VOLUME I

REVISED FINAL REPORT

Bench-Scale Testing of On-Line Control of Column Flotation Using a Novel Analyzer (Contract No. DE-AC22-92PC92207)

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EXECUTIVE SUMMARY REVISED FINAL REPORT

Bench-Scale Testing of On-Line Control of Column Flotation Using a Novel Analyzer (Contract No. DE-AC22-92PC92207)

PROJECT INTRODUCTION

This document contains the project final report for a bench-scale coal flotation project performed by Process Technology, Inc. (PTI). The 13-month project was sponsored by the U.S. Department of Energy's (DOE's) Pittsburgh Energy Technology Center (PETC). The project involved testing of an integrated continuous coal flotation circuit combining a KEN-FLOTE™ Flotation Column with PTI's On-Line Quality Monitor and Control System. This cost-shared project was principally funded through DOE's Coal Preparation Program, as part of a High Efficiency Preparation (HEP) Initiative. The HEP Initiative's goals are to assist industry in developing low-cost, near-term solutions for processing coal fines, through bench-scale and pilot-scale projects. PTI provided approximately 11% cost-share for the project.

The 13-month project, performed from October, 1992, through October, 1993, was broken down into three phases. Those phases included:

- Phase I - Preparation: The preparation phase was performed principally at PTI's Calumet facilities from October through December, 1992. It involved building of the equipment and circuitry for the bench-scale testing, as well as some preliminary equipment testing.
- Phase II - Bench-Scale Circuit Installation and Testing: The installation and testing portion of the project was performed at PETC's Coal Preparation Process Research Facility (CPPRF) from January through June, 1993, and was the major focus of the project. It involved testing of a continuous 200-300 lb./hr. flotation circuit using two different bituminous coals.
- Phase III - Project Finalization: The project finalization phase occurred from July through October, 1993, at PTI's Calumet offices. It involved finalizing the analytical work and data evaluation, as well as the final project reporting.

As mentioned, the major focus of the project was the continuous bench-scale testing of the emerging technology (ET Circuit) at PETC's CPPRF. Figure S-1 contains an illustration of the bench-scale testing circuit, including flow balances and all water, air and reagent additions. The coal processing circuit itself was fairly straightforward, consisting principally of a 12"-diameter by 14'-high KEN-FLOTE™ Column that was sampled and controlled by PTI's Multiplexer Sampling System and On-Line Quality Monitor, which were tied into PTI's computer control panel (in the control room and not illustrated in Figure S-1). Although the processing circuit was fairly simple, the state-of-the-art instrumentation, process monitoring and process control made it truly unique.

Figure S-1

PROJECT TEAM

The project team was put together to insure that all expertise required to successfully complete the project was accounted for within the project organization. The team also took advantage of existing licensing agreements and commercial teaming arrangements that had worked well in past commercial installations, and are being organized for the future. The key organizations within the project team included:

- PTI as prime contractor and project manager. PTI managed all subcontracts and provided the operating personnel for the ET Circuit installed at PETC's CPPRF.
- Lincoln Contracting and Equipment Company who was subcontracted to install and commission PTI's ET Circuit at the CPPRF site.
- Engineers and consultants from the University of Kentucky's (UK) Center for Applied Energy Research (CAER). The CAER staff invented the KEN-FLOTE™ Column and was subcontracted to assist in the KEN-FLOTE™ Column design, commissioning and test matrix development, as well as performing dewatering tests to obtain economic information for the final report. PTI has obtained a world-wide license to manufacture and sell the KEN-FLOTE™ Column to the coal and mineral processing industries, and has worked closely with the CAER staff on development and commercialization of the technology.
- Stockhausen Mining Chemicals technical staff provided guidance on flotation reagent additions and flotation control, and will provide assistance for developing a marketing strategy for the technology following the conclusion of the project.

Since the project was performed at PETC's CPPRF site, PETC staff and Gilbert Commonwealth staff (the on-site contractor responsible for operating the CPPRF) also worked closely with PTI on a daily basis to insure completion of the testing matrices and project goals within the tight six-month CPPRF, on-site schedule.

PROJECT GOALS

The three main technologies being integrated within this project included:

- The KEN-FLOTE™ Column Technology
- PTI's On-Line Coal Slurry Quality Monitor
- PTI's Supervisory Control System

The KEN-FLOTE™ Column technology has been under development at UK's CAER for approximately six years, and has been tested through various DOE-sponsored and State-sponsored projects. The KEN-FLOTE™ Column technology has also been commercially installed at Powell Mountain Coal Company's, Mayflower Preparation Plant in St. Charles, Virginia, where four 8' diameter by 22' high KEN-FLOTE™ Columns are presently economically recovering a salable product (7.0 Wt% ash) from a previously discarded 100M x 0 cyclone overflow slurry (40-60 Wt% ash). The Powell Mountain installation occurred in early 1990, and PTI obtained the license to manufacture and sell the KEN-FLOTE™ Column in early 1992.

The second technology (PTI's On-Line Quality Monitor) was invented and developed by PTI over the same six year period (1987-1993). To date, PTI has sold eight On-Line Slurry Monitors to the commercial coal preparation industry. Most of these systems have been installed on existing conventional flotation banks (mechanically agitated cells) to monitor the solids content, ash content, and yield of the various flotation streams.

The third technology is the PTI Supervisory Control System, containing hardware and software that has been specifically developed for on-line, fine-coal preparation plant control. The system is based on Fuzzy Logic algorithms, and will be the basis for PTI's future control system applications. PTI's existing On-Line Quality Monitor commercial installations have included some rudimentary process control algorithms involving adjustment of flotation reagents, based on the On-Line Monitor readings. However, this new supervisory control system offers much more flexibility and artificial intelligence capabilities.

Although the first two technologies involved in the bench-scale project have been previously commercialized, the bench-scale testing project was the first time that both had been integrated into a combined system, including the supervisory control. The general goal of the project was to test PTI's newly developed supervisory control system for column flotation, based on PTI's On-Line Monitor readings, which maximizes column yield while maintaining consistent concentrate quality, for varying feed conditions.

The bench-scale testing for both the Upper Freeport Seam Coal (first coal) and Pittsburgh No. 8 Seam Coal (second coal) was broken down into a multivariable testing stage and a control testing stage. The specific primary goals of the various testing stages included:

- Multivariable Testing Goal #1 - Determine and quantify the impact of key circuit operating variables on the KEN-FLOTE™ Column performance, and select variables to be adjusted during the control testing.
- Multivariable Testing Goal #2 - Determine the accuracy and reliability of PTI's On-Line Quality Monitor measurements for solids and ash contents in the column flotation concentrate and tailings stream, where the monitor had not previously been applied.
- Control Testing Goal #1 - Develop and test control algorithms that adjust key circuit operating variables to achieve the desired column performance (i.e., concentrate ash content and yield), for changing feed conditions.
- Control Testing Goal #2 - Quantify the supervisory control system's ability to reduce concentrate quality variability and increase yield for changing feed conditions.

The remainder of this discussion summarizes the results from the multivariable and control testing stages of the project, with specific emphasis on these primary project goals.

MULTIVARIABLE TESTING RESULTS

Multivariable testing was initiated using the Upper Freeport Seam Coal. However, a number of persistent problems occurred during the bench-scale testing for the first coal that compromised the ability to complete the project goals for this coal. Those problems included:

- Inconsistent and uncontrollable column performance caused by an excessively fine grind (76-87 Wt% minus 400M) and extreme variability of feed composition (24-38 Wt% ash).
- Foaming problems within PTI's On-Line Quality Monitor caused by the high reagent dosages, which limited the accuracy and reproducibility of PTI's On-Line Quality Monitor readings. The low solids content of the flotation concentrate samples, also caused by the fine grind and high reagent dosages, also limited the reliability of the On-Line Monitor readings.

These problems were overcome during the Pittsburgh No. 8 Seam Coal testing (second coal) through improving the coal blending strategy, coarsening of the CPPRF plant grind and by addition of a defoamer to PTI's On-Line Quality Monitor. This led to much more conclusive results for the Pittsburgh No. 8 Seam Coal, particularly with regards to quantifying accomplishment of the specified project goals. For this reason, the remainder of this Executive Summary discussion focuses on the Pittsburgh No. 8 Seam multivariable and control testing results. Discussion of the testing results for the Upper Freeport Seam coal is included within the main body of this Final Report.

The multivariable testing stage for the Pittsburgh No. 8 Seam Coal occurred during the month of May, 1993, and encompassed 46 different multivariable tests (i.e., snapshot tests) run at differing column operating conditions. Each 45-minute multivariable test included a 25 to 30 minute stabilization period, followed by a 15 to 20 minute sampling and ash monitor counting period. The sampling period involved collecting sequential samples of concentrate, tailings and feed, that included a bypass split (sample bucket for lab analysis) and a split for the On-Line Monitor (nuclear counts), as shown in Figure S-1. The goal of the testing was to determine the impact of key process variables on column performance, as well as determine the optimum test conditions for best column efficiency. Several innovations, including a dual-cylinder column approach, a polyacrylic acid addition for pyrite depression, and an On-Line Monitor upgrade to measure pyritic sulfur in the flotation concentrate, were also tested. The variables that provided the best performance sensitivity, while maintaining near optimum column efficiency, were then adjusted during control testing stage which followed.

Table S-1 contains the composite size analysis of the ground feed coal fed to PTI's circuit over the entire duration of the multivariable testing stage. The ground Pittsburgh No. 8 Seam Coal was fed as an approximately 20 Wt% slurry to PTI's agitated feed sump (see Figure S-1). Table S-1 illustrates that the grind was fairly coarse (13.2 Wt% plus 100M) for a flotation circuit feed due to the open-loop dry grinding approach utilized in the existing CPPRF grinding circuit. This coarser grind was utilized to insure that less than 50 Wt% of the feed was ground into the 400M x 0 size fraction, since excessive fines (76-87 Wt% plus 400M) caused column control problems with the Upper Freeport Seam Coal. The coarser grind did cause some loss in yield (approximately 3 Wt%) due to the inability of the KEN-FLOTE™ Column to efficiently recover the 4.3 Wt% plus 50M that was present in the feed (see Table S-1). In an actual plant operation, this plus 50M would be removed from the flotation circuit (screened out) and treated in some other unit operation (water only cyclones, tables or spirals).

Table S-1
FEED COMPOSITE SIZE ANALYSIS
Pittsburgh No. 8 Seam Raw Coal, PETC Grind
(Dry Basis)

Size Fraction (USA Mesh)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
Top x 30M	1.0	28.68	5.19	3.10
30M x 50M	3.3	28.68	5.19	3.10
50M x 70M	3.5	21.50	4.64	2.59
70M x 100M	5.4	18.74	4.74	2.89
100M x 200M	16.0	14.98	5.00	2.96
200M x 400M	22.6	14.08	5.25	3.49
400M x 0	48.2	32.43	3.83	2.45
TOTAL	100.0	24.21	4.47	2.82
HEAD	100.0	23.40	4.51	2.69

Early in the Pittsburgh No. 8 Seam multivariable testing, PTI determined that the KEN-FLOTE™ could be operated efficiently at solids feed rates of 200-300 #/hr., provided the feed solids content was kept fairly high (7-10 Wt%) to allow reasonable retention times (6-8 minutes). Optimum froth wash and launder water additions were found to be approximately 3.5 and 3.0 GPM, respectively, for column feed rates in the range of 6-8 GPM.

Later in the Pittsburgh No. 8 Seam multivariable testing stage, PTI conducted an eight test matrix to determine the relative impacts of the three main potential column control variables, which seemed to have the greatest impact on column performance. They included:

- Reagent Dosages (both MIBC frother and No. 2 Fuel Oil collector).
- Froth Thickness (inches from the top of the column).
- Air Rate Through The Static Sparger (determined in CFM @ 50 psi).

PTI utilized a system developed by researchers at Ames Laboratory at Iowa State University to monitor and control the column froth thickness to within one inch of the desired setpoint. The system utilized multiple DP bubble tubes at various depths within the pulp and froth phases. A variable speed tailings pump was used to maintain the differential pressure of the probes at a certain target, which correspond to the desired froth thickness.

Table S-2 contains the results from the eight test matrix (VT#39-VT#46). There were some differences in feed composition that make the evaluation somewhat difficult. However, in general, it can be observed that the largest differences in composition and yield were caused by the change in reagent dosages from 0.7 and 1.4 #/ton of MIBC and No. 2 Fuel Oil, respectively, to 1.3 and 2.6 #/ton of MIBC and No. 2 Fuel Oil, respectively. The higher reagent dosages in tests VT#43-VT#46 led to significantly higher yields, higher concentrate ash contents, and higher tailings ash concentrates. At a given reagent dosage, the other two changes (froth thickness changes from 30" to 18" and air rate changes from 1.7 CFM to 2.3

CFM) had a less significant and consistent impact on concentrate yield and quality. However, lower froth thicknesses and higher air rates seemed to lead to slightly higher yields and higher concentrate ash contents, for similar feed compositions.

Based on the results from the multivariable testing PTI decided that the column feed rate would be kept fairly low (6.1 GPM) during the control testing, and the froth wash water would be kept fairly high (3.5 GPM) to insure a positive bias (net downward flow) within the column during the Pittsburgh No. 8 Seam control testing. A positive bias was necessary to improve froth washing and minimize concentrate ash content for given reagent dosage. PTI also decided that the principle variables that would be used to alter column performance, during the control testing would be MIBC frother and No. 2 Fuel Oil dosage rates. The reagents would be kept at a 1:2 ratio of MIBC to Fuel Oil, respectively, and altered upward or downward proportionally. The second and third level variables that would be altered, in the cases where MIBC or Fuel Oil reach maximum or minimum acceptable dosage, would be air rate and froth thickness, respectively. The approach and results from the Pittsburgh No. 8 Seam control testing is discussed in more detail later in this summary.

As part of the laboratory testing effort PTI also performed a series of laboratory column tests at PTI's Calumet facilities. Those tests provided anticipated performance information prior to the bench-scale testing. These laboratory flotation tests were performed with representative samples of the same ground Pittsburgh No. 8 Seam Coal, using a 2" diameter by 6' high laboratory KEN-FLOTE™ Column system available at PTI's Calumet laboratories. Table S-3 contains a comparison of the optimum column test results for the Pittsburgh No. 8 Seam Raw Coal that occurred for both the 2" laboratory and 12" bench-scale KEN-FLOTE™ Columns.

For feed coal with similar ash contents (22.0-22.5 Wt%), the performance of the two columns were very similar. The main difference between the results was that the 2" diameter lab column gave a much higher concentrate solids content (28.0 Wt%) than the 12" diameter bench-scale column (12.8 Wt%). This may have been somewhat due to scale-up dynamics that occur on larger columns. However, PTI feels that the air distribution and air aspirator system used within the bench-scale circuit may also have had something to do with the drop in concentrate solids content for the 12" diameter column. The bench-scale column had a lower aspirator cross-sectional area to column cross-sectional area ratio than the 2" diameter column, and therefore had higher air velocities required to meet the air volume flow rate targets. This may have contributed to the lower concentrate solids content and is a phenomena that PTI desires to research further in the future; particularly since it leads to some detrimental side affects, such as requiring much higher froth wash water rates to obtain a positive bias. The low concentrate solids contents reduce the sensitivity of the On-Line Monitor counts to changes in ash content, due to the limited attenuation caused by low solids content, concentrate samples.

