmental Sampling Program" is contained in Appendix B of the Final

Report for DOE Contract No. DE-AC20-79ET14102 "Synthetic Fuels From U.S. Oil Shales - A Technical and Economic Verification of the HYTORT Process" published January 1983. The environmental report developed by Pace Company indicates that tests for the following additional constituents in the product should be conducted:

- Carbon disulfide
- Thioethers
- Ozone
- Arsenic
- Lead
- Beryllium
- Selenium
- Cadmium
- Fluorine
- Asbestos.

This list and the analyses from the BSU program are not intended to represent a complete testing program. However, they do provide an indication of the scope which must be encompassed by a full environmental sampling program. These recommended analyses should be reviewed by qualified environmental organizations to assure that future sampling programs will address all of the present environmental concerns as defined by existing and pending statutes.

Table 17. Environmental Sampling Train Results¹

	-----Run-----					
	<u>8201</u>	<u>8205</u>	<u>8206</u>	<u>8207</u>	<u>8209</u>	<u>8211</u>
<u>Acid Scrub</u>						
TOC	0.08	0.11	0.14	0.13	0.08	0.09
Nitrogen in Ammonia ²	0.005	0.007	0.009	0.06	0.009	0.02
Phenols	0.006	0.006	0.005	0.003	0.004	0.004
Nitrites	0.00007	0.000001	----	----	----	----
Nitrates	0.002	0.002	0.004	0.003	0.003	0.003
Organic Nitrogen	0.024	0.009	0.05	0.05	0.025	0.05
<u>Base Scrub</u>						
Cyanide	0.00030	0.00023	0.00016	0.0002	0.0011	0.0002
Thiocyanate	0.0016	0.0017	0.0052	0.004	0.005	0.004
Sulfides	32.5	24.8	53.2	37.7	40.8	41.8
Sulfates	0.2	18.2 ³	0.32	6.9	3.4	4.3

1. All units reported in pounds per ton DRS.
2. Note that due to the high solubility of ammonia in water, most of the ammonia formed is in the sour water which is condensed along with product oil prior to the gas sampling location for the EST. The nitrogen in ammonia reported here is the residual that remains after the product oil condenser. As such, the concentrations observed do not follow the results of the nitrogen distribution (Section 4.2) indicating a temperature dependence for ammonia concentration in the gas.
3. Sulfate reported for run 8205 listed as suspect in the EST report and not included in the average and range reported in the Table 18.

Table 18. Environmental Sampling Train Results¹

	<u>Average</u>	<u>Range</u>
<u>Acid Scrub</u>		
TOC	0.11	0.08 - 0.14
N in NH ₃	0.018	0.005 - 0.06
Phenols	0.005	0.003 - 0.006
Nitrites	0.00001	0.0 - 0.00007
Nitrates	0.003	0.002 - 0.004
Organic Nitrogen	0.04	0.009 - 0.05
<u>Base Scrub</u>		
Cyanide	0.00037	0.00016 - 0.0011
Thiocyanate	0.0036	0.0016 - 0.0052
Sulfides	38.4	24.8 - 53.2
Sulfates ²	3.0	0.2 - 6.9

1. All units in pounds per ton DRS.
2. Run 8205 not included in sulfates average due to suspect analytical results.

Table 19. Summary of BSU Product Gas Analyses
for Sulfur Species

Run	Hydrogen Sulfide (H ₂ S)	Carbonyl Sulfide (COS)	Methyl Mercaptan (CH ₄ S)	Ethyl Mercaptan and Dimethyl Sulfide (C ₂ H ₆ S)
	Vol%	----- ppm -----		
8201	0.96	—	—	—
8202	0.96	—	—	—
8205	1.05	25	—	—
8206	1.24	17	56	21
8207	1.09	—	44	15
8209	1.02	49	69	12
8211	1.15	21	83	16
8212	0.98	16	84	26
8213	1.17	<8	95	65
8214	1.10	<8	71	48
8215	1.17	<10	69	19
8218	1.11	<10	53	11
8219	1.20	<10	51	27
8220	1.16	<10	48	24
8221	1.06	<10	38	21
8222	1.10	<10	41	17

4.4 Sour Water Trace Constituents

As was discussed in the sections on sulfur distribution and nitrogen distribution, the sour water composition, although also dependent on gas concentrations of the various constituents, is primarily determined by the process conditions which lead to the formation of the condensate. Therefore, the ammonia and hydrogen sulfide constituents of the sour water were assumed to be contained in the retort product gas for the purpose of nitrogen and sulfur distribution analysis (Section 4.1.1 and Section 4.2.1).

Despite the above limitations, there was some data collected on the sour water trace constituents produced in runs 8205 and 8206. The original purpose of this analysis was to provide justification for the simplification of the method for forcing material balance closures by assuming all sour water nitrogen was in the form of ammonia and all sulfur was in the form of hydrogen sulfide. A combination gas chromatography/mass spectrometer (GC/MS) analysis was performed on this effluent. Because of the expense, a continuation of this analysis was not justified for subsequent runs. The analytical results provide an indication of the organic compounds present and their concentrations in untreated sour water. At present there is no data available on the composition of treated water effluent, however, the analysis of untreated sour water did not identify any compounds which cannot be treated using existing waste water treatment processes.

4.4.1 Analysis

Test results showing chemical oxygen demand, dissolved solids, suspended solids, pH, and the normal environmental sampling train analysis are contained in Table 20. The analytical results of the GC/MS of the sour

product water for BSU runs 8205 and 8206 are contained in Table 21.

The sour water sample was treated with methylene chloride at the time of collection to stabilize the trace constituents. The GC/MS analysis was run on the resulting mixture. The identified components are reported in the following format:

- I Aromatic hydrocarbons
- II Nitrogen containing compounds
- III Oxygen containing compounds
- IV Aliphatic hydrocarbons
- V Sulfur containing compounds
- VI Unidentified (by boiling point).

A total of approximately 70 compounds has been identified.

The results of the GC/MS supported the simplifying assumptions used in closing the material balances for use in conceptual commercial plant designs. The pertinent assumptions substantiated by the GC/MS analysis are:

- All nitrogen in the sour water is in the form of ammonia
- All sulfur in the sour water is in the form of hydrogen sulfide.

4.4.2 Environmental Concerns

The sour water (termed product water in BSU reports) collected during BSU runs was obtained by cooling the exit gas temperature to approximately 80°F to 90°F. As such, this condensate may provide a general indication of the maximum expected quantities of trace constituents from the oil condensing equipment in a commercial plant. Current commercial plant designs specify exit gas temperatures from the oil condensers to be 100°F, prior to entry into the lean oil scrubbers. In a commercial plant the trace constituent concentrations can be expected to be lower due to the

increased water loading from higher raw feed shale moisture contents. The higher shale moisture content is inherent in a commercial HYTORT plant as currently envisaged because the raw shale feed to the high pressure reactor is accomplished through a hydraulic lockhopper system. Additionally, in a commercial plant this stream will be combined with other effluent streams from the process train.

After treatment in the stills, primarily for the removal of ammonia (although quantities of H_2S and HCN will also be removed), the effluent stream will be pH adjusted and sent to the waste water treatment plant. Prior waste water treatment work (unrelated to oil shale processing, i.e., refineries, coal chemical plants, etc.) indicates that a properly designed and operated activated-sludge system can achieve virtually complete recovery of the organic substances from the effluent stream identified by this analysis. In short, based on currently available data, all of the various process effluent streams from a HYTORT plant can be treated to assure compliance with environmental regulations.

Table 20. Product Water Analysis¹

	Run	
	<u>8205</u>	<u>8206</u>
Ammonia-Nitrogen	2.6	1.9
COD ²	6.3	— ⁵
Cyanide	0.0001	0.000007
Thiocyanate	0.01	0.02
Sulfide	6.5	3.8
Sulfate	0.9	— ⁵
Nitrite	0.0000002	— ⁵
Nitrate	0.07	— ⁵
Organic-Nitrogen	0.7	— ⁵
Nitrogen-Total	3.2	2.11
TDS ³	0.8	2.0
TSS ⁴	0.1	0.6
Phenols	0.009	0.029
pH	9.1	9.6

1. All units in pounds per ton DRS, except for pH which is dimensionless.
2. Chemical oxygen demand.
3. Total dissolved solids.
4. Total suspended solids.
5. Not reported.

Table 21. Product Water Analysis¹

	Run			
	<u>8205</u>		<u>8206</u>	
	<u>mg/l</u>	<u>lb/ton DRS</u>	<u>mg/l</u>	<u>lb/ton DRS</u>
<u>I. Aromatic Hydrocarbons</u>				
Benzene	25	0.003	250	0.037
C ₁ -Benzene	30	0.004	160	0.024
C ₂ -Benzene	50	0.007	210	0.031
C ₃ -Benzene	65	0.009	120	0.018
Indan	15	0.002	---	---
Naphthalene	35	0.005	200	0.029
C ₁ -Naphthalene	50	0.007	240	0.035
C ₂ -Naphthalene	70	0.01	200	0.029
Biphenyl	5	0.0007	45	0.007
Fluorene	5	0.0007	40	0.006
C ₁ -Fluorene	15	0.002	20	0.003
Phenanthrene	15	0.002	75	0.011
C ₁ -Phenanthrene	25	0.003	30	0.004
Phenylnaphthylenes	2	0.0003	10	0.001
Fluoranthene	5	0.0007	15	0.002
Pyrene	20	0.003	100	0.015

1. GC/MS analysis.

Table 21. Product Water Analysis (Continued)

	Run -----			
	<u>8205</u>		<u>8206</u>	
	<u>mg/l</u>	<u>lb/ton DRS</u>	<u>mg/l</u>	<u>lb/ton DRS</u>
II. <u>Nitrogen Containing Compounds</u>				
Acetonitrile	230	0.031	150	0.022
Pyridine	2	0.0003	---	---
Pyrrole	110	0.015	120	0.018
C ₁ -Pyrrole	170	0.023	210	0.031
C ₂ -Pyrrole	---	---	70	0.010
C ₃ -Pyrrole	---	---	30	0.004
Aniline	170	0.023	270	0.040
C ₁ -Aniline	110	0.015	100	0.015
Quinolines	5	0.0007	20	0.003
Indole	20	0.003	40	0.006
Acridines	5	0.0007	5	0.0007
Carbazoles	20	0.003	25	0.004
Aminonaphthalenes	20	0.003	30	0.004
Acetamides	80	0.011	40	0.006
C ₁ -Acetamides	50	0.007	20	0.003
C ₂ -Acetamides	20	0.003	10	0.001
Pyrrolidinone	---	---	40	0.006