Table S-2
DETAILED TEST RESULTS
Pittsburgh No. 8 Seam Multivariable Testing
(Dry Basis)

Test Number	Reagents (#/T)		Froth Thickness (Inches)	Air Rate @ 50 Psi (CFM)	Actual Feed Sample			Concentrate Sample					Tailings Sample		
	MIBC	No. 2 F.O.			Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)	Yield (Wt%)	Comb. Rec. %	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
VT#39	0.70	1.40	30	1.7	23.50	4.99	3.13	62.3	75.7	7.07	3.92	1.73	50.63	4.90	—
VT#40	0.70	1.40	30	2.3	24.29	4.44	2.44	64.4	78.3	7.94	3.99	1.84	53.83	5.36	—
VT#41	0.70	1.40	18	1.7	22.72	4.07	2.26	67.0	78.9	8.96	3.73	1.68	50.66	3.81	—
	0.70	1.40	18	2.3	24.95	4.57	2.91	65.5	78.5	10.06	3.93	1.99	53.27	4.80	—
VT#43	1.30	2.60	30	1.7	24.79	4.87	3.12	74.5	89.3	9.84	4.46	2.36	68.34	4.29	3.55
VT#44	1.30	2.60	30	2.3	21.98	4.71	2.63	78.3	90.6	9.71	4.42	2.24	66.20	4.91	—
VT#45	1.30	2.60	18	1.7	22.22	4.86	2.81	79.9	91.0	11.43	4.58	2.38	65.15	4.70	3.96
	1.30	2.60	18	2.3	26.31	5.56	3.65	73.3	86.2	13.37	4.89	2.88	61.85	5.72	—

Notes: - Comb. - Combustibles

- Yields are based on ash balance from feed, concentrate, and tailings samples.
- All tests performed targeting 250 #/Hr. feed rate and 25.0 Wt% feed solids to PTI's feed sump (undiluted).
- All tests performed with column feed rate of 6.1 GPM at 8.0 Wt% solids with no inner sleeves or polyacrylic acid addition.
- All tests performed with Hammermill set at 4912 RPM with 1/4" screen.
- All tests performed with froth wash bar set at 12", 3.5 GPM froth wash and 3.0 GPM launder water wash.

Table S-3
SCALE-UP PERFORMANCE COMPARISON
OPTIMUM 2" LABORATORY AND 12" PILOT-PLANT COLUMN TESTS
Pittsburgh No. 8 Seam Coal

Column Size (D x H)	Sample	Solids (Wt%)	Dry Basis Results			
			Yield (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
2" x 6'	Feed	5.9	100.0	22.1	3.99	2.30
	Concentrate	28.0*	80.3	10.3	4.25	2.27
	Tailings	1.1	19.7	69.9	2.92	2.42
12" x 14'	Feed	9.1	100.0	22.4	4.43	2.74
	Concentrate	12.8*	77.3	10.0	4.21	2.22
	Tailings	2.2	22.7	64.4	5.18	4.52

Note: - * - Prior to launder water addition.

Despite the solids content concern, the optimum 12" diameter column results seemed to fairly well match the optimum 2" diameter column results when a 10.0 Wt% ash content product was produced. The 12" diameter plant led to only slightly lower yields than the 2" diameter laboratory column (77.3 Wt% versus 80.3 Wt%).

As a further comparison, Figure S-2 contains the ash versus yield relationship plots for some of the optimum 2" laboratory column tests and the optimum 12" diameter, bench-scale column tests. Figure S-2 also contains the washability analysis results and flotation release analysis results for the Pittsburgh No. 8 Seam Raw Coal. All the tests shown in Figure S-2 were performed with feed coal samples obtained from PETC's open loop, dry grinding circuits with feed ash contents in the range of 23-25 Wt%.

As expected, the results illustrate that the best separations were obtained with the washability (i.e., the raw coal liberation), and that there was a progressive deterioration upon going to the flotation release analysis (i.e., the best possible flotation separation), and finally to the 2" diameter laboratory column and 12" diameter plant column tests. Figure S-2 also illustrates that the 2" diameter laboratory column results were slightly more efficient than the 12" diameter bench-scale column in the range of 9-12 Wt% concentrate ash contents.

Figure S-2
ASH VERSUS YIELD PERFORMANCE COMPARISONS
WASHABILITY, RELEASE ANALYSIS AND CONTINUOUS COLUMN TESTS
 Pittsburgh No. 8 Seam Raw Coal, PETC Grind
 (Dry Basis)

Lastly, Figure S-2 illustrates that the curve for the 12" diameter column began to break and flatten out at approximately 10.0 Wt% ash content. Therefore, a concentrate composition of approximately 10.0 Wt% ash content was targeted for the Pittsburgh No. 8 Seam Coal control testing, with target yields being in the range of 70-80 Wt%, for the anticipated variations in feed composition.

CONTROL TESTING APPROACH AND RESULTS

During the month of June, 1993, PTI conducted the Pittsburgh No. 8 Seam Control Testing. The control testing consisted of ten extended runs (WT #1 - WT #10) each with a duration of 6-10 hours. Each run was either a regulatory test (uncontrolled), where reagents, air rate and froth thickness were held constant, or a supervisory test (controlled), where the computer adjusted those variables to target 10.0 Wt% concentrate ash content. Table S-4 contains a listing of the control testing approach for the two types of tests that were performed (regulatory tests and supervisory tests). Table S-4 illustrates that column feed rate, launder wash water rate and froth wash water weight were held constant for all tests. Using the weigh belt feeders and the two product bins, the feed slurry from the CPPRF facility was randomly altered to target the desired feed composition and solids feed rate. One product bin contained raw coal and the other product bin contained a 50/50 raw/precleaned mix, so the subsequent feed coal ash content could be varied to the circuit by changing the blend from the bins.

Table S-4
CONTROL TESTING APPROACH
Pittsburgh No. 8 Seam Coal

	Regulatory Tests	Supervisory Tests
Column Feed Rate	Constant, 6.1 GPM	Constant, 6.1 GPM
Launder Wash Water	Constant, 3.0 GPM	Constant, 3.0 GPM
Froth Wash Water	Constant, 3.5 GPM	Constant, 3.5 GPM
Raw/Precleaned Mix	G/C Vary, 100/0 - 50/50 Wt%	G/C Vary, 100/0 - 50/50 Wt%
Solids Feed Rate	G/C Vary, 220-280 #/hr.	G/C Vary, 220-280 #/hr.
Frother (MIBC)	Constant, 1.0 #/T	Level #1 Control, 0.7-1.3 #/T
Collector (No. 2 Fuel Oil)	Constant, 2.0 #/T	Level #1 Control, 1.4-2.6 #/T
Air Rate (50 PSI)	Constant, 2.0 CFM	Level #2 Control, 1.7-2.3 CFM
Froth Thickness	Constant, 24"	Level #3 Control, 30"-18"

Table S-4 also illustrates that, for the regulatory tests, the reagent dosages, air rates and froth thicknesses were held constant at their optimum levels, determined from the multivariable testing. However, in the supervisory tests, the reagent dosages, air rates and froth thicknesses were altered to target setpoint concentrate quality (10.0 Wt% ash) and a desired column yield range (65-85 Wt%). The methodology of the supervisory control is presented later in the discussion.

As mentioned, the CPPRF used a blending strategy from the product bins to obtain the various feed rates and feed compositions. This blending strategy was used to simulate the expected variability in a commercial plant. Table S-5 shows the blending approach for the six-hour run schedule that was used in the testing. For longer duration tests, the blending pattern was repeated by going back to run hour #1. This approach led to variations in solids feed rate from 220-280 lb/hr, and feed ash content ranges from approximately 20-30 Wt%, which was approximately the desired range for the pattern specified in Table S-4.

Table S-6 shows a simplified version of the control logic for the supervisory (controlled) tests. The on-line control system was used to collect concentrate and tailings samples on 20-minute increments during the testing, and the on-line monitor readings were compared to target concentrate ash content (10.0 Wt%) and yield ranges (65-85 Wt%). Table S-6 shows that the main control variable was concentrate ash content. The control software made step changes on 20-minute intervals based on the magnitude of the difference between the measured concentrate ash content and the desired concentrate ash content, as shown by the magnitude of the responses in Table S-6. However, if yield was outside of the range from 65-85 Wt%, the control logic would override the main control variable and control to maintain yield ranges within 65-85 Wt%.

Table S-5
FEED COMPOSITION AND FEED RATE VARIATIONS
Pittsburgh No. 8 Seam Coal
(6 Hour Schedule)

Run Hour	Bin #1 Raw/Precleaned Mix Average 19 Wt% Ash (Feed Rate, #/hr.)	Bin #2 Raw Coal Average 25 Wt% Ash (Feed Rate, #/hr.)
1	0	250
2	0	280
3	220	0
4	280	0
5	0	220
6	0	250

** Repeat If Necessary **

Table S-6
SUPERVISORY CONTROL LOGIC (SIMPLIFIED)
Pittsburgh No. 8 Seam Coal
(Step Changes on 20-Minute Intervals)

Control Variable	Low	Med. Low	Target	Med. High	High
Main: Conc. Ash Content (Wt%)	<8.5	8.5-9.5	9.5-10.5	10.5-11.5	>11.5
#1 Override: Low Yield (Wt%)	<60	60-65	NA	NA	NA
#2 Override: High Yield (Wt%)	NA	NA	NA	85-90	>90
Response	++	+	0	-	--
Level #1: MIBC (0.7-1.3 #/T)	+2	+1	0	-.1	-.2
Level #1: No. 2 F.O. (1.4-2.6 #/T)	+4	+2	0	-.2	-.4
Level #2: Air Rate (1.7-2.3 CFM)	+2	+1	0	-.1	-.2
Level #3: Froth Thickness (30"-18")	-3.0	-1.5	0	+1.5	+3.0

Notes: - Control Logic also adjusts response based on convergence/divergence.
- Response was based on a weighted average of most recent three readings.

In the control logic, shown in Table S-6, the Level #1 control adjusted both MIBC frother and fuel oil collector between ranges from 0.7-1.3 lb/ton for MIBC and 1.4-2.6 lb/ton for fuel oil. In essence, the fuel oil-to-MIBC ratio was kept at a constant 2:1 ratio with the two reagents being adjusted up and down proportionally. When the Level #1 control reached the maximum or minimum allowable value shown in Table S-6, the control system then jumped into Level #2 control to adjust air rate. If the air rate reached maximum or minimum values, the control system would then jump into the Level #3 froth thickness control. In the case where the

concentrate quality or yield began to reverse itself, the control system worked its way out of Level #3 and Level #2 control, sequentially, back into Level #1 control to stabilize the circuit. This approach worked fairly well for the Pittsburgh No. 8 Seam Coal testing and often led to significant yield improvements as a result of the supervisory control. The remainder of this summary contains a discussion of the yield improvements and economic benefits achieved through the supervisory control.

Table S-7 contains a comparison between regulatory test results and supervisory test results for two comparative tests performed during the early part of the Pittsburgh No. 8 Seam control testing (WT #3 and WT #5). These two tests provide a good basis for evaluation of the supervisory control benefits (i.e., PTI's On-Line Monitoring System benefits), because they both had about the same average feed ash content (24.3 Wt% versus 24.2 Wt%) and feed ash content ranges (approximately 21-31 Wt%). In addition, the average concentrate ash contents were also very close (9.7-9.8 Wt%) and slightly less than the control testing target (10.0 Wt% ash).

During the supervisory test (WT #5), the control system gradually increased reagents in an attempt to reach the 10.0 Wt% ash target. Meanwhile, the regulatory test kept the constant optimum reagent levels to ensure that the 10.0 Wt% ash content limit was not exceeded. As a result, the supervisory test had an approximately 2.8 Wt% yield improvement over-and-above the regulatory testing (73.6 Wt% versus 70.8 Wt%). The combustibles recovery was also significantly higher and averaged an approximately 3.0 Wt% increase (87.5 versus 84.5 Wt%).

Unfortunately, due to the difficulty in obtaining comparable feed conditions from day to day, those increments could not be reproduced in some of the later testing. However, the results in Table S-7 do illustrate the advantages of the supervisory control for obtaining increased yield. It seems feasible that a supervisory control, involving PTI's On-Line Slurry Quality Monitoring System, could increase yields in the range of 2-5 Wt%, provided the readings from the monitor have the following ranges of RMS errors:

- 0.5 Wt% for concentrate sample solids and ash contents,
- 0.5 Wt% for feed sample solids and ash contents,
- 0.5 Wt% for tailings sample solids contents, and
- 2.0 Wt% for tailings sample ash contents.

PTI plans to upgrade a number of components within the on-line monitors source and detector block, to ensure that those RMS error limits can be achieved without requiring excessive recalibration of the unit.

Table S-7
SUMMARY CONTROL TESTING COMPARISONS
Pittsburgh No. 8 Seam Coal

	WT#3 Regulatory Test (6/01/93 - 10 Hr. Run)	WT#5 Supervisory Test (6/07/93 - 6 Hr. Run)
Average Feed Ash (Wt%)	24.3	24.2
Feed Ash Range (Wt%)	21.1-30.7	21.0-29.1
Average Conc. Ash (Wt%)	9.7	9.8
Conc. Ash Range (Wt%)	8.7-11.2	8.6-12.0
Average Yield (Wt%)	70.8	73.6
Yield Range (Wt%)	64.3-75.6	62.8-78.7
Average Comb. Recovery (Wt%)	84.5	87.5
Comb. Recovery Range (Wt%)	79.0-89.4	77.9-90.2

ECONOMIC EVALUATION

The key economic evaluation which can be made, based upon the Pittsburgh No. 8 Seam Coal Control Testing results, was:

- Will the increased yield and improved concentrate quality consistency resulting from the supervisory control system (PTI's On-Line Quality Monitoring System) provide adequate payback on the capital investment?

Table S-8 contains an example of the economics for installing a flotation column supervisory control, based on PTI's On-Line Monitoring System. The economics assume a plant with four 8' diameter x 22' high columns, which is treating a total of 50 tons/hr of 100M x 0 feed coal slurry. The economics also assume that a yield improvement of 3.0 Wt% over-and-above regulatory control could be achieved by adopting a supervisory control (based on the Table S-7 results).

Based on those estimates, and assuming the operating schedule and clean coal price shown in Table S-8, the additional revenues for the supervisory control would be about \$157K per year. When those revenues are compared to the on-line monitoring system capital cost of approximately \$150K (which includes purchase and installation of the On-Line Monitor Control Panel and Multiplexer Sampling System), it appears that a payback period of about one year can be achieved.

In PTI's existing commercial installations, where the on-line monitoring system is used for conventional flotation control, the payback periods have often been substantially less (3-9 months), due to two reasons:

- The higher inefficiency of the uncontrolled conventional flotation circuits, as compared to a tight regulatory control for column flotation circuit, which represent the uncontrolled baseline condition in each case.
- The higher throughput of the conventional flotation circuits, which causes each yield unit increase to correspond to more additional revenues.

Both of these factors magnify the additional revenues achieved through incorporation of PTI's On-Line Monitoring System, for the less-efficient, conventional flotation circuits.

Table S-8
ON-LINE MONITORING SYSTEM ECONOMICS
Comparing Regulatory to Supervisory Control

ASSUMPTIONS

- Plant With Four 8' Diameter x 22' High Columns
- Columns Treat 50 TPH of 100M x 0 Feed Coal Slurry
- Operate 14 Hrs./Day, 5 Days/Wk., 50 Wks./Yr. (3,500 Hrs./Yr.)
- Yield Increase of 3.0 Wt% Due to Supervisory Control (1.5 TPH)
- Clean Coal Price of \$30 Per Ton (Dry Basis)

SUPERVISORY SYSTEM PAYBACK PERIOD

- On-Line Monitoring System Cost \$150K (Including Installation)
- Additional Revenues of \$157K Per Year (1.5 TPH * 3500 Hr/Yr * \$30/Ton)
- Payback Period of Approximately One Year

CONCLUSIONS

The preceding discussion of the bench-scale testing results for the Pittsburgh No. 8 Seam Coal, including the economic evaluation, illustrated that the project goals were successfully completed for the Pittsburgh No. 8 Seam Coal testing. The On-Line Monitoring and Control System showed the potential to improve yield while maintaining product quality. Payback periods of one year or shorter should be realized.

Throughout the course of the project, PTI also learned valuable information on what hardware, software and approaches worked, as well as what aspects of PTI's available products (both the KEN-FLOTE™ Column and the On-Line Monitor) needed to be improved. The well controlled environment within PETC's CPPRF offered ideal conditions to test and implement this technology on a continuous, well-controlled bench-scale basis. The ability to accurately monitor, test, and sample the CPPRF-installed circuit was pivotal toward obtaining conclusive results with regards to the overall project goals. PTI's previous experience with on-line monitoring systems in commercial flotation applications have proven that it very difficult to quantify improvements, or even obtain reliable sampling results in commercial plants.

For the Pittsburgh No. 8 Seam Coal testing, the primary project goals were all demonstrated and accomplished to varying degrees. These accomplishments included:

- Multivariable Testing Goal #1 - PTI determined and quantified the impact of key circuit variables on the KEN-FLOTE™ Column performance, and selected three variables (reagent dosages, air rate, froth height) to be adjusted during the control testing.
- Multivariable Testing Goal #2 - PTI determined the accuracy of PTI's On-Line Monitor to be within ± 0.5 Wt% (RMS error) for concentrate sample solids and ash content, as well as tailings sample solids content. Tailings sample ash contents were accurate only to within ± 4.0 Wt% (RMS error).
- Control Testing Goal #1 - PTI developed and tested control algorithms which adjusted the three key operating variables to achieve the desired column performance (10.0 Wt% concentrate ash content at 65-85Wt% yields) for changing feed conditions.
- Control Testing Goal #2 - PTI quantified the supervisory control system's ability to maintain concentrate quality (10.0 Wt% ash) and increase yield (approximately 3.0 Wt%), for changing feed conditions.

The main limitation of the integrated supervisory control system was the difficulty in obtaining accurate ash content measurements for low solids content column tailings streams, due to the interdependency of solids and ash content measurements. A second limitation of the integrated system was the drift in PTI's On-Line Monitor nuclear detection system electronics, which necessitated frequent recalibration to maintain accurate On-Line Monitor readings for concentrate samples (± 0.5 Wt% RMS error for solids and ash contents).

Based on the project findings, PTI feels there are a number of improvements which must be made in the KEN-FLOTE™ Column technology and the on-line monitor to improve the commercial feasibility of the column flotation supervisory control system. The main modifications being proposed, based on the results from this bench-scale project, are to alter the hardware which will be used within all future PTI On-Line Monitors. Those modifications include:

- Changing to a dual-isotope source (1 mCi ^{137}Cs and 1 mCi ^{241}Am) rather than the single-isotope source (1 mCi ^{241}Am) presently used, so that independent solids and ash content measurements can be made for the various flotation slurry samples.
- Substituting solid state sodium iodide (NaI) crystal detectors and associated electronics for the xenon gas-filled proportional counters and electronics used in previous On-Line Monitors, which are subject to drift and frequent recalibration requirements.

These modifications should, not only, improve the accuracy and reduce the recalibration requirements within the any future applications, but should also improve reliability, as the gas-filled detectors are also prone to failure in strenuous and vibratory plant environments.

The main area for improvement within the KEN-FLOTE™ Column technology is to research alternative aspirator designs and column designs, which can both:

- Increase the concentrate solids content obtained from the column, and
- Decrease the reagent addition requirements to obtain acceptable yields in larger units.

Both of these factors will, improve column economics, through reduced reagent cost and reduced downstream dewatering costs. These improvements should also increase the accuracy of PTI's On-Line Monitoring System measurements for concentrate samples through potentially eliminating the need for the defoaming reagent, as well as allowing better sensitivity of concentrate ash content measurement due to the higher solids content of the concentrate stream.

VOLUME I

REVISED FINAL REPORT

**Bench-Scale Testing of On-Line Control of Column Flotation
Using a Novel Analyzer
(Contract No. DE-AC22-92PC92207)**

SECTION 1 - INTRODUCTION

This document contains the Final Report for PTI's bench-scale testing project of a circuit integrating PTI's KEN-FLOTE™ Column Flotation technology and PTI's On-Line Quality Monitor and Control System. The 13-month project involved installation and testing of a 200-300 lb/hr., bench-scale coal flotation circuit at PETC's Coal Preparation Process Research Facility (CPPRF) for two bituminous coals (Upper Freeport and Pittsburgh No. 8 Seam Coals). Figure 1 contains the project plan, as well as the approach, to completing the major tasks within the 13-month project schedule. The project was broken down into three phases, which included:

- Phase I - Project Preparation: The project preparation phase was performed principally at PTI's Calumet facilities from October through December, 1992. It involved building of the equipment and circuitry, as well as some preliminary equipment testing.
- Phase II - ET Circuit Installation and Testing: The installation and testing phase of the project was performed at PETC's CPPRF from January through mid-June, 1993, and was the major focus of the project. It involved testing of the continuous 200-300 lb/hr coal flotation circuit.
- Phase III - Project Finalization: The project finalization phase occurred from July through October, 1993, at PTI's Calumet offices. It involved finalizing analytical work and data evaluation, as well as the final project reporting.

This Revised Final Report summarizes the results from all the major tasks within the project, including all of the results from the bench-scale testing with both coals. It also contains an economic evaluation of the technology that PTI demonstrated during the project, as well as recommendations for improvements which must be made prior to implementing the technology at a commercial scale.

Figure 2 contains the 13-month project schedule, on a task-by-task basis. The project was originally scheduled for 12 months, but was extended to 13 months to accommodate an additional three weeks of bench-scale testing.

Figure 1
PROJECT PLAN AND APPROACH

Figure 2
PROJECT SCHEDULE TIMELINE
(By Month)

Figure 3 contains PTI's Emerging Technology (ET) Circuit flowsheet including flow balances which occurred during the testing. The major pieces of equipment within the circuit included:

- The Agitated Feed Sump and Pump to accept product from the existing CPPRF comminution circuit and feed it to the KEN-FLOTE™ Column at the desired capacity (GPM and Wt% solids). PTI and PETC staff targeted a nominal 100M topsize grind (90-95 Wt% passing 100M) for the project.
- The 12" diameter x 14' high KEN-FLOTE™ Column, which was equipped with removable inner sleeves, which were used to test PTI's dual-cylinder design option.
- The column tailings pump which was used to control the froth/pulp interface level within the column.
- PTI's Multiplexer Sampling System which automatically collected samples of column feed, product and tailings, and divided the samples into a split for PTI's Quality Monitor and a bypass split for ASTM analysis (5-gallon bucket).
- PTI's On-Line Quality Monitor which made the nuclear measurements on the sample splits reporting to the monitor and correlated the resultant measurements to compositions obtained from the bypass split. This information was then used to determine calibration relationships which were eventually used to control the column performance (yield and product quality) during the control testing portion of the testing for both coals.
- Circuit Discharge Sump and Pump which pumped the circuit product streams to the CPPRF thickener or sludge tank for solid/liquid separation and water recycling.

The column tailings pump was controlled by a software algorithm based on reading from multiple DP bubble tubes in the froth and pulp phase on top of the column. This approach was first tested at Ames Laboratory at Iowa State University, and proved much more feasible for maintaining tight froth depth control than conventional DP transducer and valve combinations. PTI utilized Ames' approach, which provided froth depth control to within one inch of the desired setpoint.

The ET Circuit also contained state-of-the-art instrumentation which tightly controlled the material balance within the circuit from PTI's Control Room Computer, which is not illustrated in the diagram in Figure 3.

As illustrated in Figure 1, the Phase I - Project Preparation tasks were completed during the months of October through December, 1992, at PTI's Calumet facilities. PTI subcontracted Lincoln Contracting of Boswell, Pennsylvania to install the circuit at the CPPRF, and Lincoln Contracting assisted PTI with the conceptual design during Phase I. Lincoln Contracting also built the skid modules into which the modular circuit was installed in December, 1992. The schedule of events at the CPPRF (Phase II) that occurred from the beginning of the installation through the decommissioning were as follows:

- December 28, 1992, through January 20, 1993 - PTI and Lincoln Contracting completed mechanical and electrical installation of the ET Circuit at the CPPRF, including the electrical tie-in of PTI's control room computer and mobile laboratory.
- January 25 through February 5, 1993 - PTI completed functionality testing and water commissioning of the ET Circuit to ensure that there were no circuit leaks and the circuit could be accurately monitored and balanced using the as-installed, plant instrumentation.

Figure 3
ET CIRCUIT FLOWSHEET AND FLOW BALANCES

- February 8 through February 26, 1993 - PTI conducted the coal/water slurry commissioning using the Upper Freeport Seam Coal.
- February 26 through March 30, 1993 - PTI conducted the multivariable testing for the Upper Freeport Seam Coal (Coal #1). A vast range of test conditions were implemented during this testing matrix to evaluate impacts of process variables and obtain Quality Monitor final calibrations for the control testing.
- April 2 through April 18, 1993 - A two-week break in the testing to allow DOE staff to perform maintenance on the existing CPPRF circuits, and to allow PTI to compile sample analyses and data evaluation.
- April 19 through April 30, 1993 - PTI conducted the control testing for the Upper Freeport Seam Coal (Coal #1).
- May 3 through May 28, 1993 - PTI completed the multivariable testing for the Pittsburgh No. 8 Seam Coal (Coal #2).
- June 1 through June 16, 1993 - PTI completed the control testing for the Pittsburgh No. 8 Seam Coal (Coal #2).
- June 17 through June 23, 1993 - PTI staff completed decommissioning of the ET Circuit.

The remaining four months of the project (July through October, 1993) were spent finalizing the analytical and data evaluation, as well as completing all required project reporting. The next section outlines the project goals and objectives for the bench-scale testing which was conducted at the CPPRF during the Phase II portion of the project.

SECTION 2 - PROJECT GOALS AND OBJECTIVES

The 13-month bench-scale testing project involved combining two commercially available technologies being marketed by PTI, with a third control technology currently under development. The technologies include:

- The KEN-FLOTE™ Flotation Column which PTI licensed from the University of Kentucky's (UK's) Center for Applied Energy Research (CAER) in late-1991. The KEN-FLOTE™ Column has been extensively tested at both laboratory and bench-scales in past DOE- and privately-sponsored coal flotation projects. The technology has also been commercialized at Powell Mountain Coal Company's Mayflower Preparation Plant, located in St. Charles, Virginia, where four 8' diameter x 22' high columns are recovering fine coal from a 100M x 0 classifying cyclone overflow stream.
- PTI's On-Line Quality Monitor which measures solids and ash content in flotation feed and product slurries. PTI's On-Line Quality Monitor has been installed and tested in conventional flotation circuits at six coal preparation plants in the United States and Canada, and is presently being used for some limited flotation control within those facilities.
- PTI's Supervisory Computer Control Instrumentation and Software, which was developed specifically for this project, and any future commercial On-Line Monitor

installations. The Supervisory Control System was designed with an extensive degree of flexibility and artificial intelligence capability, so it can be used in many fine-coal preparation circuits.

The overall objective of this development effort was to integrate the KEN-FLOTE™ Column with PTI's On-Line Quality Monitoring and Control System to provide an efficient, computer-controlled flotation system which can achieve high flotation efficiency and circuit yield for varying feed conditions, while maintaining the required coal product specifications. This bench-scale testing project represented a first step in evaluating the feasibility of the approach, prior to moving toward commercialization of the system.

This bench-scale testing for each coal was broken down into a multivariable testing stage (where short duration matrix tests were performed) followed by a control testing stage (where longer duration variability tests were performed). The primary project goals for the two testing stages included:

- Multivariable Testing Goal #1 - Determine and quantify the impact of key circuit operating variables on KEN-FLOTE™ Column performance, and select variables to be adjusted during the control testing.
- Multivariable Testing Goal #2 - Determine the accuracy and reliability of PTI's On-Line Quality Monitor measurements for solids and ash content in the column flotation concentrate and tailings streams, where the monitor had not previously been applied.
- Control Testing Goal #1 - Develop and test control algorithms that alter the key circuit operating variables to achieve desired column performance (i.e., concentrate ash content and yield), for changing feed conditions.
- Control Testing Goal #2 - Quantify PTI's On-Line Control System's ability to reduce concentrate quality variability, and increase column yield (i.e., increase revenues), for changing feed conditions.

In addition, PTI also incorporated three secondary project goals (i.e., project research goals), which were tested during the multivariable stage of the project. Those secondary goals included:

- Evaluate the performance of polyacrylic acid dispersant as a depressant for pyrite.
- Determine the applicability of PTI's dual-cylinder column option for improving flotation performance over-and-above the standard KEN-FLOTE™ Column design.
- Determine the ability of PTI's On-Line Quality Monitor to measure pyritic sulfur content of the flotation concentrate when an X-Ray fluorescence (XRF) system has been incorporated into the existing nuclear source/detector configuration. The XRF system was designed to measure iron k-alpha, x-rays which had been previously correlated to pyritic sulfur contents.

Both the dual-cylinder column design and the XRF pyritic sulfur measurement showed some promise when tested at a laboratory-scale at PTI's Calumet facilities as part of other DOE-sponsored projects (Phase I SBIR program). The polyacrylic acid, pyritic sulfur depressant had also been tested in previous laboratory studies done by DOW Chemical personnel. The secondary project goals were to evaluate the feasibility of these novel approaches and design upgrades in a continuous bench-scale application, where they had never previously been tested.

This Final Report contains a complete discussion of the project approach, as well as the results from the testing, as they relate to the specific goals listed above. The shortcomings of various components evaluated during the project, as well as PTI's overall integrated column control system being developed by PTI are discussed, with particular emphasis on the improvements that need to be made before the system is scaled up to larger commercial applications.