Table 21. Product Water Analysis (Continued)

	Run			
	8205		8206	
	<u>mg/l</u>	<u>lb/ton DRS</u>	<u>mg/l</u>	<u>lb/ton DRS</u>
III. <u>Oxygen Containing Compounds</u>				
Phenol	65	0.009	85	0.013
C ₁ -Phenol	75	0.010	80	0.012
C ₂ -Phenol	25	0.003	25	0.004
Acetone, etc.	280	0.038	37	0.005
C ₁ -Acetone	130	0.018	22	0.003
C ₂ -Acetone	3	0.004	---	---
Acids (e.g., acetic acid, etc.)	1150	0.157	1360	0.200
C ₁ -Acids	770	0.105	300	0.044
C ₂ -Acids	300	0.041	125	0.018
C ₃ ⁺ -Acids	330	0.045	215	0.032
Methoxyethanols	6	0.0008	40	0.006
C ₁ -Methoxyethanols	8	0.001	---	---
C ₂ -Methoxyethanols	40	0.006	---	---
C ₃ ⁺ -Methoxyethanols	350	0.048	---	---
Carbon Dioxide	21000	2.86	27000	3.965

Table 21. Product Water Analysis (continued)

	Run			
	8205		8206	
	<u>mg/l</u>	<u>lb/ton DRS</u>	<u>mg/l</u>	<u>lb/ton DRS</u>
IV. Aliphatic Hydrocarbons ² (n-alkanes)(Carbon No.)				
5	4	0.0006	---	---
6	---	---	---	---
7	25	0.003	60	0.009
8	40	0.006	70	0.010
9	60	0.008	75	0.011
10	55	0.008	75	0.011
11	60	0.008	70	0.010
12	40	0.006	65	0.010
13	30	0.004	50	0.007
14	35	0.005	45	0.007
15	25	0.003	30	0.004
16	20	0.003	25	0.004
17	15	0.002	20	0.003
18	20	0.003	15	0.002
19	10	0.001	10	0.001
20	10	0.001	8	0.001
21	9	0.001	6	0.0009
22	8	0.001	5	0.0007
23	5	0.0007	---	---
24	4	0.0005	---	---
25	3	0.0004	---	---
26	2	0.0003	---	---

2. 1-n-alkenes and others present, but much smaller than n-alkanes and left unidentified.
3. Obscured by methylene chloride.

Table 21. Product Water Analysis (Continued)

	----- Run -----			
	<u>8205</u>		<u>8206</u>	
	<u>mg/l</u>	<u>lb/ton DRS</u>	<u>mg/l</u>	<u>lb/ton DRS</u>
<u>V. Sulfur Containing Compounds</u>				
Benzothiophene	---	---	10	0.001
Dibenzothiophene	---	---	5	0.0007
Carbon Disulfide	---	---	84	0.012
C ₂ H ₄ S ₂ , etc.	1200	0.16	510	0.075
 <u>VI. Unidentified</u>				
Boiling below naphthalene	2000	0.273	800	0.118
Boiling between naphthalene and anthracene	1200	0.164	1500	0.22
Boiling above anthracene	200	0.027	300	0.044

4.5 Spent Shale

As part of this contract, HYCRUDE conducted an extraction procedure toxicity test on the spent shale from run 8219. The results of run 8219 were used as the basis for the commercial plant process design. The results of the test show that the trace metal concentrations in the leachate are well below the maximum allowable limits as specified in Volume 40 of the Federal Register (40 CFR 261) for extraction procedures on toxic wastes. The leachate concentration limits are promulgated by the Toxic Substances Control Act contained in RCRA legislation. One criterion for defining a waste as hazardous is if the extract concentration exceeds the drinking water standards by a factor of ten or greater. At the present time, the EPA does not consider processed shale to be a hazardous waste. The extraction procedure toxicity test has not identified any trace metal constituents in the Eastern spent shale from hydroretorting as potential pollution concerns.

4.5.1 Analysis

The extraction procedure toxicity test as defined in Volume 45 of the Federal Register uses a weight of water twenty (20) times that of the solids sample as the basis. The leachate from the test is analyzed for eleven trace metals and solution concentrations are calculated. The results of this test and the maximum allowable limits are shown in Table 22. Comparison of the test results with the maximum allowable limits indicate that the majority of trace metal concentrations in the leachate are lower than the specified concentrations by a factor of one hundred. All trace metal concentrations in the leachate are lower than the maximum allowable limits by at least a factor of ten.

4.5.2 Environmental Concerns

The results of the extraction procedure toxicity test indicate that potential trace metals concentrations in leachate from hydrotreated Eastern spent shale are well within the maximum allowable limits as defined by the Toxic Substances Control Act. A previous and much more exhaustive study on metals recovery from hydrotreated Chattanooga spent shale by the Oak Ridge National Laboratory addressed the leaching problems associated with shale disposal (Reference 4). The findings of this study also indicated the trace metal concentrations contained in the spent shale leachate are within the maximum allowable limits specified by the EPA.

These results are promising; however, the application of the studies to a full scale commercial plant requires identification of a specific site. Knowledge of the site topography, meteorology, and hydrology is required to determine the impact of solid waste leachates on the environment. Baseline information about the spectrum of plant and animal species present in an affected area is also required as impacts are most often biologically specific. Prior to site selection, work can be conducted in areas such as the development of technology to control leachate generation, development of solid waste disposal techniques, and studies of shale residue leachates in existing disposal sites. A complete environmental analysis should also analyze the solid waste generated from all oil shale process areas. Other solid wastes include catalysts and sludges from various plant operations which generally have a higher potential for release of pollutants than the shale.

Table 22. EPA Toxicity Test Results and Standards

	<u>Leachate</u> ^{1,2}	<u>Allowable Limits</u> ³
	(mg/l)	(mg/l)
Arsenic	0.01	5.0
Barium	0.15	100.0
Cadmium	0.036	1.0
Chromium	0.0025	5.0
Copper	0.05	---
Lead	0.017	5.0
Mercury	0.00008	0.2
Nickel	1.4	---
Selenium	0.0033	1.0
Silver	0.0004	5.0
Zinc	3.5	---

1. Leachate resulting from EPA toxicity test procedure identified in Volume 45 of the Federal Register (pg. 33127), May 1980.
2. Shale residue from design run 8219.
3. Limits of leachates identified in Volume 40 of the Federal Register (40 CFR261).

5.0 METHODS FOR ADDRESSING ENVIRONMENTAL CONCERNS

Environmental protection is dependent upon a number of factors.

First, there is a need for adequate understanding of the existing environment. The existing environment can be described in terms of air quality, water quality, the biological components and their physical and chemical support systems including soils, topography, and climate. This description of the baseline environment is accomplished by such methods as short-to-long-term monitoring; population and productivity studies; species searches; mapping; and chemical and physical laboratory analyses. As a continuing effort in addressing environmental concerns, specific candidate plant sites should be chosen based on previous Eastern shale leasing patterns and on an assessment of their suitability from the standpoint of shale resource, labor, and water availability; environmental factors such as Air Quality PSD Classification; and market availability. While much of the environmental information to be developed will be generic (non-site-specific) in nature, the chosen sites will be used to provide a context for evaluating the effects of commercial plant development on the environment. This will help to place the air and water quality, consumption, and emission information, which the HYTORT data base can supply, into perspective with regard to their seriousness and potential cost effects.

Second, it is necessary to understand the nature of the proposed disturbance. The quantity and quality of liquid, solid, gaseous, and thermal by-products of the disturbing process must be determined. The commitment of natural resources and their retrievability, renewability, and rehabilitation potential must be characterized. This report includes information about the retort portion of the necessary data base. The

gaseous, liquid, and solid materials emanating from the retort are examples of what must be dealt with in some manner to prevent environmental damage.

The success of environmental protection is measured against a set of rules, regulations, norms and standards promulgated by Federal, State, and local authorities. Federal environmental laws applicable to the oil shale industry include those pertaining to air and water quality, hazardous and toxic materials and rare and endangered species protection. State and local laws are more specific in terms of site and industry. At the present time, of the states in the Eastern oil shale region, only Kentucky has a set of regulations specific to the industry. It will be necessary to examine the regulations in the context of an overall plant design during future program phases to properly assess the environmental concerns.

Application of the rules and regulations requires an assessment of the water consumption levels, land use requirements, gaseous and liquid pollutant emission rates, and other major potential impacts which are anticipated from a commercial plant. Further development and analysis of this type of information, together with its application in the context of chosen specific sites, will be the major activity in upcoming phases of this effort.

Additional analysis of the chemical part of the HYTORT data base described in this report, coupled with process and mechanical design information from other parts of the HYTORT data base, can provide a methodology for dealing with the environmental concerns identified in Section 4.0 as they pertain to a commercial facility. Section 5.1 provides a general indication of the data base available from the HYTORT Feasibility Study which can be used to address environmental concerns. Sections 5.2

and 5.3 delineate the areas of study which should be addressed in a continuing analysis of environmental concerns. The suggested program divides naturally into two phases:

Phase 2 - Generic (non site-specific) Environmental Analysis

Phase 3 - Site-Specific Environmental Analysis.

Phase 2 would detail the anticipated emissions from a commercial plant operating on a typical Eastern shale, whereas Phase 3 would utilize this information to assess the effects of plant emissions on chosen sites in the context of applicable laws and regulations. Section 5.4 provides a preliminary project schedule.

5.1 HYTORT Feasibility Study Data Base

HYTORT process development work over the past three years was divided into three basic areas (References 5, 6, and 7):

- Chemistry of hydrotretorting
- Experimental work to support mechanical design of HYTORT reactors
- Process design, reactor mechanical design, and cost estimation work.

Further analysis of data in these areas, along the lines detailed in the following sections, will provide means for addressing many of the environmental concerns identified in this report.

Experimental work on the chemistry of hydrotretorting was primarily conducted in the BSU and is addressed in detail in the preceeding sections of this report. The objective of the BSU program was to further study the basic process chemistry of hydrotretorting and the effects of selected process variables on the behavior of a specific Indiana New Albany shale. Additionally, a substantial amount of experimental work was conducted in the following units:

- Process development unit (PDU)
- Thermobalance (TB)
- Differential scanning calorimeter (DSC).

Testing in the one-foot diameter, one ton per hour PDU provided the initial demonstration module process designs, examined oil refluxing and heat of reaction effects, and demonstrated the operability of a countercurrent vertical-shaft retort. Data on the hydroretorting of seven Eastern shales was accumulated in the PDU under DOE sponsorship (Reference 1). The TB using small samples of oil shale, provided an extensive data base allowing for the prediction of expected shale carbon conversions in larger units. Kinetic models were developed from the results of thermobalance testing. The high-pressure DSC provided raw and spent shale heat capacity measurements necessary for commercial plant process designs.

Experimental work specific to verification of HYTORT reactor mechanical designs was conducted in the Cold-Flow Modeling (CFM) facility. A 6-foot diameter, 80-foot tall CFM vessel was utilized for conducting tests on solids drawdown, solids distribution, gas distribution, and zone sealing (the separation of adjacent retort zone gas flows without mechanical devices). The results of tests in the CFM and ancillary testing facilities, such as the 24-inch diameter dewatering screw and liquid sealed lockhopper, provided ample verification of the retort mechanical designs identified by Bechtel Group, Inc. In essence, the HYTORT Feasibility Study experimental work conducted in the BSU and CFM provided the basis for the conceptual plant designs discussed below.

Throughout the course of the HYTORT Feasibility Study, HYCRUDE Corporation and Bechtel Group, Inc. conducted a continuing review of experimental efforts to assure that the experimental programs addressed

areas important to the demonstration module, semi-works unit, and commercial plant designs. In addition, the following design studies were conducted jointly by HYCRUDE and Bechtel:

- Process and mechanical design and cost estimate for an 8-foot diameter demonstration module (September 1981)
- Process and mechanical design and cost estimate for a 3-ft diameter semi-works unit (March 1983)
- Initial, conceptual process and mechanical design and cost estimate for a 50,000 BPD commercial HYTORT plant (November 1982)
- Updated conceptual process design and cost estimate for commercial HYTORT plants at various product capacities (May 1983).

The primary goal of these studies was to establish a commercial plant design and cost estimate, and to outline alternative scaleup strategies. These designs encompassed both the HYTORT retorts themselves and the balance of the commercial facility, including shale handling, gas processing, hydrogen production, and oil upgrading equipment. This information is important to the assessment of environmental impacts of HYTORT plant operations in the Eastern U.S., which is one of the main issues to be addressed in future environmental assessment efforts.

5.2 Phase 2 - Environmental Analysis of Generic Factors

The overall goal of this phase of the effort is to quantify, to the extent possible, those gaseous, liquid, and solid waste emissions which would be expected from a commercial HYTORT plant operating on a typical Eastern shale. The anticipated emissions will be compared to existing environmental regulations for determination of compliance. Such a commercial Eastern oil shale plant would impact the environment and the quality of life in the following general areas:

1. Air quality
2. Water quality and supply
3. Land use
4. Social and economic.

The HYTORT Feasibility Study data base will be utilized extensively in refining the existing conceptual commercial plant design to provide an adequate definition of the effluent streams and emissions which are anticipated in a commercial HYTORT facility.

5.2.1 HYTORT Process Design Basis

Original plans for the Phillips Petroleum Company-sponsored HYTORT Feasibility Study called for two BSU design point runs which were to provide the design basis for a preliminary commercial plant design. However, early termination of the feasibility study did not permit completion of the BSU program. These two design point tests and the ensuing preliminary commercial plant design were to provide an adequate basis for the identification of environmental concerns to be addressed in the various process areas of a commercial shale oil plant. Although it is possible to develop a preliminary commercial plant design from the existing data base, the completion of the HYTORT Feasibility Study design point tests would provide a well-documented, reproducible data base from which the preliminary designs and identification of environmental concerns could be developed.

The generic environmental impact studies (outlined above and described in detail below) which would constitute Phase 2 of this effort, would be most meaningful if they were to be based on these two design point runs. The sampling program for these tests would be structured to provide accurate material balances and address the full range of environmental

concerns. Therefore, it is recommended that these runs be conducted during Phase 2 of this effort, and that revised, optimized conceptual process designs and cost estimates be prepared to reflect these results. The cost estimates are necessary because the evaluation of alternate pollution control strategies which will be part of the work described above requires consideration of costs.

5.2.2 Air Quality Impacts

Current commercial HYTORT plant designs utilize an elevated-pressure, closed-loop recycle gas processing system for conditioning and replenishment of the hydrogen-rich recycle gas used in the HYTORT reactors. The potential gaseous emission points within this loop will be identified. The solids handling systems and plant utilities emissions will also be delineated.

Air pollutant emissions during normal operation will be quantified by selecting the appropriate control technology in each area and projecting its performance on process streams in a HYTORT plant design. Published information and vendor contacts will be used for this purpose along with information on utility plant emissions, potential flue stack emissions, and solids handling dust emissions contained in the HYTORT Feasibility Study conceptual commercial plant designs.

Additionally, there are potentials for fugitive gaseous emissions (process upsets, leaks, spills, etc.) throughout the plant. These will be assessed, insofar as possible, by analogy with similar operating equipment elsewhere.

5.2.3 Water Quality and Supply Impacts

There are two major sources of waterborne emissions from a commercial HYTORT plant: the mine workings and spent shale disposal/land reclamation

area, and the wastewaters from the HYTORT plant itself. Leaching tests on HYTORT spent shale can provide some of the basis needed for evaluating potential emissions from the mine and land reclamation workings. However, the site-specific factors associated with these emissions will require that specific projections of loadings, etc., be undertaken in Phase 3 of this effort (see Section 5.3).

Waterborne emissions from a HYTORT plant itself, excluding the mine workings, can be evaluated with little reference to siting. Analyses of retort wastewaters, discussed elsewhere in this report, will be combined with projections of wastewater quantity and composition from other sections of the plant. The performance of conventional wastewater treatment processes operating on this feedstock will be projected, yielding estimates of discharge water composition and quantity.

Water requirements are dependent on HYTORT process configuration and their impact on water supply is a site-specific concern. For these reasons, the impact of water consumption level is addressed in Phase 3.

5.2.4 Land Use Impacts

The potential impacts in this area are more site-specific in nature. Therefore, it is planned to address them in Phase 3 of the environmental analysis.

5.2.5 Socioeconomic Impacts

The potential impact of a HYTORT facility on socioeconomic factors is site-specific and, therefore, will be addressed in Phase 3, should it be deemed within the scope of this work to analyze this area.

5.3 Phase 3 - Site-Specific Environmental Analysis

Knowledge of the pollutant emissions from a typical HYTORT process plant, such as would be developed in detail during Phase 2 of this effort,

would only provide half of the overall picture. The other half requires understanding of an existing environment, application of projected emissions to that environment, and assessment of the effects of those emissions in the context of applicable laws and regulations. Completion of this phase of the effort will result in a comprehensive environmental impact analysis for HYTORT process application at selected Eastern U.S. locations.

The first objective of this phase of the effort will be to select several candidate commercial plant sites in Eastern shale resource areas. Among the site selection factors to be considered are the following:

- Quality and concentration (i.e., carbon content and pay thickness) of shale resource and projected mining costs
- Mineability of resource, suitability of site for land reclamation, and importance of pre-development land uses
- Availability and cost of process water
- Proximity to markets (refineries) and labor sources
- Relationship to NAAQS, PSD, and SIP regulations at candidate sites, and projected costs of compliance.

Choice of candidate sites will require that a balance be struck between these factors.

As in Phase 2, for each site, four major impact areas (air quality, water quality and supply, land use, and socioeconomics) must be addressed. During this phase of the work, however, the emphasis on site-specific aspects of the process will concentrate effort in the areas of land use and socioeconomic impacts.

5.3.1 Air Quality Impacts

For each candidate site, emission limits imposed by applicable air quality regulations will be tabulated. A selection and cost estimate for appropriate control measures will be made, and the effect of the resulting

controlled emission levels of significant, regulated pollutants identified in Phase 2 will be projected for nearby areas using appropriate dispersion models. This may be an iterative process in the case of PSD requirements in some areas, because of the need to meet specifications on ambient air quality rather than on emission rates. Completion of this activity will provide information on the air quality effects of HYTORT plant operation for each candidate site and on the cost of compliance with regulations for each site.

5.3.2 Water Quality and Supply Impacts

Estimation of water pollutant emission rates from the HYTORT plant itself will have been accomplished during Phase 2. Assessment of emissions from the mine workings will be site-specific and will require formulation of a conceptual mining and reclamation plan for each candidate site. These plans will be combined with information on spent shale leaching to yield estimates of the range of potential water pollutant emissions at each site. For sites with shale resources which differ chemically (especially inorganically) from Indiana New Albany shale, a leaching test on a spent shale sample for the particular site may be desirable. Where appropriate, the costs of alternate mining/land reclamation strategies will be evaluated and the choice of plans will be guided accordingly.

HYTORT plant configurations can be altered to provide a fairly wide range of water consumption levels. For each candidate site, water availability and cost data will be used to guide this part of the plant design specifications. After this has been established, the impact of a commercial HYTORT plant on the local water supply will be projected.

5.3.3 Land Use Impacts

Qualitative consideration will be given to land use impacts during the candidate site selection process which begins this phase of the effort. The conceptual mining and land reclamation plans described in Section 5.3.2 will then be used to assess the impacts of commercial plant operation quantitatively for each site. This activity will occur simultaneously with water quality assessment work because much of the same basic design information is required.

Additionally, the spent shale must be studied to discover its reclamation potential. Color, temperature, particle size, wettability, ability to support a microbiological community, water absorption and retention properties, texture, and other variables affect a material's ability to support vegetation.

5.3.4 Socioeconomic Impacts

Although identification of socioeconomic factors is not strictly necessary to determine the impact of the HYTORT plant facility proper on the environment, these factors can indicate areas of environmental concern stemming from the population increase and new support industries. For this reason, it is suggested that an analysis of socioeconomic factors be conducted in Phase 3.