SECTION 3 - PROJECT TEAM ORGANIZATION

The project team was put together to ensure that all expertise to successfully complete the project was accounted for within the project organization. The team also took advantage of existing licensing agreements and commercial teaming arrangements that have worked well in past commercial installations, and are being further organized for the future. Figure 4 contains the project team organization chart, including the PETC/CPPRF personnel involved in the project. The key organizations within the project included:

- DOE/PETC Project and Site Management Staff.
- PTI Project Management and Site Personnel, as well as PTI Laboratory Technicians required to do the analytical work performed at PTI's Calumet facilities.
- Gilbert Commonwealth (GC) Engineers and Technicians who operated the existing CPPRF circuit that provided feed coal to PTI's bench-scale testing circuit. GC staff also assisted in the decommissioning effort.
- Lincoln Contracting and Equipment Company who was subcontracted to install and commission PTI's ET Circuit at the CPPRF site.
- University of Kentucky Engineers and Consultants who assisted in the KEN-FLOTE™ Column debugging and testing, as well as performing dewatering tests to obtain economic information for the Final Report.
- Stockhausen Mining Chemical's Technical Consultants who provided guidance on flotation reagent additions and flotation control, and will provide assistance in developing market strategies for the technologies after the project is completed.

As Figure 4 illustrates, PTI's Principle Investigator/Project Manager was Peter Suardini, PTI's Vice President of Research and Development. He was stationed in Calumet, Michigan and was responsible for all project reporting and technical project management, as well as management of PTI's laboratory efforts (including QA/QC). He was also responsible for all communications, reporting and contracting requirements with DOE's Technical Project Manager (Carl Maronde) and DOE's Contract Specialist (Eric Bell). Mr. Suardini also substituted as Site Manager on the project on certain occasions to give Robert Greenlund a break from on-site work.

Figure 4
PROJECT TEAM ORGANIZATION CHART
 (Including Key Project Personnel)

As mentioned, PTI's Site Manager at the CPPRF was Robert Greenlund, PTI's Senior Engineer and KEN-FLOTE™ Column Product Manager. As PTI's Site Manager, Mr. Greenlund managed the day-to-day engineering and technical aspects of the project, including overseeing Lincoln's subcontract and PTI's engineers and technicians that were stationed at the CPPRF during the second phase of the project. PTI decided to split these responsibilities for overall project management and project task management because of the heavy work load. This approach worked well in coordinating the project and minimizing schedule slippages and miscommunications.

SECTION 4 - PROJECT ACCOMPLISHMENTS BY TASK SERIES

As discussed, PTI divided the 12-month project into three separate phases. Figures 5 through 7 contain the schedule by major task series and subtasks for each of the three project phases. The schedules in Figures 5 through 7 are broken down on a weekly basis and represent the actual schedule by which the project was accomplished, not merely the initial plan. The figures include:

- Figure 5: Phase I - Project Preparation Schedule, by task and subtask (October 5, 1992, through December 24, 1992).
- Figure 6: Phase II - Circuit Installation and Testing Schedule, by task and subtask (December 28, 1992, through June 25, 1993).
- Figure 7: Phase III - Project Finalization Schedule, by task series (June 28, 1993, through October 29, 1993).

The schedule assumes submission of this Revised Final Report will occur sometime in the week of September 27, 1993, and that the Revised Final Report will be completed and submitted by October 29, 1993. Those are the only project reporting or task requirements still outstanding.

The remainder of this section summarizes the project accomplishments by the various tasks listed in Figures 5 through 7. The discussion includes the approach to accomplishing each task series, as well as a chronology of events that led to the various decisions made during the project. The Task 1100 - Data Evaluation Section contains the detailed discussion of the testing results with respect to the primary and secondary project goals.

SECTION 4.1 - TASK 100: PROJECT PLANNING AND MANAGEMENT

PTI's Bench-Scale Testing Project was the first project performed on-site at PETC's CPPRF. It also was conducted under a condensed and aggressive 13-month project schedule (October 1, 1992 through October 31, 1993). Therefore, efficient planning, management and communication was vital for the success of the project. As mentioned earlier, PTI divided responsibilities for project management between PTI's Project Manager (Pete Suardini) and PTI's Site Manager (Bob Greenlund). PTI's Project Manager was responsible for all project reporting, as well as management of the prime contract and subcontracts. The Project Manager also coordinated all contract communications during the Phase I and Phase III portions of the project. PTI's Site Manager coordinated day-to-day efforts at the CPPRF during the Phase II, and made strategic decisions on the testing plan, based on the overall project goals.

Figure 5
 PHASE I: PROJECT PREPARATION
 SCHEDULE BY TASK AND SUBTASK
 (Weekly Basis for 13-Month Project)

Figure 6
 PHASE II: PROJECT PREPARATION
 SCHEDULE BY TASK AND SUBTASK
 (Weekly Basis for 13-Month Project)

Figure 7
**PHASE III: PROJECT PREPARATION
 SCHEDULE BY TASK AND SUBTASK**
 (Weekly Basis for 13-Month Project)

Task	Description	Weeks Are Listed By First Day in Week																
		1993																
		Jun. 28	Jul. 05	12	19	Aug. 02	09	16	23	30	Sept 06	13	20	27	Oct. 04	11	18	25
100	PROJECT PLANNING AND MANAGEMENT																	
	101 Notice of Energy R&D Project																	
	102 Draft Project Work Plan (ESH and QA/QC Plan)																	
	103 Final Project Work Plan (ESH and QA/QC Plan)																	
	104 Hazardous Substance Plan																	
	105 NEPA and Environmental Assessment Questions																	
	106 Milestone Schedule, Labor and Cost Plans																	
	107 Project Management Plan																	
	108 Draft ET Circuit Design Report (Two SSA's)																	
	109 Final ET Circuit Report (Two SSA's)																	
	110 Procurement and Fabrication Plan																	
	111 Installation and Shakedown Plan																	
	112 Coal Procurement, Handling and Logistics Plan																	
	113 Operation and Maintenance Manual																	
	114 Test, Sampling and Analytical Plan																	
	115 Decommissioning Plan (Equipment List)																	
200	EQUIPMENT AND CIRCUIT, DESIGN AND PROCUREMENT																	
	201 Equipment Design and Procurement																	
	202 Circuit Design Finalization																	
300	EQUIPMENT FABRICATION, CONSTRUCTION AND SHAKEDOWN																	
	301 Equipment Fabrication and Construction																	
	302 Equipment Shakedown																	
400	SOFTWARE DEVELOPMENT																	
	401 PTI Monitor Software Alterations																	
	402 Initial Circuit Software Programming																	
	403 Circuit Software Finalization (Coal No. 1)																	
	404 Circuit Software Finalization (Coal No. 2)																	
500	CIRCUIT FABRICATION AND INSTALLATION																	
	501 Skid Fabrication																	
	502 Equipment Mounting																	
	503 Skid and Equipment Installation																	
	504 Piping and Electrical Installation																	
600	COAL PROCUREMENT																	
	601 Initial Coal Procurement																	
	602 Preliminary Lab Testing																	
	603 Coal No. 1 Procurement and Blending																	
	604 Coal No. 2 Procurement and Blending																	
700	CIRCUIT COMMISSIONING AND SHAKEDOWN																	
	701 Water Commissioning																	
	702 Slurry Commissioning																	
800	CIRCUIT TESTING AND SAMPLE PREP																	
	801 Preliminary Multivariable Testing (Coal No. 1)																	
	802 Primary Multivariable Testing (Coal No. 1)																	
	803 Control Testing (Coal No. 1)																	
	804 Primary Multivariable Testing (Coal No. 2)																	
	805 Control Testing (Coal No. 2)																	
900	PTI ANALYTICAL																	
1000	CIRCUIT DECOMMISSIONING																	
1100	DATA EVALUATION																	
1200	FINAL REPORTING																	
	1201 DOE Property Report																	
	1202 Hazardous Waste Report																	
	1203 Draft Final Report																	
	1204 Revised Project Final Report																	

Table 1 contains a listing of one-time project reports which PTI was required to submit at the appropriate times during the project. The one-time reporting requirements provided a method for DOE to review PTI's work plan and assess the applicability of the work plan to achieve not only the project goals, but also meet PETC's contracting and on-site Environmental Safety and Health (ESH) regulations. The one-time project reporting was a key element of the overall project planning process.

To satisfy the requirements of the National Environmental Policy Act (NEPA) documentation was prepared evaluating the full environmental consequences of the project. Based on this information, a categorical exclusion was granted.

Table 2 contains the periodic project reporting requirements, which PTI submitted on a regular basis (weekly, monthly and quarterly). The contract and financial reporting provided a means to check project accomplishments and spending-to-date, versus the initial schedule and spending plans. The monthly financial reporting provided an excellent means to assess the financial situation of the project and make necessary adjustments in the project work plans to assure that the overall project schedule and budget were met.

The lower part of Table 2 contains the routine technical reporting requirements. These weekly, monthly and quarterly status reports provided a chronology of the project successes and failures, as well as a means to document changes in the project work plan, which were required as the project progressed. The routine technical reporting requirements also ensured that PTI kept up-to-date on the data evaluation for the project. The monthly and quarterly technical status reports provided the detailed data evaluations used for this final report.

SECTION 4.2 - TASK 200: EQUIPMENT AND CIRCUIT, DESIGN AND PROCUREMENT

The equipment and circuit design and procurement task occurred over the first six weeks of the project (October 1 through November 15, 1992). During this period, PTI and Lincoln Contracting finalized the equipment layout for the ET Circuit, including the design of the skid modules, onto which the equipment was to be located. PTI also finalized the design of the 12" diameter KEN-FLOTE™ Column (with internal sleeves) and PTI's On-Line Quality Monitor (adapted with pyritic sulfur monitoring capabilities). Table 3 contains a list of all the major processing and process control equipment which had to be purchased for the project, as well as ancillary equipment which was either procured or set up to do the CPPRF testing.

In mid-November, PTI submitted a draft ET Circuit Design Report which detailed the equipment and circuit design and listed all the processing equipment and instrumentation which were required to be purchased as part of the project. PTI received the authorization to purchase those items during the late-November time frame so that they could be obtained in time for the late-December installation date. A copy of PTI's skid module design drawings, including the equipment locations, is included in Appendix B.

Table 1
ONE-TIME PROJECT REPORTING REQUIREMENTS

Description	Submission Dates
1. Notice of Energy R&D Project	October 07, 1992
2. Draft Project Work Plan (ESH & QA/QC Plan)	November 03, 1992
3. Final Project Work Plan (ESH & QA/QC Plan)	December 02, 1992
4. Hazardous Substance Plan	October 15, 1992
5. NEPA Categorical Exclusion Licensing & Environmental Assessment Questionnaires	October 09, 1992
6. Milestone Schedule, Status and Cost Plans (Forms)	October 12, 1992
7. Project Management Plan	December 22, 1992
8. Draft ET Circuit Design Report (SSA/ESH Plan)	November 16, 1992
9. Final ET Circuit Design Report (SSA/ESH Plan)	December 18, 1992
10. Procurement and Fabrication Plan	November 19, 1992
11. Installation and Shakedown Plan	December 11, 1992
12. Coal Procurement, Handling & Logistics Plan	January 02, 1993
13. Operation and Maintenance Manual	January 27, 1993
14. Test, Sampling and Analytical Plan	February 02, 1993
15. Decommissioning Plan (Equipment Lists)	June 07, 1993
16. DOE Property Report	September 01, 1993
17. Hazardous Waste Report	September 01, 1993
18. Draft Final Report	September 28, 1993
19. Revised Project Final Report	October 29, 1993 *

* Proposed Submission Date

Table 2
PERIODIC PROJECT REPORTING REQUIREMENTS

I. Contract and Financial Reporting Requirements

Description	Frequency
1. Project Invoicing	Monthly
2. Cost Management Forms	Monthly
3. Labor Management Forms	Monthly
4. Milestone Schedule/Status Forms	Monthly
5. Financial Summary Report	Monthly

II. Technical Reporting Requirements

Description	Frequency
1. Schedule/Status Sheet	Weekly
2. Technical Status Report	Monthly
3. Key Personnel Staffing Report	Quarterly
4. Technical Progress Report	Quarterly
5. Consolidated and Capital Equipment Listings	Semi-Annual

Table 3
MAJOR PROCESSING, PROCESS CONTROL AND ANCILLARY EQUIPMENT

I. Processing Equipment List

1. Column Feed Sump
2. Variable Speed Column Feed Sump Agitator
3. Variable Speed Column Feed Pump
4. KEN-FLOTE™ Column (12" x 14')
5. Variable Speed Column Tailings Pump
6. Circuit Discharge Sump
7. Circuit Discharge Pump (Air Operated)
8. Three Variable Speed Reagent Pumps

II. Process Control Equipment and Instrument List

1. PTI's 3-Stream Multiplexer Sampling System
2. PTI's On-Line Quality Monitor (Including Control Room Computer and Modem)
3. PTI's Pyritic Sulfur Monitoring Gauge
4. Column Feed Sump Level Controller (DP Cell and Valve)
5. Five Magnetic Flowmeters
 - Column Feed Sump Dilution Water Line
 - Column Feed Line
 - Column Tailings Line
 - Column Spray Water Line
 - Column Launder Water Line
6. Column Air Flowmeter and Control Valve
7. Four DP Transducers For Column Interface Detection
8. Special Input/Output Module For Computer

III. Ancillary Equipment List

1. Office Trailer Installation and Office Equipment (Fax and Phone)
2. Spare Parts (Control and Processing Equipment)
3. Mobile Laboratory, Including Dust Collection System and Pressure Filters
4. Process Frames, Gauges, Valves and Regulators (Small Manual Items)

SECTION 4.3 - TASK 300: EQUIPMENT FABRICATION, CONSTRUCTION AND SHAKEDOWN

During the period from November 1 through December 23, 1992, PTI constructed all major processing equipment for the project. Table 4 contains a detailed listing of the major pieces of equipment, including the unit size, throughput capacity, and power, air and water requirements. The major items included:

- The 12" diameter x 14' high KEN-FLOTE™ Flotation Column, which was constructed by Calumet Machine Company in Calumet, MI (a local machining and fabrication shop subcontracted by PTI). A drawing of PTI's 12" diameter x 14' high KEN-FLOTE™ Demonstration Column, which was used for the bench-scale testing, is shown in Figure 8.
- PTI's On-Line Quality Monitoring System, including the Multiplexer Sampling System, PTI's On-Line Quality Monitor and PTI's Computer Control Panel, which were constructed at PTI's Calumet facility by PTI staff.
- The Column Feed Sump, including the Variable Speed Agitator and Variable Speed Column Feed Pump, which were mounted on the small platform for bolting to the floor skid module that Lincoln Contracting constructed.
- The Reagent Storage Rack, including the three Variable Speed Reagent Pumps and Reagent Storage and Containment Area, which was also mounted to the floor skid module that Lincoln Contracting constructed.
- The Variable Speed Column Tailings Pump and associated framework, which would be mounted on the main skid modules that were constructed by Lincoln Contracting.
- The Circuit Discharge Sump and Pump (air operated) which also was to be mounted on the main skid modules that were constructed by Lincoln Contracting.
- The frameworks for PTI's On-Line Quality Monitor, Multiplexer and KEN-FLOTE™ Flotation Column, which would allow for proper location of the On-Line Monitor, Multiplexer and Column on the vertically stacked skid modules being constructed by Lincoln.

During the same time period, Lincoln Contracting was finalizing the design and constructing the four skid modules, onto which PTI's equipment would be installed. On December 7, 1992, PTI shipped all of the above mentioned equipment, with the exception of the On-Line Quality Monitor and Computer Control Panel, to Lincoln Contracting for pre-installation on the skid modules, prior to going to the PETC site. The On-Line Quality Monitor and Computer Control Panel were kept at PTI for additional testing and precalibration during the week of December 21, 1992, to ensure that all operational problems were worked out of the monitor prior to the installation period. The On-Line Quality Monitor, Computer Control Panel and all fragile instrumentation were then taken to site for installation on December 28, 1992, in PTI's Mobile Laboratory for the installation task, which began during that same week.