As part of this effort, local demographic data for each candidate site will be used to provide an indication of the impact of commercial HYTORT plant construction and operation for each chosen site. The resulting summary will provide forward planning information which will be useful for any Eastern oil shale recovery technology.

5.4 Project Schedule

A preliminary schedule for Phase 2 and Phase 3 of this effort is shown in Figure 18. It is estimated that Phase 2 would take approximately eight months if the two BSU design point runs are included. Without the BSU runs, Phase 2 would constitute a four month program. Phase 3 of this suggested effort would require approximately six additional months.

Figure 18. Preliminary Project Schedule

6.0 REFERENCES AND ACRONYMS

This section contains the references cited in the text of the report and the acronyms used herein.

References

1. IGT, "Synthetic Fuels from U.S. Oil Shales A Technical and Economic Verification of the HYTORT Process." Report prepared for the United States Department of Energy under Contract No. DE-AC20-79ET14102, Final Report-January 1983.
2. IGT, "Hydrogasification of Oil Shale." Report prepared for Gas Research Institute under contract No. 5014-322-0138, January 1980.
3. Attari, Amir, et.al., "Determination of Organic Oxygen Content of Oil Shale." Paper presented at 1982 Eastern Oil Shale Symposium, Lexington, Kentucky, October 11-13, 1982.
4. Spiewak, I., et. al., "Chattanooga Shale; An Assessment of the Resource and Technology for the Recovery of Hydrocarbons and Minerals," Oak Ridge National Laboratory Report ORNL/TM-7920, April 1982.
5. Roberts, Michael J., et.al., "Eastern Shale Hydroretorting." Paper to be presented at the American Chemical Society Meeting, St. Louis, Missouri, April 8-13, 1984.
6. Rex, Raymond C., Jr., et.al., "Selection of a Commercial Plant Process Design for the HYTORT Process." Paper presented at Synthetic Fuels From Oil Shale and Tar Sands Symposium, Louisville, Kentucky, May 17-19, 1983.
7. Rex, Raymond, C., Jr., et.al., "Experimental Test Program of the HYTORT Feasibility Study." Paper presented at 1983 Eastern Oil Shale Symposium, Lexington, Kentucky, November 13-16, 1983.

Acronyms

BACT	Best Available Control Technology
BSU	Bench Scale Unit
CFM	Cold Flow Model
DRS	Dry Raw Shale
EPA	Environmental Protection Agency
EST	Environmental Sampling Train
GC/MS	Gas Chromatograph/Mass Spectrometer
NAAQS	National Ambient Air Quality Standards
NPDES	National Pollution Discharge Elimination System
PDU	Process Development Unit
RCRA	Resource Conservation and Recovery Act
TB	Thermobalance

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7.0 APPENDIX

7.1 INTRODUCTION

This appendix contains the SAS computer plots used for the analysis of sulfur and nitrogen distribution contained in the main body of the report. Section 2.0 of this appendix contains the plots of sulfur distribution which are discussed in section 4.1 of the report. The nitrogen distribution plots contained in section 3.0 of this appendix are discussed in section 4.2 of the report. Some of the plots contained herein have been included in the main text where appropriate for the detailed discussions.

7.2 SULFUR DISTRIBUTION

This section contains the SAS computer printout of the program utilized for the detailed analysis of the sulfur distribution presented in section 4.1 of the report. The SAS program instructions are contained in the first eight pages of the printout. The plotting instructions are delineated in this section along with a page reference for each plot. Note that these page references refer to the computer page numbers located in the upper right hand corner of the SAS plots. Table 1 contained the sulfur distribution variable identifications for reference.

Table 1. Sulfur Distribution Variable Identification

<u>VARIABLE</u>	<u>DESCRIPTION</u>
LETID	Letter identification of run for plotting
RUNID	Run identification number
PS	Sulfur to products - weight percent
PSH2S	Sulfur to hydrogen sulfide - weight percent
PSOIL	Sulfur to oil - weight percent
LBH2S	Hydrogen sulfide production - pounds per pound of dry raw shale
TOCC	Total organic carbon conversion - weight percent
MAXT	Maximum bed temperature - degrees Farenheit
TOTREST	Total shale residence time - minutes
H2DRS	Ratio of hydrogen to shale - SCF per pound dry raw shale
TPRESS	Total pressure - psia
H2PRES	Hydrogen partial pressure - psia

1 SAS LOG OS SAS 82.3 VS2/MVS JOB BG STEP SAS

NOTE: THE JOB BG HAS BEEN RUN UNDER RELEASE 82.3 OF SAS AT UNIVERSITY COMPUT

NOTE: SAS OPTIONS SPECIFIED ARE:
SORT=4

```

1      OPTIONS LS=76 PS=60;
2      DATA BSUDAT;
3      INPUT LETID $ RUNID $ TPRESS H2PRES HTUPR MAXT PRHT PRREST
4      RETREST TOTREST MASSFL H2DRS WRS RSH2O #2
5      RSC RSH RSO RSN RSS RSC02 RSHTO RSMM BATCH
6      FA SSBAL #3 SSC SSH SSO SSN SSS SSC02 SSHTO
7      SSMM SSOBS TOCC #4 SELOIL SELGAS H2CON
8      OILBAL OILAPI OILC OILH OILS OILN OILO #5
9      GPT OILOBS WATPC SWNH3 SWH2S SWC02
10     WATPO WNH3 WH2S #6 WCO2 PGMULE CO C02
11     CH4 C2H6 C3H8 C4H10 C2H4 C3H6 #7
12     C4H8 C6H6 NH3 H2S COS;
13     DRS=WRS-(WRS*RSH2O/100.0);
14     GASH2S=PGMULE*H2S*0.3408;
15     PSOIL=OILN*OILBAL/(DRS*RSS)*100.0;
16     PS=((SWH2S+GASH2S)*32.06/34.08+OILN*OILBAL/100.0)
17     /(DRS*RSS/100.0)*100.0;
18     PSH2S=((SWH2S+GASH2S)*32.06/34.08)/(DRS*RSS/100.0)*100.0;
19     LBH2S=(SWH2S+GASH2S)/DRS;
20     LABEL MAXT=MAXIMUM BED TEMPERATURE - DEG F.
21     TOTREST=TOTAL SHALE RESIDENCE TIME - MINUTES
22     H2DRS=HYDROGEN TO SHALE RATIO - SCF PER LB DRS
23     TPRESS=TOTAL PRESSURE - PSIA
24     H2PRES =HYDROGEN PARTIAL PRESSURE - PSIA
25     TOCC=TOTAL ORGANIC CARBON CONVERSION - WT PCT
26     PSOIL=SULFUR CONVERTED TO OIL WT PCT
27     PS=SULFUR CONVERTED WEIGHT PERCENT
28     LBH2S=H2S PRODUCTION LBS PER LB DRS
29     PSH2S=SULFUR CONVERTED TO H2S WT PCT
30     PRHT=SHALE PREHEATING;
31     CARDS;

```

NOTE: THE VARIABLE H2PRESS IS UNINITIALIZED.

NOTE: DATA SET WORK.BSUDAT HAS 21 OBSERVATIONS AND 75 VARIABLES. 31 OBS/TRK.

NOTE: THE DATA STATEMENT USED 0.41 SECONDS AND 236K.

```

179     TITLE;
180     TITLE2 *****;
181     TITLE3 HYCRUDE CORPORATION;
182     TITLE4 ANALYSIS OF EASTERN SHALE DATA BASE;
183     TITLE5 *****;
184     TITLE6;
185     PROC PLOT;
186     PLOT PS*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
187     HAXIS=50 TO 100 BY 5;
188     TITLE7 SULFUR CONVERTED TO PRODUCTS;
189     TITLE8 VERSUS;
190     TITLE9 TOTAL ORGANIC CARBON CONVERSION;

```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGE 1.

191 PROC PLOT; BY PRHT; 102

192 PLOT PS*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
193 HAXIS=50 TO 100 BY 5;

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 2 TO 3.

194 PROC PLOT;
195 PLOT PS*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
196 HAXIS=850 TO 1300 BY 50 HSPACE=7;
197 TITLE9 MAXIMUM BED TEMPERATURE;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 4.

198 PROC PLOT; BY PRHT;
199 PLOT PS*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
200 HAXIS=850 TO 1300 BY 50 HSPACE=7;

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 5 TO 6.

201 PROC PLOT;
202 PLOT PS*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
203 HAXIS=0 TO 65 BY 5 HSPACE=5;
204 TITLE9 TOTAL SHALE RESIDENCE TIME;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 7.

205 PROC PLOT; BY PRHT;
206 PLOT PS*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
207 HAXIS=0 TO 65 BY 5 HSPACE=5;

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 8 TO 9.

208 PROC PLOT;
209 PLOT PS*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
210 HAXIS=15 TO 20 BY 0.5 HSPACE=6;
211 TITLE9 HYDROGEN TO SHALE RATIO;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 10.

212 PROC PLOT; BY PRHT;
213 PLOT PS*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
214 HAXIS=15 TO 20 BY 0.5 HSPACE=6;

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 11 TO 12.

215 PROC PLOT;
216 PLOT PS*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
217 HAXIS=0 TO 1100 BY 100 HSPACE=6;
218 TITLE9 TOTAL PRESSURE;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K

AND PRINTED PAGE 13.

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219      PROC PLOT; BY PRHT;
220      PLOT PS*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
221                      HAXIS=0 TO 1100 BY 100 HSPACE=6;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 14 TO 15.

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222      PROC PLOT;
223      PLOT PS*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
224                      HAXIS=0 TO 1100 BY 100 HSPACE=6;
225      TITLE9 HYDROGEN PARTIAL PRESSURE;
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NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 16.

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226      PROC PLOT; BY PRHT;
227      PLOT PS*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
228                      HAXIS=0 TO 1100 BY 100 HSPACE=6;
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NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 17 TO 18.

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229      PROC PLOT;
230      PLOT PSH2S*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
231                      HAXIS=50 TO 100 BY 5;
232      TITLE7 SULFUR CONVERTED TO HYDROGEN SULFIDE;
233      TITLE8 VERSUS;
234      TITLE9 TOTAL ORGANIC CARBON CONVERSION;
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NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 19.

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235      PROC PLOT; BY PRHT;
236      PLOT PSH2S*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
237                      HAXIS=50 TO 100 BY 5;
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NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 20 TO 21.

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238      PROC PLOT;
239      PLOT PSH2S*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
240                      HAXIS=850 TO 1300 BY 50 HSPACE=7;
241      TITLE9 MAXIMUM BED TEMPERATURE;
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NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 22.

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NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 23 TO 24.

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245      PROC PLOT;
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6      PLOT PSH2S*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
7                      HAXIS=0 TO 65 BY 5 HSPACE=5;
8      TITLE9 TOTAL SHALE RESIDENCE TIME;

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TE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 25.

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9      PROC PLOT; BY PRHT;
0      PLOT PSH2S*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
1                      HAXIS=0 TO 65 BY 5 HSPACE=5;

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TE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 26 TO 27.

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2      PROC PLOT;
3      PLOT PSH2S*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
4                      HAXIS=15 TO 20 BY 0.5 HSPACE=6;
5      TITLE9 HYDROGEN TO SHALE RATIO;

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TE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 28.

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6      PROC PLOT; BY PRHT;
7      PLOT PSH2S*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
8                      HAXIS=15 TO 20 BY 0.5 HSPACE=6;

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TE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 29 TO 30.

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9      PROC PLOT;
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1                      HAXIS=0 TO 1100 BY 100 HSPACE=6;
2      TITLE9 TOTAL PRESSURE;

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TE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 31.

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3      PROC PLOT; BY PRHT;
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TE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
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8                      HAXIS=0 TO 1100 BY 100 HSPACE=6;
9      TITLE9 HYDROGEN PARTIAL PRESSURE;

```

TE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 34.

```

0      PROC PLOT; BY PRHT;
1      PLOT PSH2S*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
2                      HAXIS=0 TO 1100 BY 100 HSPACE=6;

```

TE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K

AND PRINTED PAGES 35 TO 36.

```
273      PROC PLOT;
274      PLOT PSOIL*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
275                      HAXIS=50 TO 100 BY 5;
276      TITLE7 SULFUR CONVERTED TO OIL;
277      TITLE8 VERSUS;
278      TITLE9 TOTAL ORGANIC CARBON CONVERSION;
```

NOTE: THE PROCEDURE PLOT USED 0.32 SECONDS AND 236K
AND PRINTED PAGE 37.

```
279      PROC PLOT;BY PRHT;
280      PLOT PSOIL*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
281                      HAXIS=50 TO 100 BY 5;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 38 TO 39.

```
282      PROC PLOT;
283      PLOT PSOIL*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
284                      HAXIS=850 TO 1300 BY 100 HSPACE=7;
285      TITLE9 MAXIMUM BED TEMPERATURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 40.

```
286      PROC PLOT ;BY PRHT;
287      PLOT PSOIL*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
288                      HAXIS=850 TO 1300 BY 100 HSPACE=7;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 41 TO 42.

```
289      PROC PLOT;
290      PLOT PSOIL*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
291                      HAXIS=0 TO 65 BY 5 HSPACE=5;
292      TITLE9 TOTAL SHALE RESIDENCE TIME;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 43.

```
293      PROC PLOT;BY PRHT;
294      PLOT PSOIL*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
295                      HAXIS=0 TO 65 BY 5 HSPACE=5;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 44 TO 45.

```
296      PROC PLOT;
297      PLOT PSOIL*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
298                      HAXIS=15 TO 20 BY 0.5 HSPACE=6;
299      TITLE9 HYDROGEN TO SHALE RATIO;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 46.


```
300 PROC PLOT;BY PRHT;
301 PLOT PSOIL*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
302 HAXIS=15 TO 20 BY 0.5 HSPACE=6;
```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 47 TO 48.

```
303 PROC PLOT;
304 PLOT PSOIL*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
305 HAXIS=0 TO 1100 BY 100 HSPACE=6;
306 TITLE9 TOTAL PRESSURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 49.

```
307 PROC PLOT;BY PRHT;
308 PLOT PSOIL*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
309 HAXIS=0 TO 1100 BY 100 HSPACE=6;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 50 TO 51.

```
310 PROC PLOT;
311 PLOT PSOIL*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
312 HAXIS=0 TO 1100 BY 100 HSPACE=6;
313 TITLE9 HYDROGEN PARTIAL PRESSURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 52.

```
314 PROC PLOT;BY PRHT;
315 PLOT PSOIL*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
316 HAXIS=0 TO 1100 BY 100 HSPACE=6;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 53 TO 54.

```
317 PROC PLOT;
318 PLOT LBH2S*TOCC=LETID/HAXIS=50 TO 100 BY 5 VZERO;
319 TITLE7 SULFUR CONVERTED TO HYDROGEN SULFIDE;
320 TITLE8 VERSUS;
321 TITLE9 TOTAL ORGANIC CARBON CONVERSION;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 55.

```
322 PROC PLOT;BY PRHT;
323 PLOT LBH2S*TOCC=LETID/HAXIS=50 TO 100 BY 5 VZERO;
```

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 56 TO 57.

```
324 PROC PLOT;
325 PLOT LBH2S*MAXT=LETID/HAXIS=850 TO 1300 BY 50 HSPACE=7 VZERO;
326 TITLE9 MAXIMUM BED TEMPERATURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K

AND PRINTED PAGE 58.

```
327      PROC PLOT; BY PRHT;
328      PLOT LBH2S*MAXT=LETID/HAXIS=850 TO 1300 BY 50 HSPACE=7 VZERO;
```

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 59 TO 60.

```
329      PROC PLOT;
330      PLOT LBH2S*TOTREST=LETID/HAXIS=0 TO 65 BY 5 HSPACE=5 VZERO;
331      TITLE9 TOTAL SHALE RESIDENCE TIME;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 61.

```
332      PROC PLOT; BY PRHT;
333      PLOT LBH2S*TOTREST=LETID/HAXIS=0 TO 65 BY 5 HSPACE=5 VZERO;
```

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 62 TO 63.

```
334      PROC PLOT;
335      PLOT LBH2S*H2DRS=LETID/HAXIS=15.5 TO 20 BY 0.5 HSPACE=6 VZERO;
336      TITLE9 HYDROGEN TO SHALE RATIO;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 64.

```
337      PROC PLOT; BY PRHT;
338      PLOT LBH2S*H2DRS=LETID/HAXIS=15.5 TO 20 BY 0.5 HSPACE=6 VZERO;
```

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 65 TO 66.

```
339      PROC PLOT;
340      PLOT LBH2S*TPRESS=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;
341      TITLE9 TOTAL PRESSURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 67.

```
342      PROC PLOT; BY PRHT;
343      PLOT LBH2S*TPRESS=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;
```

NOTE: THE PROCEDURE PLOT USED 0.35 SECONDS AND 236K
AND PRINTED PAGES 68 TO 69.

```
344      PROC PLOT;
345      PLOT LBH2S*H2PRES=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;
346      TITLE9 HYDROGEN PARTIAL PRESSURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 70.

```
347      PROC PLOT ; BY PRHT;
348      PLOT LBH2S*H2PRES=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;
```

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 71 TO 72.

```
349      PROC PRINT N D;ID LETID;
350      VAR RUNID TOCC MAXT TOTREST H2DRS TPRESS H2PRES;
351      TITLE7 EASTERN SHALE DATA BASE;
```

NOTE: THE PROCEDURE PRINT USED 0.31 SECONDS AND 228K
AND PRINTED PAGE 73.