Table 4
DETAILED LIST OF MAJOR EQUIPMENT

<u>Equipment</u>	<u>Unit Size</u>	<u>Throughput Capacity</u>	<u>Power</u>	<u>Air</u>	<u>Water</u>
Reagent Pumps (3)	5"Dia x 10"L	.06-6ml/min.	110 VAC	---	---
Feed Sump	20"L x 20"W x 54"H	42 Gal	---	---	5.5-10 GPM
Agitator	36"L Shaft	---	110 VAC	---	---
Sump DP Cell & Controller	6"L x 6"W x 8"H	2.5' Span	110 VAC	---	---
Column Feed Pump (Moyno)	28.75"L x 11.75"W x 9"H 2 x 2 Size	25 GPM	240 VAC, 1 ϕ	---	---
Slurry Monitor	36"L x 36"W x 72"H	5 Gal	110 VAC	50 CFM @ 80 psi	0-4 GPM
Control Panel	36"L x 26"W x 72"H	---	110 VAC	---	---
Circuit Discharge Sump	24"L x 18" W x 24"H	35 Gal	---	---	---
Circuit Discharge Pump (Air)	11.25"L x 10.2"W x 4.13"H 1 x 1 Size	30 GPM	---	35 CFM @ 70 psi	---
Multiplexer	36"L x 36"W x 42"H	20 GPM	110 VAC	.5 CFM @ 80 psi	0-4 GPM
Column Tailings Pump (Moyno)	28.75"L x 11.75"W x 9"H 2 x 2 Sizes	25 GPM	240 VAC, 1 ϕ	---	---
KEN-FLOTE TM Column	12"ID x 15'H	12 GPM	---	5 CFM @ 40 psi	1.6-8.1 GPM
Mobile Laboratory	Truck	---	240 VAC, 1 ϕ	---	---
Miscellaneous	---	---	110 VAC	10 CFM @ 80 psi	0-3 GPM

PROCESS
TECH

PROTECH TECHNOLOGY, INC.
812 CALVERT AVENUE
GALVESTON, TEXAS 77550-1708
(713) 337-0883
FAX (713) 337-0823

PIU'S KEN-FLOTE COLUMN

1. NO.	2. DATE	3. BY	4. REVISED

SECTION 4.4 - TASK 400: SOFTWARE DEVELOPMENT

The project software programming was broken down into two major efforts. The first effort was the initial software development, which occurred from November, 1992, through January, 1993, and included:

- Alteration of PTI's existing On-Line Monitoring System software, and
- Preliminary circuit control software programming.

The final software development efforts were of shorter duration and occurred in early April and early June, 1993, and included:

- Finalization of the control software for Coal #1 (Upper Freeport Seam Coal).
- Finalization of the control software for Coal #2 (Pittsburgh No. 8 Seam Coal).

Figures 5 and 6 illustrate the scheduling of the various software development tasks.

PTI's Staff Engineers performed the initial software development during the months of November, 1992, through January, 1993. Although the control software for the combination of PTI's On-Line Quality Monitor, Multiplexer Sampling System and Computer Control Panel had already been developed, three modifications were required for the bench-scale testing project. Those modifications included:

- Substitution of 3-way valves for the sample splitting system inside PTI's On-Line Quality Monitoring System. PTI felt that accurate division of each sample into two splits (one that goes into the monitor and that goes into an ASTM sample bucket) was not possible due to the low flowrates being used. Therefore, a toggling valve was installed above the On-Line Monitor feed sump. For each sample, the valve would be toggled to get six separate cuts into the Monitor and six separate cuts into the bypass sample bucket. The software was altered to ensure that the valve would provide the proper amount for both the analyzer portion and the bypass split, while meeting ASTM requirements to obtain a gross sample from coal process testing (at least six cuts per stream).
- The Multiplexer interface software also had to be slightly modified due to the addition of a Level Probe within PTI's On-Line Quality Monitor receiving sump.

The final initial modification was writing the nuclear software to make the pyritic sulfur measurement through the iron k-alpha, X-ray backscatter measurement. This programming was done in the late December, 1992, time frame, once the final version of the Pyritic Sulfur Gauge (source/detector/block combination) had been designed, fabricated and tested using appropriate Upper Freeport Seam Coal samples.

The November, 1992, through January, 1993, time frame was also used to develop the preliminary control software for the ET Circuit installed at the CPPRF. Figure 9 contains a P&ID illustration of all the field instrumentation which PTI utilized for the ET Circuit. The drawing contains an illustration of all instruments monitored by PTI's Computer Control Panel (CM), as well as all instruments controlled by PTI's Computer Control Panel (CC). Although the circuit itself was fairly simple, the process, monitoring and control were state-of-the-art.

Table 5 contains a listing of all the computer monitored instruments (inputs) which were incorporated into PTI's ET Circuit. The inputs include level measurement, liquid flow (GPM), and air flow (CFM), as well as a number of inferred or calculated inputs. By comparison, Table 6

Figure 9
ET CIRCUIT INSTRUMENTATION

TECH

PROCESS TECHNOLOGY, INC.
102 CALUMET AVENUE
CALUMET, ILLINOIS 61113-1031
(815) 337-0000
(815) 337-0001
(815) 337-0002

PROJECT NO.	DE-AC22-92
DATE	01-08-91
REVISED	
BY	
CHECKED	
APPROVED	

PDCA FLOW DIAGRAM

Table 5
PTI PROCESS "MONITORING" INSTRUMENTATION
(Inputs to PTI Computer from Circuit)

Measured Variables	Comments
1. Level in Feed Sump (%)	Received from Local Foxboro DP Controller
2. Feed Sump Dilution Water (GPM)	Factory Calibrated Magnetic Flowmeter ($\pm 2\%$)
3. Column Feed Rate (GPM)	Factory Calibrated Magnetic Flowmeter ($\pm 2\%$)
4. Column Tailings Rate (GPM)	Factory Calibrated Magnetic Flowmeter ($\pm 2\%$)
5. Column Froth Wash Water (GPM)	Factory Calibrated Magnetic Flowmeter ($\pm 2\%$)
6. Column Launder Water (GPM)	Factory Calibrated Magnetic Flowmeter ($\pm 2\%$)
7. Air Flow through Aspirator (CFM)	Factory Calibrated Mass Flowmeter ($\pm 5\%$)
8. Column Froth Head Pressure	2 DP Level Probes (Air Bubblers)
9. On-Line Monitor Readings	Vacuum Pressure, Sump Level, Probe Status, and Nuclear Detector Timed Count Information
Inferred or Calculated Inputs	Comments
1. Column Concentrate Rate (GPM)	Inferred from Flow Balance of Other Streams
2. Column Froth/Pulp Interface	From Existing DP Level Probe Calibration
3. Concentrate and Tailings Solids and Ash Content	From Specific Sample Nuclear Counts and Existing Calibration Relationships

Table 6
PTI PROCESS "CONTROL" INSTRUMENTATION
(Outputs From PTI Computer to Circuit)

Controlled Variables	Means of Control	Based on Setpoint Target For
1. Column Froth Wash Water (GPM)	Electronically Actuated Valve	Water Magnetic Flowmeter
2. Column Launder Water (GPM)	Electronically Actuated Valve	Water Magnetic Flowmeter
3. Air Flow Through Aspirator (CFM)	Electronically Actuated Valve	Air Mass Flowmeter
4. Reagent Additions (#/T)	Reagent Pump RPM	Existing Pump Calibration
5. Column Feed rate (GPM)	Feed Pump RPM	Feed Magnetic Flowmeter
6. Column Froth/Pulp Interface Level	Tailings Pump RPM	Existing DP Probe Calibration
7. Analyzer and Bypass Sample Collection	Sequencing Multiplexer Valve and Toggling Analyzer Valve	Level in Analyzer Fill Sump
8. Analyzer Operation	Analyzer Control Software	---

contains a listing of all the computer controlled variables (outputs) which were controlled by PTI's Computer Control Panel using various instruments located in the field. The controlled variables included water addition rates (GPM) and air flow rate (CFM) which were controlled by electronically actuated valves. The Computer Control Panel also controlled variable speed reagent pumps and Moyno slurry pumps to provide the desired reagent additions and flow rates, respectively, throughout the ET Circuit during the testing phase.

This preliminary software development was all completed by the end of January, 1993, prior to beginning the circuit commissioning in February, 1993. Minor modifications in the software programming were made during the commissioning period to ensure that the circuit could be properly operated during the testing portion of the project.

The final control software development for both coals was performed prior to the control testing stage based on the results from the multivariable testing. The control testing software which was written was specific to the response of each coal, as observed during the multivariable testing. The control software was written to provide tight control of flotation concentrate quality and yield for varying feed conditions and took approximately one week of programming time to be completed. The logic and approach to the control testing software is discussed in more detail in the data evaluation section (Section 4.11).

SECTION 4.5 - TASK 500: CIRCUIT FABRICATION AND INSTALLATION

The circuit fabrication and installation task began with the final design and construction of the skid modules by Lincoln Contracting at their Boswell, Pennsylvania facility (November 27 through December 23, 1992). It also encompassed the four week installation period (December 28, 1992, through January 22, 1993) when Lincoln Contracting installed the circuit at PETC's CPPRF. Figure 10 contains a CAD drawing of the skid module circuit that Lincoln Contracting installed in the ET Circuit area of the CPPRF. Figure 11 contains a schematic illustration of the circuit to help verify any components which cannot be identified from the CAD drawing in Figure 10. The various skid modules, illustrated in Figure 10, included:

- The Floor Skid Module, which had a 5' x 8' footprint and was approximately 5' high. It was offset from the main vertically-stacked skid modules to allow for gravity flow from the CPPRF grinding circuit. It included the column feed sump, agitator and pump, as well as the reagent rack containing the three flotation reagent feeders and catch-basins.
- The Elevation 1086 Skid Module on the ground floor (12' x 10' footprint and 10' high) which contained PTI's On-Line Quality Monitor and the circuit discharge sump and pump.
- The Elevation 1096 Skid Module (12' x 10' footprint and 10' high) which was mounted on top of the 1086 Skid Module and included the lower portions of the KEN-FLOTE™ Column, the Multiplexer Sampling System and the column tailings pump.
- The Elevation 1106 Skid Module (8' x 10' footprint and 10' high) which was mounted on top of the 1096 Skid Module and contained the mounting supports for the various sections of the KEN-FLOTE™ Column, as well as the KEN-FLOTE™ Column feed line.

Figure 10

Figure 11
ET CIRCUIT FLOWSHEET AND FLOW BALANCES

- The Elevation 1116 Top Framework (8' x 10' footprint and 3' high) which sat on top of the 1106 Skid Module and merely contained the framework for the top column sprays and launders, as well as the mounting components for the differential pressure air bubble tubes.

The total height of the vertically mounted skid module was 34'-3" and it reached approximately 3' from the ceiling of the CPPRF building. All remaining drawings from the ET Circuit Design Report are included in Appendix B.

PTI and Lincoln Contracting began installation of the ET Circuit on December 28, 1992. The installation of the equipment was completed on January 22, 1993. Figure 12 contains the overhead layout of PTI's ET Circuit equipment, including all outside PTI installations that were required at the CPPRF. The final week of December, 1992, concentrated on placement of PTI's main skid module stack and floor skid on the location shown in Figure 12. PTI and Lincoln Contracting also located PTI's Computer Control Panel and all process equipment into their final locations within the skid module during the final week of December, 1992. During December, 1992, GELCO Space also delivered the office trailer, which contained PTI's office equipment, phone and fax machine. Gilbert Commonwealth provided the electrical installation for the office trailer and also a drop-off of a 100 amp 220 service for PTI's Mobile Laboratory, which was brought to site in early January, 1993. PTI's Mobile Laboratory was temporarily located at the east end of the parking lot for the duration of PTI's ET testing project. All piping and electrical runs for the ET Circuit and the ancillary equipment was completed during the period from January 2 through January 22, 1993.

A complete listing of the design, fabrication, construction and installation requirements, which Lincoln Contracting followed, are listed in Table 7. Lincoln Contracting also had a welder and an electrician on-site during the commissioning period to correct any flaws within the circuit which appeared during the functionality and shakedown testing. PTI signed off on Lincoln's installation subcontract on January 29, 1993. The ESH permits for the ET Circuit were then obtained on February 8, 1993, after DOE safety and environmental inspections were completed and all problems were corrected.

SECTION 4.6 - TASK 600: COAL PROCUREMENT AND LAB TESTING

Based on PTI's previous experience with other DOE-sponsored projects, PTI selected two coals which had the proper characteristics for the bench-scale testing project. The two coals were Upper Freeport Seam Raw Coal from Valley Camp's Helen Mine in Homer City, Pennsylvania and Pittsburgh No. 8 Seam Raw Coal from Ohio Valley Coal Company's Powhatan No. 6 Preparation Plant in Alledonia, Ohio.

The two coals were selected for a number of reasons, which include:

- They both exhibit good flotation behavior (relatively low reagent addition requirements).
- They both have ash contents between 25 Wt% and 30 Wt%, which is common in existing natural fine streams.
- They both have high pyritic sulfur contents, with the majority of the sulfur being present in the pyritic form.

Figure 12
LAYOUT OF PTI'S ET CIRCUIT EQUIPMENT
AND OUTSIDE INSTALLATIONS

Table 7
ET CIRCUIT DESIGN, FABRICATION, CONSTRUCTION
AND INSTALLATION REQUIREMENTS FOR LINCOLN CONTRACTING

1. Finalize design and construction drawings for module, skid, and equipment support structure. Lincoln additions will include flooring, handrails, bracing and lighting.
2. Supply all process and utility piping, hoses, steel, flooring, electricals and lighting for fabrication and installation of the circuit. In general, all that is required beyond PTI's equipment list.
3. Fabricate structure, bracing, flooring and handrails.
4. Receive equipment from PTI (except Quality Monitor) via truck and install on modules skids as much as possible prior to going to PETC for installation.
5. Follow and abide by all applicable local, state and federal codes.
6. Follow the PETC Health and Safety Guidelines for the facility while on site.
7. Install all structure, equipment, piping, hoses, fittings, electricals, and lighting of the ET Circuit, including tie-in points to CPPRF Circuit. Final electrical connections to the Analyzer, Multiplexer and Control Room Computer will be performed by PTI.
8. Provide power and grounding to mobile laboratory breaker box.
9. Provide assistance through the Equipment Functionality Testing part of the Commissioning and Shakedown phase of the project to take corrective action for:
 - a. piping and hose leaks
 - b. equipment electrical supply problems
10. Clean site area of construction debris.
11. Correct any damage occurring through installation to CPPRF property to make whole to the acceptance of the DOE COR.

In addition, they have an extensive data base from previous DOE-sponsored advanced coal cleaning projects, conducted by PTI and other DOE contractors. In earlier studies, PTI has found that the vast majority of the ash and pyrite present in these coals are liberated from the coal matrix after nominal 100M topsize grinding (80-90 Wt% passing 100M). Therefore, testing the efficiency of ash and pyritic sulfur removal would be very applicable for these coals, even at the relatively coarse nominal 100M grind which was used for the ET Circuit testing.