```
352      PROC PRINT N D;ID LETID;
353      VAR RUNID PS PSH2S PSOIL LBH2S;
354      TITLE7 SULFUR CONVERTED TO PRODUCTS,;
355      TITLE8 HYDROGEN SULFIDE, AND OIL - WT PCT;
356      TITLE9 AND S TO H2S - LBS PER LB DRS;
```

NOTE: THE PROCEDURE PRINT USED 0.31 SECONDS AND 228K
AND PRINTED PAGE 74.

NOTE: SAS USED 236K MEMORY.

NOTE: SAS INSTITUTE INC.
SAS CIRCLE
PO BOX 8000
CARY, N.C. 27511-8000

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PS*TOCC SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHALE PREHEATING=0

PLOT OF PS*TOCC SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=1

PLOT OF PS*TOCC SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF PS*MAXT SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=0

PLOT OF PS*MAXT SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=1

PLOT OF PS*MAXT SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF PS*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
 VERSUS
 TOTAL SHALE RESIDENCE TIME
 SHALE PREHEATING=0

PLOT OF PS*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF PS*TOTREST SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF PS*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=0

PLOT OF PS*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=1

PLOT OF PS*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL PRESSURE

PLOT OF PS*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

7 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL PRESSURE
SHAPE PREHEATING=0

PLOT OF PS*TPRESS SYMBOL IS VALUE OF LETID

H
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NOTE: 5 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=1

PLOT OF PS*TPRESS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO PRODUCTS
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF PS*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=0

PLOT OF PS*H2PRES SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

SULFUR CONVERTED TO PRODUCTS
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=1

PLOT OF PS*H2PRES SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PSH2S*TOCC SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHALE PREHEATING=0

PLOT OF PSH2S*TOCC SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHALE PREHEATING=1

PLOT OF PSH2S*TOCC SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS

MAXIMUM BED TEMPERATURE

PLOT OF PSH2S*MAXT SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=0

PLOT OF PSH2S*MAXT SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=1

PLOT OF PSH2S*MAXT SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF PSH2S*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

2 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS

TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=0

PLOT OF PSH2S*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF PSH2S*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF PSH2S*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN TO SHALE RATIO
SHAPE PREHEATING=0

PLOT OF PSH2S*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
 VERSUS
 HYDROGEN TO SHALE RATIO
 SHALE PREHEATING=1

PLOT OF PSH2S*H2DRS SYMBOL IS VALUE OF LETID.

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL PRESSURE

PLOT OF PSH2S*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

7 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
 VERSUS
 TOTAL PRESSURE
 SHALE PREHEATING=0

PLOT OF PSH2S*TPRESS SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=1

PLOT OF PSH2S*TPRESS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF PSH2S*H2PRES SYMBOL IS VALUE OF LETID

HYDROGEN PARTIAL PRESSURE - PSIA

NOTE:

3 OBS HIDDEN

143

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=0

PLOT OF PSH2S*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
 VERSUS
 HYDROGEN PARTIAL PRESSURE
 SHALE PREHEATING=1

PLOT OF PSH2S*H2PRES SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PSOIL*TOCC SYMBOL IS VALUE OF LETID

NOTE:

6 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHALE PREHEATING=0

PLOT OF PSOIL*TOCC SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=1

PLOT OF PSOIL*TOCC SYMBOL IS VALUE OF LETID

NOTE:

3 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF PSOIL*MAXT SYMBOL IS VALUE OF LETID

NOTE: 6 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=0

PLOT OF PSOIL*MAXT SYMBOL IS VALUE OF LETID

NOTE: 4 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=1

PLOT OF PSOIL*MAXT SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF PSOIL*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

7 OBS HIDDEN

SULFUR CONVERTED TO OIL
 VERSUS
 TOTAL SHALE RESIDENCE TIME
 SHALE PREHEATING=0

PLOT OF PSOIL*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF $PSOIL * TOTREST$ SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO OIL
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF PSOIL*H2DRS SYMBOL IS VALUE OF LETID

NOTE: 4 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=0

PLOT OF PSOIL*H2DRS SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=1

PLOT OF PSOIL*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO OIL
VERSUS
TOTAL PRESSURE

PLOT OF PSOIL*TPRESS SYMBOL IS VALUE OF LETID

NOTE: 14 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=0

PLOT OF $PSOIL * TPRESS$ SYMBOL IS VALUE OF LETID

NOTE: 8 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=1

PLOT OF PSOIL*TPRESS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO OIL
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF $PSOIL * H_2PRES$ SYMBOL IS VALUE OF LETID

NOTE: 9 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=0

PLOT OF $PSOIL \cdot H_2PRES$ SYMBOL IS VALUE OF LETID

NOTE: 6 OBS HIDDEN

SULFUR CONVERTED TO OIL
VERSUS
HYDROGEN PARTIAL PRESSURE
SHAPE PREHEATING=1

PLOT OF PSOIL*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF LBH2S*TOCC SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=0

PLOT OF LBH2S*TOCC SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHALE PREHEATING=1

PLOT OF LBH2S*TOCC SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF LBH2S*MAXT SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=0

PLOT OF LBH2S*MAXT SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=1

PLOT OF LBH2S*MAXT SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF LBH2S*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL SHALE RESIDENCE TIME
SHAPE PREHEATING=0

PLOT OF LBH2S*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF LBH₂S*TOTREST SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF LBH2S*H2DRS SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=0

PLOT OF LBH2S*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=1

PLOT OF LBH2S*H2DRS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL PRESSURE

PLOT OF LBH2S*TPRESS SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL PRESSURE
SHAPE PREHEATING=0

PLOT OF LBH2S*TPRESS SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=1

PLOT OF LBH2S*TPRESS SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF LBH2S*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=0

PLOT OF LBH₂S*H₂PRES SYMBOL IS VALUE OF LETID

SULFUR CONVERTED TO HYDROGEN SULFIDE
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=1

PLOT OF LBH2S*H2PRES SYMBOL IS VALUE OF LETID

EASTERN SHALE DATA BASE

LETID	RUNID	TOCC	MAXT	TOTREST	H2DRS	TPRESS	H2PRE
A	8201	85.44	995	57	17.2	1039	896
B	8202	85.28	1000	57	17.6	1012	897
C	8205	87.96	1260	59	16.7	1009	861
D	8206	84.95	1250	60	16.6	1014	839
E	8207	84.48	1000	58	17.4	1011	891
F	8209	86.53	1220	59	17.2	1021	880
G	8211	87.05	1240	57	15.9	1011	875
H	8212	80.73	1000	59	17.8	1024	895
I	8213	67.06	850	30	16.7	1003	892
J	8214	82.57	1000	31	16.5	1001	875
K	8215	74.30	850	62	16.2	1018	904
L	8218	84.86	961	46	15.7	1018	888
M	8219	78.82	965	47	16.0	610	548
N	8220	79.92	980	47	15.9	816	704
O	8221	80.19	1121	46	16.1	609	533
P	8222	79.33	960	47	16.3	816	722
Q	8223	50.98	1020	21	18.7	1017	941
R	8224	75.27	1035	21	19.3	1003	914
S	8225	77.81	974	28	16.2	1017	908
T	8301	69.84	1048	47	16.7	415	366
U	8302	70.41	1050	49	17.0	423	371

N=21

SULFUR CONVERTED TO PRODUCTS,
HYDROGEN SULFIDE, AND OIL - WT PCT
AND S TO H2S - LBS PER LB DRS

LETID	RUNID	PS	PSH2S	PSOIL	LBH2S
A	8201	48.1239	44.8717	3.25215	0.0209875
B	8202	49.6742	44.8844	4.78985	0.0197052
C	8205	50.6731	46.4776	4.19554	0.0218375
D	8206	48.4626	44.1208	4.34182	0.0196045
E	8207	51.1665	46.1934	4.97307	0.0205745
F	8209	53.5494	49.2904	4.25905	0.0223207
G	8211	47.4124	43.0716	4.34073	0.0183600
H	8212	58.1056	53.1335	4.97202	0.0216888
I	8213	54.1989	50.0620	4.13690	0.0226701
J	8214	54.0018	48.6680	5.33375	0.0206420
K	8215	47.3136	42.6249	4.68870	0.0171727
L	8218	54.7347	48.9347	5.80000	0.0201829
M	8219	56.0145	50.7745	5.24006	0.0207798
N	8220	51.0339	45.4185	5.61543	0.0181051
O	8221	59.6623	54.7236	4.93869	0.0248393
P	8222	52.4685	47.0847	5.38377	0.0197202
Q	8223	46.4869	43.4744	3.01252	0.0190862
R	8224	51.0646	46.3281	4.73648	0.0186647
S	8225	50.7012	45.3519	5.34930	0.0201997
T	8301	48.6711	44.3548	4.31637	0.0185297
U	8302	53.3978	49.2989	4.09883	0.0221674

N=21

7.3 NITROGEN DISTRIBUTION

This section contains the SAS computer printout of the program utilized for the detailed analysis of the nitrogen distribution presented in section 4.1 of the report. The SAS program instructions are contained in the first eight pages of the printout. The plotting instructions are delineated in this section along with a page reference for each plot. Note that these page references refer to the computer page numbers located in the upper right hand corner of the SAS plots. Table 2 contains the nitrogen distribution variable identifications for reference.

Table 2. Nitrogen Distribution Variable Identification

<u>VARIABLE</u>	<u>DESCRIPTION</u>
LETID	Letter identification of run for plotting
RUNID	Run identification number
PN	Nitrogen to products - weight percent
PNNH3	Nitrogen to ammonia - weight percent
PNOIL	Nitrogen to oil - weight percent
LBNH3	Ammonia production - pounds per pound of dry raw shale
TOCC	Total organic carbon conversion - weight percent
MAXT	Maximum bed temperature - degrees Farenheit
TOTREST	Total shale residence time - minutes
H2DRS	Ratio of hydrogen to shale - SCF per pound dry raw shale
TPRESS	Total pressure - psia
H2PRES	Hydrogen partial pressure - psia

NOTE: THE JOB BG HAS BEEN RUN UNDER RELEASE 82.3 OF SAS AT UNIVERSITY COMPUTI

NOTE: SAS OPTIONS SPECIFIED ARE:

SORT=4

```

1      OPTIONS LS=76 PS=60;
2      DATA BSUDAT;
3      INPUT LETID $ RUNID $ TPRESS H2PRES HTUPR MAXT PRHT PRREST
4      RETREST TOTREST MASSFL H2DRS WRS RSH2O #2
5      RSC RSH RSO RSN RSS RSC02 RSHTO RSMM BATCH
6      FA SSBAL #3 SSC SSH SSO SSN SSS SSC02 SSHTO
7      SSMM SSOBS TOCC #4 SELOIL SELGAS H2CON
8      OILBAL OILAPI OILC OILH OILS OILN OILO #5
9      GPT OILOBS WATPC SWNH3 SWH2S SWC02
10     WATPO WNH3 WH2S #6 WCO2 PGMOLE CO CO2
11     CH4 C2H6 C3H8 C4H10 C2H4 C3H6 #7
12     C4H8 C6H6 NH3 H2S COS;
13     DRS=WRS-(WRS*RSH2O/100.0);
14     GASNH3=PGMOLE*NH3*0.1703;
15     PNOIL=OILN*OILBAL/(DRS*RSN)*100.0;
16     PN=((SWNH3+GASNH3)*14.07/17.03+OILN*OILBAL/100.0)
17     /(DRS*RSN/100.0)*100.0;
18     PNNH3=((SWNH3+GASNH3)*14.07/17.03)/(DRS*RSN/100.0)*100.0;
19     LBNH3=(SWNH3+GASNH3)/DRS;
20     LABEL MAXT=MAXIMUM BED TEMPERATURE - DEG F.
21     TOTREST=TOTAL SHALE RESIDENCE TIME - MINUTES
22     H2DRS=HYDROGEN TO SHALE RATIO - SCF PER LB DRS
23     TPRESS=TOTAL PRESSURE - PSIA
24     H2PRES =HYDROGEN PARTIAL PRESSURE - PSIA
25     TOCC=TOTAL ORGANIC CARBON CONVERSION - WT PCT
26     PNOIL=NITROGEN CONVERTED TO OIL WT PCT
27     PN=NITROGEN CONVERTED WEIGHT PERCENT
28     LBNH3=NH3 PRODUCTION LBS PER LB DRS
29     PNNH3=NITROGEN CONVERTED TO NH3 WT PCT
30     PRHT=SHALE PREHEATING;
31     CARDS;

```

NOTE: THE VARIABLE H2PRESS IS UNINITIALIZED.

NOTE: DATA SET WORK.BSUDAT HAS 21 OBSERVATIONS AND 75 VARIABLES. 31 OBS/TRK.

NOTE: THE DATA STATEMENT USED 0.42 SECONDS AND 236K.

```

179     TITLE;
180     TITLE2 *****;
181     TITLE3 HYCRUDE CORPORATION;
182     TITLE4 ANALYSIS OF EASTERN SHALE DATA BASE;
183     TITLE5 *****;
184     TITLE6;
185     PROC PLOT;
186     PLOT PN*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
187           HAXIS=50 TO 100 BY 5;
188     TITLE7 NITROGEN CONVERTED TO PRODUCTS;
189     TITLE8 VERSUS;
190     TITLE9 TOTAL ORGANIC CARBON CONVERSION;

```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGE 1.

```

191     PROC PLOT;BY PRHT;

```



```

192      PLOT PN*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
193                HAXIS=50 TO 100 BY 5;

```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 2 TO 3.

```

194      PROC PLOT;
195      PLOT PN*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
196                HAXIS=850 TO 1300 BY 50 HSPACE=7;
197      TITLE9 MAXIMUM BED TEMPERATURE;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 4.

```

198      PROC PLOT; BY PRHT;
199      PLOT PN*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
200                HAXIS=850 TO 1300 BY 50 HSPACE=7;

```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 5 TO 6.

```

201      PROC PLOT;
202      PLOT PN*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
203                HAXIS=0 TO 65 BY 5 HSPACE=5;
204      TITLE9 TOTAL SHALE RESIDENCE TIME;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 7.

```

205      PROC PLOT; BY PRHT;
206      PLOT PN*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
207                HAXIS=0 TO 65 BY 5 HSPACE=5;

```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 8 TO 9.

```

208      PROC PLOT;
209      PLOT PN*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
210                HAXIS=15 TO 20 BY 0.5 HSPACE=6;
211      TITLE9 HYDROGEN TO SHALE RATIO;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 10.

```

212      PROC PLOT; BY PRHT;
213      PLOT PN*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
214                HAXIS=15 TO 20 BY 0.5 HSPACE=6;

```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 11 TO 12.

```

215      PROC PLOT;
216      PLOT PN*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
217                HAXIS=0 TO 1100 BY 100 HSPACE=6;
218      TITLE9 TOTAL PRESSURE;

```

NOTE: THE PROCEDURE PLOT USED 0.30 SECONDS AND 236K

AND PRINTED PAGE 13.

```
219      PROC PLOT; BY PRHT;
220      PLOT PN*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
221              HAXIS=0 TO 1100 BY 100 HSPACE=6;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 14 TO 15.

```
222      PROC PLOT;
223      PLOT PN*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
224              HAXIS=0 TO 1100 BY 100 HSPACE=6;
225      TITLE9 HYDROGEN PARTIAL PRESSURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 16.

```
226      PROC PLOT; BY PRHT;
227      PLOT PN*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
228              HAXIS=0 TO 1100 BY 100 HSPACE=6;
```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 17 TO 18.

```
229      PROC PLOT;
230      PLOT PNNH3*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
231              HAXIS=50 TO 100 BY 5;
232      TITLE7 NITROGEN CONVERTED TO AMMONIA;
233      TITLE8 VERSUS;
234      TITLE9 TOTAL ORGANIC CARBON CONVERSION;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 19.

```
235      PROC PLOT; BY PRHT;
236      PLOT PNNH3*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
237              HAXIS=50 TO 100 BY 5;
```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 20 TO 21.

```
238      PROC PLOT;
239      PLOT PNNH3*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
240              HAXIS=850 TO 1300 BY 50 HSPACE=7;
241      TITLE9 MAXIMUM BED TEMPERATURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 22.

```
242      PROC PLOT; BY PRHT;
243      PLOT PNNH3*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
244              HAXIS=850 TO 1300 BY 50 HSPACE=7;
```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 23 TO 24.

```
245      PROC PLOT;
```

```

246      PLOT PNNH3*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
247                      HAXIS=0 TO 65 BY 5 HSPACE=5;
248      TITLE9 TOTAL SHALE RESIDENCE TIME;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 25.

```

249      PROC PLOT; BY PRHT;
250      PLOT PNNH3*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
251                      HAXIS=0 TO 65 BY 5 HSPACE=5;

```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 26 TO 27.

```

252      PROC PLOT;
253      PLOT PNNH3*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
254                      HAXIS=15 TO 20 BY 0.5 HSPACE=6;
255      TITLE9 HYDROGEN TO SHALE RATIO;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 28.

```

256      PROC PLOT; BY PRHT;
257      PLOT PNNH3*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
258                      HAXIS=15 TO 20 BY 0.5 HSPACE=6;

```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 29 TO 30.

```

259      PROC PLOT;
260      PLOT PNNH3*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
261                      HAXIS=0 TO 1100 BY 100 HSPACE=6;
262      TITLE9 TOTAL PRESSURE;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 31.

```

263      PROC PLOT; BY PRHT;
264      PLOT PNNH3*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
265                      HAXIS=0 TO 1100 BY 100 HSPACE=6;

```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 32 TO 33.

```

266      PROC PLOT;
267      PLOT PNNH3*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
268                      HAXIS=0 TO 1100 BY 100 HSPACE=6;
269      TITLE9 HYDROGEN PARTIAL PRESSURE;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 34.

```

270      PROC PLOT; BY PRHT;
271      PLOT PNNH3*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
272                      HAXIS=0 TO 1100 BY 100 HSPACE=6;

```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K

AND PRINTED PAGES 35 TO 36.

```
273 PROC PLOT;
274 PLOT PNOIL*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
275 HAXIS=50 TO 100 BY 5;
276 TITLE7 NITROGEN CONVERTED TO OIL;
277 TITLE8 VERSUS;
278 TITLE9 TOTAL ORGANIC CARBON CONVERSION;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 37.

```
279 PROC PLOT; BY PRHT;
280 PLOT PNOIL*TOCC=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
281 HAXIS=50 TO 100 BY 5;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 38 TO 39.

```
282 PROC PLOT;
283 PLOT PNOIL*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
284 HAXIS=850 TO 1300 BY 100 HSPACE=7;
285 TITLE9 MAXIMUM BED TEMPERATURE;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 40.

```
286 PROC PLOT ; BY PRHT;
287 PLOT PNOIL*MAXT=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
288 HAXIS=850 TO 1300 BY 100 HSPACE=7;
```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 41 TO 42.

```
289 PROC PLOT;
290 PLOT PNOIL*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
291 HAXIS=0 TO 65 BY 5 HSPACE=5;
292 TITLE9 TOTAL SHALE RESIDENCE TIME;
```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 43.

```
293 PROC PLOT; BY PRHT;
294 PLOT PNOIL*TOTREST=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
295 HAXIS=0 TO 65 BY 5 HSPACE=5;
```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 44 TO 45.

```
296 PROC PLOT;
297 PLOT PNOIL*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
298 HAXIS=15 TO 20 BY 0.5 HSPACE=6;
299 TITLE9 HYDROGEN TO SHALE RATIO;
```

NOTE: THE PROCEDURE PLOT USED 0.30 SECONDS AND 236K
AND PRINTED PAGE 46.

```

300      PROC PLOT; BY PRHT;
301      PLOT PNOIL*H2DRS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
302                HAXIS=15 TO 20 BY 0.5 HSPACE=6;

```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 47 TO 48.

```

303      PROC PLOT;
304      PLOT PNOIL*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
305                HAXIS=0 TO 1100 BY 100 HSPACE=6;
306      TITLE9 TOTAL PRESSURE;

```

NOTE: THE PROCEDURE PLOT USED 0.30 SECONDS AND 236K
AND PRINTED PAGE 49.

```

307      PROC PLOT; BY PRHT;
308      PLOT PNOIL*TPRESS=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
309                HAXIS=0 TO 1100 BY 100 HSPACE=6;

```

NOTE: THE PROCEDURE PLOT USED 0.33 SECONDS AND 236K
AND PRINTED PAGES 50 TO 51.

```

310      PROC PLOT;
311      PLOT PNOIL*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
312                HAXIS=0 TO 1100 BY 100 HSPACE=6;
313      TITLE9 HYDROGEN PARTIAL PRESSURE;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 52.

```

314      PROC PLOT; BY PRHT;
315      PLOT PNOIL*H2PRES=LETID/VAXIS=0 TO 100 BY 5 VSPACE=2
316                HAXIS=0 TO 1100 BY 100 HSPACE=6;

```

NOTE: THE PROCEDURE PLOT USED 0.34 SECONDS AND 236K
AND PRINTED PAGES 53 TO 54.

```

317      PROC PLOT;
318      PLOT LBNH3*TOCC=LETID/HAXIS=50 TO 100 BY 5 VZERO;
319      TITLE7 NITROGEN CONVERTED TO AMMONIA;
320      TITLE8 VERSUS;
321      TITLE9 TOTAL ORGANIC CARBON CONVERSION;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 55.

```

322      PROC PLOT; BY PRHT;
323      PLOT LBNH3*TOCC=LETID/HAXIS=50 TO 100 BY 5 VZERO;

```

NOTE: THE PROCEDURE PLOT USED 0.35 SECONDS AND 236K
AND PRINTED PAGES 56 TO 57.

```

324      PROC PLOT;
325      PLOT LBNH3*MAXT=LETID/HAXIS=850 TO 1300 BY 50 HSPACE=7 VZERO;
326      TITLE9 MAXIMUM BED TEMPERATURE;

```

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K

AND PRINTED PAGE 58.

327 PROC PLOT; BY PRHT;
328 PLOT LBNH3*MAXT=LETID/HAXIS=850 TO 1300 BY 50 HSPACE=7 VZERO;

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 59 TO 60.

329 PROC PLOT;
330 PLOT LBNH3*TOTREST=LETID/HAXIS=0 TO 65 BY 5 HSPACE=5 VZERO;
331 TITLE9 TOTAL SHALE RESIDENCE TIME;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 61.

332 PROC PLOT; BY PRHT;
333 PLOT LBNH3*TOTREST=LETID/HAXIS=0 TO 65 BY 5 HSPACE=5 VZERO;

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 62 TO 63.

334 PROC PLOT;
335 PLOT LBNH3*H2DRS=LETID/HAXIS=15.5 TO 20 BY 0.5 HSPACE=6 VZERO;
336 TITLE9 HYDROGEN TO SHALE RATIO;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 64.

337 PROC PLOT; BY PRHT;
338 PLOT LBNH3*H2DRS=LETID/HAXIS=15.5 TO 20 BY 0.5 HSPACE=6 VZERO;

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 65 TO 66.

339 PROC PLOT;
340 PLOT LBNH3*TPRESS=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;
341 TITLE9 TOTAL PRESSURE;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 67.

342 PROC PLOT; BY PRHT;
343 PLOT LBNH3*TPRESS=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 68 TO 69.

344 PROC PLOT;
345 PLOT LBNH3*H2PRES=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;
346 TITLE9 HYDROGEN PARTIAL PRESSURE;

NOTE: THE PROCEDURE PLOT USED 0.31 SECONDS AND 236K
AND PRINTED PAGE 70.

347 PROC PLOT ; BY PRHT;
348 PLOT LBNH3*H2PRES=LETID/HAXIS=0 TO 1100 BY 100 HSPACE=6 VZERO;

NOTE: THE PROCEDURE PLOT USED 0.36 SECONDS AND 236K
AND PRINTED PAGES 71 TO 72.