Task 600 was broken down into four subtasks, which included:

- Initial Coal Procurement
- Preliminary Lab Testing
- Final Coal #1 Procurement
- Final Coal #2 Procurement

The initial coal procurement was done early in the project to allow for the required preliminary lab testing at PTI's Calumet facilities prior to the ET Circuit installation. The final coal procurement was done to procure approximately 50 tons of each coal for the ET Circuit Testing.

SECTION 4.6.1 - INITIAL COAL PROCUREMENT AND PRELIMINARY LAB TESTING

During the first week of October 19, 1992, PTI visited both of the specified mining facilities and collected a one drum specimen raw coal from the existing stockpiles. Table 8 shows the composition which was obtained from head analysis on the one drum specimens. Both samples had high moisture contents (8-10 Wt%), due to the recent wet weather. Precautions were taken to insure that the samples obtained later, during the final procurement, would be taken from deep within the piles to minimize the moisture content and improve the handling characteristics of the coal that was obtained for the bench-scale testing.

Table 8
RAW COAL ANALYSES
(Dry Basis, Except Moisture)

Coal Seam	Size Content	Date Procured	Quantity Procured	Ash (Wt%)	Sulfur (Wt%)	Pyritic Sulfur (Wt%)	Heating Value (Btu/lb.)
Upper Freeport	3/4" x 0	10/20/92	300 lb.	27.09	2.48	1.77	11,080
Pittsburgh No. 8	2" x 0	10/20/92	300 lb.	28.40	5.17	2.94	10,318

The Upper Freeport Seam Coal (the first coal to be tested) was ground down to nominal 100 mesh top size and used for preliminary testing performed during the October-December, 1992, time frame. Those tests included:

- A number of continuous column tests performed using PTI's 2" diameter x 6' tall laboratory KEN-FLOTE™ Column. The testing was done to determine preliminary ranges of reagent dosages, froth height, air rates and feed rates (i.e., retention time) that could be used as initial targets in the upcoming bench-scale testing. The 2" laboratory column tests also were used to assess the anticipated performance of the pyritic sulfur depressant (polyacrylic acid).

- Conduct a series of source/detector block configuration tests to determine the optimum source/detector block design for good pyritic sulfur sensitivity. This testing was done as part of a Phase I DOE SBIR Project, but was very applicable to the On-Line Monitor design for the bench-scale testing.
- Debug and test PTI's On-Line Monitor in late December, 1992, and develop preliminary calibrations for both ash and pyritic sulfur.

The 2" diameter tests with KEN-FLOTE™ Column tests were repeated for the Pittsburgh No. 8 Seam Raw Coal during the months of January through March, 1993, to obtain similar information for the second coal. However, the source/detector block design testing and On-Line Monitor testing were only performed using various qualities of the Upper Freeport Seam Coal. Appendices C and D contain all of the results from the 2" laboratory column tests performed with both coals, respectively. The conclusions from the 2" laboratory column tests will be summarized in Section 4.8 - Task 800: Circuit Testing and Sample Preparation, and Section 4.11 - Task 1100: Data Evaluation.

The remainder of this section discusses the results from the source/detector block configuration tests and On-Line Monitor debugging, done with various compositions of 100M x 0 Upper Freeport Seam Coal. Figure 13 shows the test rig schematic for the source/detector block configuration tests, which were performed as part of the Phase I SBIR Project. The system utilized a source rod containing the same ^{241}Am source that PTI uses in its existing On-Line Quality Monitor. PTI tested a number of detectors and window options (within the sample container) to determine which components led to the best sensitivity of pyritic sulfur measurement. PTI also determined the optimum angle which gave high iron k-alpha peak intensity, while providing good sensitivity to various coal pyritic sulfur contents.

During the pyritic sulfur sensitivity testing, a number of samples were made up by mixing the Upper Freeport Seam Raw Coal with 100M x 0 pure pyrite and 100M x 0 Float 1.30 Upper Freeport Seam Coal (less than 0.5 Wt% pyritic sulfur). Figure 14 contains the correlation between actual pyritic sulfur content of the test samples and the pyritic sulfur predicted from iron k-alpha measurement calibrations. All tests were done using a 10.0 Wt% solids 100M x 0 feed coal slurry. The results showed promise. However, the resolution began to deteriorate at pyritic sulfur contents below 2.0 Wt%. More detailed results of the laboratory x-ray fluorescence testing can be obtained through PTI's 1992 Phase I SBIR Project Report.

Based on the results from the source/detector block testing conducted in September through November, 1992, PTI designed the final source/detector block for the On-Line Monitor used in the bench-scale testing project. Figure 15 contains a conceptual drawing of the source/detector block utilized within the On-Line Monitor. The system contained PTI's normal electronics and also utilized the same 1 mCi ^{241}Am source used in previous On-Line Monitors. The drawing shows a more sensitive neon-filled proportional counter with 2 mil beryllium window as the selected XRF detector, due to its better sensitivity than the xenon-filled proportional counter. The block was designed to allow for the ability to change the polyethylene window fairly quickly, and also try the more durable xenon-filled proportional counter if they proved sensitive enough. Prior to bringing the On-Line Monitor to the PETC site, a series of debug tests were performed using 100M x 0 samples of Upper Freeport Seam Coal, made up as a 10.0 Wt% solids slurry. The samples were made up as mixtures of Float 1.30 Upper Freeport Coal (6 Wt% ash) and Upper Freeport Raw Coal (26.5 Wt% ash).

Figure 13
XRF TEST RIG SCHEMATIC

Figure 14
PYRITIC SULFUR CORRELATION PLOT
Upper Freeport Seam Coal
(10.0 Wt% Solids, 100M x 0 Feed Coal Slurry)

Figure 15
COAL SLURRY SOLIDS, ASH AND PYRITIC SULFUR ANALYZER
 BASED ON GAMMA-RAY ATTENUATION AND X-RAY FLUORESCENCE
 (Conceptual Drawing)

Figure 16 a comparison of the lab ash contents and predicted ash contents obtained from the initial ash content calibration for the On-Line Monitor. The left side of Figure 16 contains a scatter plot illustrating the correlation between actual and predicted ash content values. The RMS error was rather high (around 1.5 Wt%), but this was a much wider ash content range than would be seen for any flotation feed or concentrate streams. In summation, the results from the initial ash content calibration were about what would be expected for PTI's On-Line Quality Monitor.

Unfortunately, there was no consistent relationship observed for the iron k-alpha, x-ray measurements to obtain a pyritic sulfur correlation. PTI decided to attempt to try different detectors and vary the window size during the bench-scale testing of the project. However, the preliminary results done during the debug testing showed little promise that this prototype system would have the required sensitivity to obtain on-line pyritic sulfur measurements. The discussion in Section 4.11 - Task 1100: Data Evaluation discusses the results from the bench-scale testing for the XRF pyritic sulfur measurement in more detail.

SECTION 4.6.2 - FINAL COAL PROCUREMENT AND BLENDING

The final procurement for the two coals was done just prior to beginning the bench-scale testing. PTI and DOE staff decided to obtain approximately 50 tons of each coal to insure that an adequate supply was available for all of the testing. Table 9 contains a listing of the raw coal analyses for both of the bulk coal samples, as well as the quantity and date on which the sample was procured. Both coals were obtained from deep in the raw coal piles, which minimized the moisture content (approximately 5 Wt%) and reduced subsequent handling problems within the CPPRF feed systems.

Figure 16
ASH CORRELATION PLOT
Upper Freeport Seam Coal
(10.0 Wt% Solids, 100M x 0 Feed Coal Slurry)

Ash Contents (Wt%)		
Lab	Pred	Error
26.36	24.31	2.05
26.36	26.45	-0.09
17.19	15.71	1.48
17.19	17.45	-0.26
10.55	11.01	-0.46
10.55	10.65	-0.10
8.14	8.50	-0.36
8.14	6.70	1.44
5.95	6.83	-0.88
5.95	4.60	1.35
13.94	16.02	-2.08
13.94	16.01	-2.07

Table 9
RAW COAL ANALYSES
(Dry Basis, Except Moisture)

Coal Seam	Size Content	Quantity Procured	Date Procured	Ash (Wt%)	Sulfur (Wt%)	Pyritic Sulfur (Wt%)	Heating Value (Btu/lb.)
Upper Freeport	3/4" x 0	54 tons	1/12/93	26.15	2.54	1.89	11,207
Pittsburgh No. 8	2" x 0	50 tons	3/08/93	23.40	4.51	2.69	11,097

After procurement, both coals were shipped to Dillner Storage in West Elizabeth, Pennsylvania. Dillner Storage was within 15 miles of the CPPRF facility, and was subcontracted by PTI to blend and store the coals to be used in the CPPRF testing.

Upon receiving the bulk coal shipment Dillner blended each of the coals into one conical pile. Dillner then long piled the 50-ton bulk sample into an approximately 8' wide x 50 yd. long "long pile". One ton slices were removed from the long pile using a small bucket loader, and

systematically placed into eight smaller lots that ended up being about 6 tons each. This approach was used to provide eight 6-ton lots, which were of approximately the same composition, and could be brought to PETC individually to feed into the raw coal and product bins at the CPPRF facility. This approach was required as the CPPRF interim storage could only hold approximately six tons of feed material. The various lot compositions obtained during the testing are included in the discussion in Section 4.11 - Task 1100: Data Evaluation.

SECTION 4.7 - TASK 700: CIRCUIT COMMISSIONING AND SHAKEDOWN

Upon completion of the circuit installation on January 22, 1993, PTI and PETC staff scheduled an inspection by PETC ESH staff to observe the circuit and comment on any safety or environmental infractions prior to commissioning. PTI's operational procedures were also reviewed by the PETC ESH staff. A number of minor short comings were observed and corrected by PTI and Lincoln staff prior to the beginning of the shakedown and commissioning on January 25, 1993. The commissioning task was broken down into three stages, which occurred along the following schedule:

- Equipment and Instrumentation Functionality and Leak Testing - The functionality and leak testing occurred from January 25 through January 29, 1993, and was the last task in which Lincoln installation personnel were involved. The major noted shortcoming was the inability of the air control ball valve to accurately control air flow to the aspirators in the column. A globe valve was substituted for the ball valve, and by the end of the week all instrumentation was deemed functional. The leak testing also proved that the circuit had sealed integrity and Lincoln Contracting was relieved of responsibility for the circuit on January 29, 1993.
- Circuit Water Commissioning - Circuit water commissioning occurred from February 1 through February 5, 1993. This task focused on precalibration of all flowmeters and instruments within the circuit, and insured that a proper flow balance could be maintained, as well as that the plant instrumentation was accurate within the required ranges.
- Coal Water/Slurry Commissioning - This was the final aspect of the commissioning period, and was scheduled to occur from February 8 through February 12, 1993. Unfortunately, there were problems that occurred during the initial coal water/slurry commissioning (tests CT#1-CT#7) and the slurry commissioning had to be repeated the week of February 22 through February 25, 1993, (DT#1-DT#6).

The entire commissioning period actually lasted for five weeks (from January 25 through February 26, 1993). Table 10 contains a list of the various equipment, functionality and calibration tasks that were involved in the subtasks within the commissioning period.

Table 11 contains the test matrix for the initial commissioning tests (CT#1-CT#7) that were conducted the week of February 8 through February 12, 1993. The tests focused on determining the required reagent dosages and air rates to obtain acceptable circuit yields and qualities. The tests also focused on fulfilling a number of QA/QC aspects of the testing, including:

- Determining the variability of feed material, as well as repeatability and reproducibility of PTI's sampling approach.

- Checking the stabilization time for the column.
- Determining the repeatability and reproducibility of PTI's On-Line Monitor counts.

During the initial commissioning tests (CT#1 - CT#7) PTI incurred problems with the peristaltic reagent pumps being used for the frother, collector and pyrite depressant additions. During the following week, PTI replaced the peristaltic pumps with piston-type pumps, which were not subject to flow variation, caused by changing liquid viscosity (due to temperature) or the wear on the reagent addition lines. The piston feeders held their calibration for the remainder of the project.

After the reagent change was made the series of commissioning tests, shown in Table 11, were repeated as tests DT#1-DT#6 during the week of February 22 through February 25, 1993. The test conditions and results from all of the commissioning tests are shown in Appendix A, and will be discussed in more detail in Section 4.11 - Task 1100: Data Evaluation. However, the following major conclusions were drawn from the commissioning tests:

- A 25 minute stabilization time was required between the multivariable tests, for the column performance to restabilize.
- MIBC frother provided higher yields and selectivity at given reagent dosages than Betz M-150 frother, and was substituted as the flotation frother to allow for lower reagent additions.
- The recycled process water from the CPPRF thickener contained excessive residual flocculant and had a detrimental affect on column performance when the recycled process water was used in the column circuit.

The decision was therefore made to switch to MIBC frother and use city water for all water additions within PTI's circuit. The water system then became a one pass system, with the clarified water being discharged into the local water treatment system.

SECTION 4.8 - TASK 800: CIRCUIT TESTING AND SAMPLE PREPARATION

The bench-scale circuit testing and sample preparation task was the major focus of the project, and was conducted at PETC's CPPRF from February 26 through June 16, 1993. The bench-scale testing for each coal was divided into two testing stages, which included:

- Multivariable Testing, and
- Control Testing.

The multivariable testing focused on a large number (50-80) of short duration tests (45 minutes) to observe the impact of key operating variables on column performance. The control testing focused on a small number (8-10) of extremely long duration tests (6-10 hours) to determine the variability of circuit performance caused by uncontrolled feed composition variations, and if PTI's On-Line Monitoring System could reduce the variability caused by feed composition changes, and improve the overall circuit performance over an uncontrolled environment.

Table 10
EQUIPMENT AND SYSTEM
COMMISSIONING AND SHAKEDOWN

<u>PROCESS EQUIPMENT</u>	<u>Functionality Testing</u>	<u>Leak Testing</u>	<u>Water Commissioning & Calibration</u>	<u>Coal Slurry Commissioning & Calibration</u>
Column Feed Sump		X		
Column Feed Sump Agitator (MC)	X			
Column Feed Sump (CC)	X		X	X
KEN-FLOTE™ Column (12" x 14")		X	X	X
Column Tailings Pump (CC)	X		X	X
Circuit Discharge Sump		X		
Circuit Discharge Pump (MC)	X		X	X
3 Reagent Feeders (CC)	X		X	X
 <u>PROCESS CONTROL EQUIPMENT/INSTRUMENTATION</u>				
PTI's 3-Stream Multiplexer	X	X	X	X
PTI's On-Line Quality Monitor	X	X	X	X
Column Feed Sump Level Controller	X			
5 Liquid Magnetic Flow Meters	X		X	X
2 Circuit Flow Control Valves	X			
1 Air Flow Meter	X		X	
1 Air Flow Control Valve	X			
4 DP Level Transducers (Column)	X		X	X
 <u>ADDITIONAL SYSTEMS</u>				
PTI's Mobile Laboratory System	X			
Clarified Water Header System		X		
City Water Header System		X		
Compressed Air Header System		X		

Notes: - (MC) - Manual Control - Circuit discharge pump (air operated) and column feed sump agitator (electrical) will be adjusted manually by a local air valve and a local drive adjustment, respectively.