```
349      PROC PRINT N D; ID LETID;  
350      VAR RUNID TOCC MAXT TOTREST H2DRS TPRESS H2PRES;  
351      TITLE7 EASTERN SHALE DATA BASE;
```

NOTE: THE PROCEDURE PRINT USED 0.30 SECONDS AND 228K
AND PRINTED PAGE 73.

```
352      PROC PRINT N D; ID LETID;  
353      VAR RUNID PN PNNH3 PNOIL LBNH3;  
354      TITLE7 NITROGEN CONVERTED TO PRODUCTS,;  
355      TITLES8 AMMONIA, AND OIL - WT PCT;  
356      TITLE9 AND N2 TO NH3 - LBS PER LB DRS;
```

NOTE: THE PROCEDURE PRINT USED 0.30 SECONDS AND 228K
AND PRINTED PAGE 74.

NOTE: SAS USED 236K MEMORY.

NOTE: SAS INSTITUTE INC.
SAS CIRCLE
PO BOX 8000
CARY, N.C. 27511-8000

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PN*TOCC SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=0

PLOT OF PN*TOCC SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=1

PLOT OF PN*TOCC SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF PN*MAXT SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=0

PLOT OF PN*MAXT SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=1

PLOT OF PN*MAXT SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF PN*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=0

PLOT OF PN*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF PN*TOTREST SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF PN*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO PRODUCTS
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=0

PLOT OF PN*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO PRODUCTS
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=1

PLOT OF PN*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO PRODUCTS VERSUS TOTAL PRESSURE

PLOT OF PN*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

5 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=0

PLOT OF PN*TPRESS SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
TOTAL PRESSURE
SHAPE PREHEATING=1

PLOT OF PN*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF PN*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
HYDROGEN PARTIAL PRESSURE
SHAPE PREHEATING=0

PLOT OF PN*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO PRODUCTS
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=1

PLOT OF PN*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PNNH3*TOCC SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=0

PLOT OF PNNH3*TOCC SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=1

PLOT OF PNNH3*TOCC SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF PNNH3*MAXT SYMBOL IS VALUE OF LETID

MAXIMUM BED TEMPERATURE - DEG F.

NOTE: 2 OBS HIDDEN

215

NITROGEN CONVERTED TO AMMONIA
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=0

PLOT OF PNNH3*MAXT SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=1

PLOT OF PNNH3*MAXT SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

217

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF PNNH3*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=0

PLOT OF PNNH3*TOTREST SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF PNNH3*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF PNNH3*H2DRS SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

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NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN TO SHALE RATIO
SHAPE PREHEATING=0

PLOT OF PNNH3*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=1

PLOT OF PNNH3*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL PRESSURE

PLOT OF PNNH3*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

2 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL PRESSURE
SHAPE PREHEATING=0

PLOT OF PNNH3*TPRESS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL PRESSURE
SHAPE PREHEATING=1

PLOT OF PNNH3*TPRESS SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF PNNH3*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN PARTIAL PRESSURE
SHAPE PREHEATING=0

PLOT OF PNNH3*H2PRES SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN PARTIAL PRESSURE
SHAPE PREHEATING=1

PLOT OF PNNH3*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF PNOIL*TOCC SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHALE PREHEATING=0

PLOT OF PNOIL*TOCC SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=1

PLOT OF PNOIL*TOCC SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF PNOIL*MAXT SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=0

PLOT OF PNOIL*MAXT SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN.

NITROGEN CONVERTED TO OIL
VERSUS
MAXIMUM BED TEMPERATURE
SHALE PREHEATING=1

PLOT OF PNOIL*MAXT SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO OIL VERSUS TOTAL SHALE RESIDENCE TIME

PLOT OF PNOIL*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

3 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=0

PLOT OF PNOIL*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

2 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF PNOIL*TOTREST SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF PNOIL*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO OIL
VERSUS
HYDROGEN TO SHALE RATIO
SHAPE PREHEATING=0

PLOT OF PNOIL*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO OIL
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=1

PLOT OF PNOIL*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL PRESSURE

PLOT OF PNOIL*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

6 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=0

PLOT OF PNOIL*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

5 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=1

PLOT OF PNOIL*TPRESS SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF PNOIL*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=0

PLOT OF PNOIL*H2PRES SYMBOL IS VALUE OF LETID

NOTE: 3 OBS HIDDEN

NITROGEN CONVERTED TO OIL
VERSUS
HYDROGEN PARTIAL PRESSURE
SHALE PREHEATING=1

PLOT OF PNOIL*H2PRES SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION

PLOT OF $\text{LBNH}_3 \cdot \text{TOCC}$ SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHALE PREHEATING=0

PLOT OF $LB\ NH_3 * TOCC$ SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL ORGANIC CARBON CONVERSION
SHAPE PREHEATING=1

PLOT OF LBNH3*TOCC SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
MAXIMUM BED TEMPERATURE

PLOT OF LBNH3*MAXT SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=0

PLOT OF $LB_{NH_3} \cdot MAXT$ SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
MAXIMUM BED TEMPERATURE
SHAPE PREHEATING=1

PLOT OF LBNH3*MAXT SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL SHALE RESIDENCE TIME

PLOT OF $LB\text{NH}_3 \cdot \text{TOTREST}$ SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=0

PLOT OF LBNH3*TOTREST SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL SHALE RESIDENCE TIME
SHALE PREHEATING=1

PLOT OF LBNH3*TOTREST SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN TO SHALE RATIO

PLOT OF LBNH3*H2DRS SYMBOL IS VALUE OF LETID

NOTE:

1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN TO SHALE RATIO
SHAPE PREHEATING=0

PLOT OF LBNH3*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN TO SHALE RATIO
SHALE PREHEATING=1

PLOT OF LBNH3*H2DRS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL PRESSURE

PLOT OF LBNH3*TPRESS SYMBOL IS VALUE OF LETID

NOTE: 2 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL PRESSURE
SHALE PREHEATING=0

PLOT OF LBNH3*TPRESS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
TOTAL PRESSURE
SHAPE PREHEATING=1

PLOT OF LBNH3*TPRESS SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN PARTIAL PRESSURE

PLOT OF $LB\text{NH}_3 \cdot H_2\text{PRES}$ SYMBOL IS VALUE OF LETID

NOTE: 1 OBS HIDDEN

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN PARTIAL PRESSURE
SHAPE PREHEATING=0

PLOT OF $\text{LBNH}_3 \cdot \text{H}_2\text{PRES}$ SYMBOL IS VALUE OF LETID

NITROGEN CONVERTED TO AMMONIA
VERSUS
HYDROGEN PARTIAL PRESSURE
SHAPE PREHEATING=1

PLOT OF $LBNH_3 \cdot H_2PRES$ SYMBOL IS VALUE OF LETID

EASTERN SHALE DATA BASE

LETID	RUNID	TOCC	MAXT	TOTREST	H2DRS	TPRESS	H2PRES
A	8201	85.44	995	57	17.2	1039	896
B	8202	85.28	1000	57	17.6	1012	897
C	8205	87.96	1260	59	16.7	1009	861
D	8206	84.95	1250	60	16.6	1014	839
E	8207	84.48	1000	58	17.4	1011	891
F	8209	86.53	1220	59	17.2	1021	880
G	8211	87.05	1240	57	15.9	1011	875
H	8212	80.73	1000	59	17.8	1024	895
I	8213	67.86	850	30	16.7	1003	892
J	8214	82.57	1000	31	16.5	1001	875
K	8215	74.30	850	62	16.2	1018	904
L	8218	84.86	961	46	15.7	1018	888
M	8219	78.82	965	47	16.0	610	548
N	8220	79.92	980	47	15.9	816	704
O	8221	80.19	1121	46	16.1	609	533
P	8222	79.33	960	47	16.3	816	722
Q	8223	50.98	1020	21	18.7	1017	941
R	8224	75.27	1035	21	19.3	1003	914
S	8225	77.81	974	28	16.2	1017	908
T	8301	69.84	1048	47	16.7	415	366
U	8302	70.41	1050	49	17.0	423	371

N=21

NITROGEN CONVERTED TO PRODUCTS,
AMMONIA, AND OIL - WT PCT
AND N2 TO NH3 - LBS PER LB DRS

LETID	RUNID	PN	PNNH3	PN0IL	LBNH3
A	8201	77.5386	38.8643	38.6743	0.00174050
B	8202	85.7026	42.6981	43.0045	0.00237731
C	8205	92.6691	49.5429	43.1262	0.00257852
D	8206	96.2766	52.0113	44.2654	0.00258108
E	8207	83.8054	32.9831	50.8223	0.00163680
F	8209	91.9166	46.5578	45.3588	0.00225410
G	8211	96.4340	54.9903	41.4436	0.00279548
H	8212	78.0436	35.6158	42.4279	0.00193988
I	8213	55.6227	14.6385	40.9842	0.00076188
J	8214	70.5553	21.0631	49.4922	0.00109625
K	8215	65.2685	22.9585	42.3099	0.00116712
L	8218	75.7261	20.8384	54.8878	0.00103411
M	8219	67.7231	19.6892	48.0339	0.00100092
N	8220	71.5818	21.4440	50.1378	0.00109013
O	8221	76.2286	26.0185	50.2100	0.00132267
P	8222	76.1287	25.6238	50.5049	0.00130261
Q	8223	41.9405	13.0064	28.9342	0.00067693
R	8224	70.2606	25.3825	44.8782	0.00122889
S	8225	70.6686	21.9435	48.7251	0.00122175
T	8301	56.3563	20.2641	36.0922	0.00115278
U	8302	57.2363	19.5449	37.6914	0.00108821

N=21