- (CC) - Computer Control - Variable speed motors controlled by 4-20 mA analog signal from PTI's computer control panel.

Table 11
TEST MATRIX FOR COMMISSIONING TESTS
(Upper Freeport Seam Raw Coal)

<u>Date</u>	<u>Test</u>	<u>Reagents (#/T)</u>		<u>Air Rate (CFM)</u>	<u>Description of Samples Taken</u>
		<u>Frother</u>	<u>Collector</u>		
2-10-93	CT#1	0.4	0.6	2.0	6 feed samples to check variability; one every 5 minutes.
2-11-93	CT#2	0.6	0.8	2.0	6 product and tailings samples every 10 minutes to check stabilization time.
2-11-93	CT#3	0.4	0.6	2.0	6 product and tailings samples every 10 minutes to check stabilization time.
2-11-93	CT#4	0.5	0.5	2.0	Regular test sampled product, tailings, and feed. Duplicated Monitor counts.
2-11-93	CT#5	0.4	0.6	2.0	Sample Repeatability Test. Sampled product, tailings, and feed twice each. Duplicated Monitor counts.
2-12-93	CT#6	0.4	0.6	3.0	High air rate test. Sampled product, tailings, and feed. Duplicated counts.
2-12-93	CT#7	0.6	0.8	3.0	Duplicate of Test #6, but higher reagents.

Notes: - 45 total slurry samples and 1 feed lot sample.
 - All tests done at targets of 6% solids, 3.0 GPM launder and froth wash water, 28" froth height, and 50 PSI air pressure.

SECTION 4.8.1 - MULTIVARIABLE TESTING APPROACH

Based on the results of the commissioning tests, PTI determined a test plan for the multivariable testing, which would be performed for each coal. Table 12 contains an outline of the testing logistics for each 40-50 minute duration multivariable test that was performed during the project. The multivariable tests were designed to be short duration (i.e., snap-shot) tests where the column was allowed to stabilize under certain testing conditions and samples of sample concentrate, tailings and feed were collected at those steady state conditions.

Table 12
MULTIVARIABLE TESTING LOGISTICS
(40-50 Minute Test Duration)

1. Startup and Set Target Conditions.
2. Monitor Circuit Until All Target Conditions are Met ($\approx$ 5 Minutes).
3. Allow 20 Minutes Column Stabilization Time.
4. Initiate Data Logging, Wait 5 Minutes.
5. Initiate Concentrate, Tailings and Feed Sampling Cycle (Pump On).
 - Multiplexer Valve Diverts Sample and Defoamer is Added.
 - Analyzer Valve Toggles Between Analyzer (5 Seconds) and Bypass (1 Second).
 - Analyzer Fills, Multiplexer Valve Returns and Defoamer is Off.
 - After Filling, Analyzer Draws Vacuum (18 in. H₂O).
 - Nuclear Measurements are Taken.
 - Analyzer Drains and Entire System Rinses.
 - Repeat For Next Sample, Until Cycle is Complete ($\approx$ 15 Minutes).
6. Set Target Conditions For Next Test, and Return to Step 2.

Table 13 contains the multivariable testing approach for both the Upper Freeport and Pittsburgh No. 8 Seam Raw Coals. The Upper Freeport Seam was the first coal tested, and the multivariable testing was broken up into two steps. The first step was the preliminary multivariable testing, where the ranges of the various operating variables were first determined. Based on the 33 preliminary multivariable results, the 87 primary multivariable tests were then conducted.

Table 13 contains the ranges of the various operating variables, as well as the multiplier quantifying the number of tests that were required to cover each operating range. In most cases two-to-four different levels of each variable were tested within the range. However, note that the multiplier only shows 1.5 to 2.0, due to the fact that all options within the set ranges of the variables could not be tested. The test matrices had to be somewhat fragmented to keep the number of total tests within a reasonable range for the available plant operating time.

Table 13
MULTIVARIABLE TESTING MATRICES
 Upper Freeport and Pittsburgh No. 8 Seam Raw Coals
 (All Tests Done With City Water and Nominal 100M Topsize Feed Coal)

I. Preliminary Multivariable Testing, Upper Freeport Seam Coal (February 26 through March 8, 1993):

Variable	Range	Options Multiplier	Total Tests (45 Minutes Each)
Frother Dosage (MIBC)	0.6-0.8 #/T	2.0	2
Collector Dosage (No. 2 F.O.)	0.6-1.0 #/T	1.5	3
Froth Height	20-28"	1.5	4.5
Air Rate (50 psi)	1.7-3.0 CFM	2.0	9
Froth Wash	0.7-3.5 GPM	1.5	13.5
Feed Solids (@250 #/hr)	5.0-7.5 Wt%	1.5	20
Insert Sleeve	None, 11-3/8"	1.5	30
Duplicates (3)	---	---	33

Notes: - F.O. - Fuel Oil
 - Slurry feed rate ranged from 6.0-10.0 GPM, launder water addition was 3.5 GPM

II. Primary Multivariable Testing, Upper Freeport Seam Coal (March 10 through March 30, 1993):

Variable	Range	Options Multiplier	Total Tests (45 Minutes Each)
Frother Dosage (MIBC)	0.8-1.3 #/T	1.5	1.5
Collector Dosage (No. 2 F.O.)	1.0-2.6 #/T	2.0	3.0
Depressant Dosage (PAC Acid)	0.0-1.3 #/T	1.5	4.5
Froth Height	24-43"	1.5	6.8
Air Rate (50 psi)	1.0-2.0 CFM	1.75	12
Froth Wash	0.8-4.0 GPM	1.5	18
Feed Solids	4.0-13.0 Wt%	1.5	27
Solids Feed Rate	150-300 #/hr.	2.0	54
Insert Sleeve	None, 11-3/8", 11-3/4"	1.5	81
Duplicates (6)	---	---	87

Notes: - PAC - Polyacrylic
 - Slurry feed rate ranged from 4.5-8.0 GPM, launder water additions was 3.5 GPM.

III. Primary Multivariable Testing, Pittsburgh No. 8 Seam Coal (May 3 through May 28, 1993):

Variable	Range	Options Multiplier	Total Tests (45 Minutes Each)
Frother Dosage (MIBC)	0.3-1.5 #/T	2.0	2
Collector Dosage (No. 2 F.O.)	0.7-2.5 #/T	1.5	3
Froth Height	18-36"	1.5	4.5
Air Rate (50 psi)	1.2-2.3 CFM	2.0	9
Froth Wash	2.0-4.0 GPM	1.5	13.5
Feed Solids	3.0-10.0 Wt%	2.0	27
Solids Feed Rate	150-300 #/hr.	1.5	40
Duplicates (6)	---	---	46

Notes: - Slurry feed rate ranged from 4.4-9.9 GPM, launder water addition was 3.0 GPM.

The preliminary multivariable results for the Upper Freeport Seam Coal proved very valuable in that they determined that the reagent dosages were somewhat low and had to be increased for the primary multivariable testing. The preliminary multivariable testing also indicated that the retention time within the column had to be increased to reduce the short circuiting of coal to flotation tailings.

The primary multivariable testing shown in Table 13 utilized these higher reagent additions, and also utilized slightly lower slurry feed rates to the column (4.5-8.0 GPM), which resulted in higher column retention times. A total of 33 tests and 87 tests were conducted during the preliminary multivariable and primary multivariable testing, respectively, for the Upper Freeport Seam Coal. The results from these tests, as well as the QA/QC results from the circuit commissioning that was performed with the Upper Freeport Seam Coal, are summarized in Section 4.11 - Task 1100: Data Evaluation.

The lower portion of Table 13 contains the multivariable testing matrix for the Pittsburgh No. 8 Seam Coal. No preliminary multivariable testing was required, as the ranges of operation for the column were already well understood from the Upper Freeport Seam Testing. Based on the fact that the polyacrylic acid (pyritic sulfur depressant) and insert sleeves did not cause any significant improvement in flotation performance for the Upper Freeport Seam Coal those two variable options were dropped from the primary multivariable matrix for the Pittsburgh No. 8 Seam Coal (see Part III in Table 13). This allowed for fairly complete testing of other variables options to be done, while still conducting only 46 total tests. The results from the Pittsburgh No. 8 Seam Coal multivariable testing are also discussed in Section 4.11 - Task 1100: Data Evaluation.

SECTION 4.8.2 - CONTROL TESTING APPROACH

As mentioned, the control tests for both the Upper Freeport and Pittsburgh No. 8 Seam Coal were of much longer duration (6-10 hours), and were designed to quantify the abilities of PTI's On-Line Monitor to increase the yield and reduce the variability in column performance. Table 14 contains the testing logistics that were used in the control testing runs, for both the:

- Regulatory tests, where column operating variables were maintained at optimum levels determined from the multivariable testing stage, and
- Supervisory tests, where key column operating variables were adjusted to attempt to maintain optimum column performance (concentrate ash content and yield).

Table 15 contains the control testing matrices that were conducted for both the Upper Freeport and Pittsburgh No. 8 Seam Coals. The control testing matrices involved approximately ten 6-10 hour tests for each of the two coals, with the major comparison being between the performance for the regulatory tests (uncontrolled) versus the supervisory tests (controlled).

Table 14
CONTROL TESTING LOGISTICS
(6-10 Hour Test Duration)

A. REGULATORY CONTROL TESTS (UNCONTROLLED)

1. Startup and set target conditions.
2. Monitor circuit until all target conditions are met ($\approx$ 5 minutes).
3. Allow 20 minute column stabilization time.
4. Collect manual feed grab sample, wait 5 minutes.
5. Initiate sample cycle:
 - Same as multivariable sampling cycle (Table 12), but no feed sample.
 - Collect bypass samples and log predicted analyzer readings (ash and solids).
1. Repeat steps 4 and 5 on 20 minute cycles, until test period is complete (6-10 hours).
2. Compare bypass samples analyses to predicted (accuracy?).
3. Do trim calibration if necessary, then do supervisory control test.

B. SUPERVISORY CONTROL TESTS (CONTROLLED)

1. Same as above, but make key control variable step adjustments once every 20 minutes after analyzer readings (to target desired performance).

Table 15
CONTROL TESTING MATRICES
Upper Freeport and Pittsburgh No. 8 Seam Coal

Variable	Description	Options Multiplier	Total tests (6-10 Hrs. Each)
Test Type	Regulatory vs. Supervisory	2	2
Conc. Ash Target	Low vs. High	2	4
Yield Override	Tight vs. Loose	2	8
Duplicates (2)	---	---	10

- Notes:
- Slurry feed rate stayed at 6.1 GPM, launder water at 3.0 GPM, and froth wash water at GPM.
 - Solids feed rate varied randomly from 220-280 #/hr., with raw/precleaned mix varied from 50/50 Wt% to 100/0 Wt%.
 - Reagents, air rate, and froth height were varied by computer control software.

During the Upper Freeport Seam Coal control testing, PTI experienced problems with reproducibility of the On-Line Monitor counts due to operational problems within the circuit. Those problems included excessive foaming within the concentrate samples due to the high reagent dosages, as well as inconsistent sample size caused by improper filling sequence within the monitor. PTI utilized a defoamer addition and changed the filling sequence for the Pittsburgh No. 8 Seam Coal control tests, which lead to much more conclusive results for the Pittsburgh No. 8 Seam Coal. Therefore, the data evaluation for the control testing will focus upon the results from the Pittsburgh No. 8 Seam Coal control testing. The results from the Upper Freeport Seam Coal are not included in the data evaluation section, due to the operational problems which lead to poor performance of the control system.

SECTION 4.8.3 - SAMPLE PREPARATION

Prior to discussing the analytical that PTI performed at its Calumet facilities, it is worthwhile to note that all bench-scale test sample preparation, as well as the moisture and ash determinations were performed at the PETC site during the project. PTI took this approach to ensure that all solids and ash determinations could be quickly turned around within a 24-hour period, to allow decisions to be made on the upcoming testing matrices. PTI took the approach of operating approximately every other day during the testing, so quick turnaround of sample results was critical.

During the bench-scale testing the two types of samples that were collected included:

- 1/4" x 0 bulk samples from the various 6-ton feed lots received at the CPPRF.
- Slurry samples obtained from PTI's Multiplexer Sampling System (bypass splits).

Tables 16 and 17, respectively, show the sampling procedures utilized for both types of samples. Table 18 contains the sample preparation procedures for the various slurry samples, utilizing PTI's mobile laboratory equipment to determine solids contents, and DOE's ashing furnaces to obtain dry ash contents of the various samples that required quick turnaround. After ashing, all samples were sent via United Parcel Service (UPS) to PTI's Calumet laboratory facilities for any additional analyses that were required (sulfur, pyritic sulfur, Btu/lb., screen analysis, washability analysis or release analysis).

SECTION 4.9 - TASK 900: PTI ANALYTICAL

PTI's Calumet facilities' analytical efforts began in December, 1992, with the preliminary 2" laboratory column testing and continued over the entire duration of the bench-scale testing period. The effort was not completed until all washability and release analyses of representative feed samples were concluded in mid-August, 1993. PTI's analytical efforts for the project focused on six main tasks, for both the Upper Freeport and Pittsburgh No. 8 Seam Coals, which included:

- Conducting 2" laboratory column tests for both coals, and comparing the results for samples ground at PTI's Calumet facilities and PETC's CPPRF circuit. The results from these tests provided information as to the anticipated impacts and operating ranges of process variables for the 12" bench-scale column, and also provided a performance comparison for scale-up to the bench-scale column (2" vs. 12"). All 2" column tests results for the Upper Freeport and Pittsburgh No. 8 Seam Coals are listed in Appendices C and D, respectively.

Table 16
FEED LOT SAMPLING AND SAMPLE PREPARATION PROCEDURES

1. When feeding 5-6 ton lots into the product bin, get 35-50 lb. sample of crushed to 1/4 inch topsize material using CPPRF sampling system.
2. Riffle down to 30 lbs. Dry at 40° C and get surface moisture content. Return remainder to product bin.
3. Riffle out 15 lbs. and send to PTI.
4. Pulverize remaining 15 lbs. Riffle down to envelope quantity. Bag and label. Put remainder into product bin.
5. Run residual moisture and ash on envelope portion (see Table 2 in Appendix C).
6. Send envelope and 15 lb. bag to PTI.

Table 17
SLURRY SAMPLING PROCEDURES

1. Computer Operator notifies the Field Operator that sampling will soon begin.
2. Field Operator places a 5-gallon sample bucket in position above the circuit discharge sump.
3. Computer Operator activates sampling of a desired stream (concentrate, tailings, feed) through computer software and keyboard control.

NOTE: Feed Sampled manually prior to PTI's feed sump for control testing.
4. Automatically the desired stream is diverted through the multiplexer to the Quality Monitor via three-way valve.
5. The desired stream then flows to a three-way valve in the monitor that toggles alternate full stream cuts to the Quality Monitor and sample bucket.
6. When the monitor is full for operation a pressure switch automatically activates the multiplexer to its normal operating position. Control Room Operator informs Field Operator that sampling is complete.
7. The Quality Monitor cycles this sample portion it received then generates count data for multivariable tests or quality data for control tests.
8. The split in the sample bucket is labeled and covered with a lid by the Field Operator.
9. The Quality Monitor automatically discharges its sample to the circuit discharge sump when complete.
10. The Quality Monitor and associated multiplexer line is then automatically flushed clean by spray water into the circuit discharge sump.
11. The Field Operator sets the next sample bucket in place and the sequence is repeated until concentrate, tailings and feed samples (if required) have been obtained for each test condition.
12. After that test condition the circuit is readied for the next test condition.
13. As the circuit attempts to reach steady state, the Sample Prep Technician begins weighing and filtering samples.
14. Filter cakes are then taken to the Mobile Lab for drying, sample prep and ash analysis (see Table 18).

Table 18
PRDA SLURRY SAMPLE PREP PROCEDURE

1. Work in kilograms with buckets (big scale) and grams with pans (small scale).
2. Number buckets. Tare with lids (T_B).
3. Record Test No., Sample, Bucket No. and TB in Table 1.
4. Take Sample and cover.
5. Record Sample plus Bucket Weight (GW_1).
6. Calculate Slurry Sample Weight (W_1).
$$W_1 = GW_1 - T_B$$
7. Filter sample and discard water.
8. Select a pan. Tare pan include one filter paper (TP). Record Pan No. and TP in Table 1.
9. Put sample in pan. Sample should include one filter paper just like when you tared pan.
10. Dry sample at temperature between 40-65°C, until weight stabilizes. If drying overnight, dry at 40°C. If drying 2-3 hours, dry at 65°C. Alter this approach as you learn how long it takes for weights to stabilize.
11. Weigh pan plus surface dry sample and filter paper (GD_1).
12. Calculate Surface Dried Sample Weight (D_1).
$$D_1 = GD_1 - TP$$
13. Note all weights in Table 1 and calculate Surface Solids Content.
$$\text{Surface Solids (Wt\%)} = \frac{D_1 \times 0.1}{W_1}$$
14. Clean all sample off of filter paper and push through 16M screen. If pulverizing is necessary, follow Step 15. If pulverizing is not necessary, follow Step 16.
15. A. Split out approximately 1/2 of sample and pulverize. Riffle out approximately 50 grams and envelope and label. Discard remaining pulverized portion. Run ash analysis on enveloped sample, using DOE ashing furnace.
B. Bag, label and store unpulverized portion. Send all bags and envelopes to PTI after enveloped portions have been analyzed for ash.
16. A. Riffle out approximately 50 grams and envelope and label. Run ash analysis on enveloped sample using DOE ashing furnace.
B. Bag, label and store unused portions. Send all bags and envelopes to PTI after enveloped portions have been analyzed for ash.
17. Calculate total solids (with inherent moisture correction, and tabulate total solids and dry ash content on data sheets.

- Head analysis, including moisture, ash, sulfur, pyritic sulfur and heating values, for the various 6-ton feed lots that were utilized during the testing portion of the project for both coals.
- Head analysis, in particular sulfur and pyritic sulfur, on optimum samples obtained during the multivariable and control testing portions of the project. The results from these head analyses are included in Appendices A for the Upper Freeport Seam Coal multivariable testing and Appendices G and H for the Pittsburgh No. 8 Seam Coal multivariable and control testing, respectively.
- Size analysis (including moisture, ash, sulfur and pyritic sulfur), by size, on some of the optimum separations performed in the 2" lab column and 12" plant column during the multivariable testing portion for both coals.
- Flotation release analyses on ground composites of both test coals to determine the optimum performance that could be anticipated in any flotation separation. These flotation release analysis are in Appendices E and F for the Upper Freeport and Pittsburgh No. 8 Seam Coals, respectively.
- Washability analysis on representative ground feed samples of both test coals to determine the degree of impurities liberation within the coals (i.e., the optimum separation that could be expected in the perfect density separation). The washability analyses are also included in Appendices E and F for the Upper Freeport and Pittsburgh No. 8 Seam Coals, respectively.

PTI performed all routine coal analysis at their Calumet facilities using ASTM analysis. PTI also sent splits of certain key samples to other laboratories (Geochemical Testing and Standard Laboratories) to insure that all detailed analysis (moisture, ash, sulfur, pyritic sulfur and Btu) met ASTM repeatability and reproducibility limits, as part of the QA/QC program. PTI used the optimum float/sink procedures, determined by PTI as part of a Phase II SBIR Project, to determine the washability results on all samples. The flotation release analysis methods used in the project were developed based on consultation with VPI and the University of Kentucky's Center for Applied Energy Research (UK/CAER). The procedures for the release analysis are also summarized in Appendices E and F, respectively.

The upcoming section on Task 1100: Data Evaluation contains a discussion of all the bench-scale testing results occurring at the CPPRF site, as well as the analytical performed at PTI's Calumet facility. The Task 1100: Data Evaluation discussion also summarizes the results from PTI's QA/QC Program, implemented to insure that the sampling and analytical procedures utilized within the project met ASTM guidelines.

SECTION 4.10 - TASK 1000: CIRCUIT DECOMMISSIONING

PTI decommissioned the ET Circuit during the period from June 17 through June 23, 1993. Gilbert Commonwealth assisted in disconnecting the ET Circuit from the permanent CPPRF circuits. Table 19 shows the decommissioning requirements that were followed for the decommissioning task. All equipment was tagged and moved to the desired location by the decommissioning crew (either Building 920 for long term storage, or to the contractor's trailer for use by VPI in their upcoming project). All process piping and electrical installations were

also removed and discarded at termination points determined by VPI and Roberts & Schaefer personnel for the next project. The decommissioning crew then loaded all of PTI's equipment into the mobile laboratory and PTI's pick-up truck. PTI used those trucks to transport the equipment to Columbus and Calumet offices at the end of the project.

Table 19
**DECOMMISSIONING REQUIREMENTS
FOR LINCOLN CONTRACTING**

1. All equipment, structure, pipe, hose, and electricals that were installed as part of the project will be removed from the facility by contractor, leaving the facility and its property in the same condition as prior to construction and installation.
2. All decommissioning activities will follow health and safety guidelines of the DOE/PETC.
3. Process piping, hose, steel, and electricals will be delivered to a scrap yard chosen by Contractor.
4. All tie-in points to the CPPRF circuit will be corrected to make whole to original condition.
5. All electrical run entrance and exit points to the MCC, Control Room, and Mobile Laboratory will be made as whole as possible. openings will be closed off according to CPPRF practices (blanks, concrete fill, etc.).
6. All facility grounds used as part of decommissioning will be made whole. For Example, ruts caused by equipment in lay down areas should be filled and leveled.
7. The floor space and pavement space used as part of decommissioning shall be cleaned by contractor to the satisfaction of on-site PTI Project Management prior to the contractor leaving site.
8. All PETC owned equipment will be placed in location designated by PTI's Project Manager.

Appendix I includes the final DOE-owned equipment listing, including the tag numbers and location of each piece of equipment. This list was compiled for PTI's Project Termination Completion Inventory.

SECTION 4.11 - TASK 1100: DATA EVALUATION

The data evaluation task occurred over the entire period from January 1, 1993, through August 30, 1993 (see Figures 5 through 7). During that period, PTI complied results from all the laboratory 2" column tests (performed at PTI's Calumet facilities), and all 12" column bench-scale testing (performed at PETC's CPPRF) for both of the test coals (Upper Freeport and Pittsburgh No. 8 Seam Raw Coals), including all the detailed analytical work and washabilities and flotation release analyses. The following discussion summarizes the results from the various testing aspects performed during the project. The discussion is broken down into three subsections, which include:

- Quality Assurance and Quality Control (QA/QC) Testing Results.
- Upper Freeport Seam Coal Laboratory and Bench-Scale Testing Results.
- Pittsburgh No. 8 Seam Coal Laboratory and Bench-Scale Testing Results.

Complete listings of all the laboratory and bench-scale test results and test conditions are included in Appendices A through H of the Appendix volume.

SECTION 4.11.1 - QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) TESTING

There were a number of specific tests that were performed during the commissioning, multivariable and control testing, as part of a Quality Assurance/Quality Control (QA/QC) program, which PTI instituted at DOE's request. The four main areas of the QA/QC testing were:

- Instrumentation - accuracy and reliability checks.
- Sampling Methods - accuracy and reproducibility checks.
- Testing Methods - accuracy and reproducibility checks.
- ASTM Analysis - accuracy and reproducibility checks.

The following section describes the results from the various aspects of the QA/QC testing.

SECTION 4.11.1.1 - INSTRUMENTATION - ACCURACY AND RELIABILITY CHECKS

The first aspect of PTI's QA/QC Program was to routinely check the accuracy of the instrumentation which monitored PTI's bench-scale testing circuit. PTI made a number of field measurements, approximately every 20 minutes during the multivariable and control testing to ensure that the circuit was operating at the desired test conditions. The operating variables and their required accuracy included:

- Checked column interface level to ensure that it was within $\pm 1"$ of the desired froth thickness, using a sight glass which PTI installed on the upper portion of the column.
- Checked all reagent dosages to ensure that they were $\pm 1\%$ of the desired reagent addition levels.
- Checked all water flow meters to ensure the magnetic flow meter readings matched, to within $\pm 2\%$, manual sight glass flow meter readings, that were also included within the water lines.
- Checked manual flow gauge on column air supply to ensure that aerate matched desired aerate to within $\pm 5\%$.

In general, the instrumentation always remained within the desired accuracy ranges. The only exception was column froth interface level, where the calibrations often became skewed over time. Slight adjustments in the calibrations were made during the individual tests to ensure that the froth interface remained within $\pm 1"$.

In addition to the routine field measurements and adjustments that were made during the individual testing, PTI also performed biweekly checks of all flow rates (column feed, column tailings, launder water addition, froth wash water addition and feed sump dilution) to ensure that the magnetic flow meter readings matched, manually-controlled timed samples taken over approximately a one minute period. Those tests were performed to ensure that the flow balance measured within the circuit was accurate to within $\pm 2\%$. The biweekly instrument checks also included a trim calibration of the DP level probes within the column to ensure that the column interface level could be maintained to within $\pm 1"$ of the desired setpoint. The combination of the daily and biweekly instrument checks proved to be a sound method of maintaining accurate measurement and control of the circuit operating conditions for both the multivariable and control testing.

SECTION 4.11.1.2 - SAMPLING METHOD ACCURACY AND REPRODUCIBILITY

The second area of PTI's QA/QC testing focused on determining the accuracy and reproducibility of PTI's sampling methods. Figure 17 contains an illustration of PTI's Multiplexer and On-Line Quality Monitor combination, with particular emphasis on the sample collection and sample splitting methods used within the project. For both the multivariable and control testing, PTI utilized the 3-way valves within the multiplexer to divert the desired sample into PTI's On-Line Quality Monitoring System. Within the monitor, PTI had a 3-way toggling valve which would toggle back and forth over the sample collection period until the analyzer fill sump was filled. The timing sequence was set up so that approximately two to three gallons would be obtained in the five gallon bypass pail within the time where the analyzer portion reached the high level probe in the fill sump (approximately five gallons).

PTI also had locations set up to obtain grab samples of the column tailings and column concentrate stream, as well as a sample of the column feed stream, prior to the column feed sump. The multiplexer and on-line quality monitor were both equipped with rinse water additions to wash out all portions of the system between samples.

During certain tests performed during the Upper Freeport Seam Coal commissioning, PTI collected the discharge (i.e., drain) from the on-line quality monitor and checked its composition against the ASTM bypass portion and a grab sample collected at the grab sample location. For the column tailings stream, the three samples checked very closely for solids content (± 0.2 Wt%) and ash content (± 0.4 Wt%).

This sample splitting QA/QC was repeated on a more detailed basis during the Pittsburgh No. 8 Seam Coal multivariable testing. Once again, the analyzer drain portion was collected and compared to the ASTM bypass portion of the sample and grab sample taken from the grab sample location. However, in this case, the comparisons were done not only for a column tailings stream but also for the column concentrate and column feed stream.

Table 20 contains more QA/QC results for two different multivariable tests (VT #8 and VT #15). The results illustrate the monitor drain and bypass splits contain very similar solids contents (± 0.2 Wt%) and ash contents (± 0.4 Wt%) for concentrate and feed and only slightly more variable ranges for solids content (± 0.2 Wt%) and ash content (± 0.8 Wt%) for tailings samples. The results were less accurate for the grab samples, which could not be taken simultaneously with the other two samples and had to be taken directly after the other two samples. Based on the results in Table 20, PTI decided that, whenever possible, it would be best to use the multiplexer and on-line monitor sampling system to obtain an ASTM bypass portion which could be assumed to match the on-line quality monitor sample for each given test. During the control testing, it was necessary to obtain a grab sample of the column feed because no automatic sampling was performed on the column feed sample stream (i.e., because it would disrupt column flow and lead to undesirably long restabilization periods). PTI realized that this approach could lead to slight errors in feed sample composition, as shown in Table 20. However, the feed ash content results for the control testing were merely used as a check to obtain an ash balance yield which could be compared to the flow balance yield.

Figure 17
PTI MULTIPLEXER AND ON-LINE QUALITY MONITOR
SAMPLE COLLECTION AND SPLITTING METHODS
(Not Drawn To Proper Scale)

PROCESS TECHNOLOGY, INC.			
322 CALHUN AVENUE CALHOUN, MICHIGAN 49813-1978 (506) 337-0000 FAX (506) 337-0023			
PTI SAMPLE COLLECTION METHODS			
DATE	FILE	DRAWING NO.	
09/23/93	NONE	01-018-17	
PAGE 1 OF 1			

Table 20
SAMPLE SPLITTING METHOD
QA/QC RESULTS
Pittsburgh No. 8 Seam Multivariable Testing
(Dry Basis, Except Solids)

Test	Sample Location	A.B.	Feed		Concentrate		Tailings	
		Yield (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
VT#8	Monitor Drain	65.5	NA	17.59	NA	8.96	NA	34.01
VT#8	Bypass Split	66.4	2.96	17.22	3.76	8.76	0.93	33.92
VT#8	Grab Samples	58.6	NA	18.55	3.86	8.39	0.76	32.91
VT#15	Monitor Drain	65.6	10.81	24.80	7.27	8.93	3.35	55.04
VT#15	Bypass Split	66.7	10.63	24.43	7.09	8.70	3.26	55.84
VT#15	Grab Samples	67.6	NA	24.28	6.92	8.42	3.27	57.40

Notes: - NA - Not Available
 - A.B. - Ash Balance

Overall, PTI was very pleased with the sample splitting method QA/QC results in Table 20, and was confident that the ASTM bypass splits were matching the splits which were reported to the on-line monitor within an acceptable range of reproducibility.

SECTION 4.11.1.3 - TESTING METHOD ACCURACY AND REPRODUCIBILITY

The third, and most difficult, area of the QA/QC program was to determine the accuracy and reproducibility of the testing methods, realizing that the blending and storage capabilities of the existing CPPRF would lead to feed composition differences for the various tests. One of the first QA/QC tests performed, regarding this issue, was to collect feed samples over a short period (30 minutes) to determine the feed variability. The upper portion of Table 21 shows the feed variability for a series of feed samples collected from PTI's Multiplexer Sampling System during the initial Upper Freeport Seam Coal commissioning period. A 6 Wt% solids content target was desired during the testing. The results show that the solids feed rate and the slurry feed rate were fairly accurate, leading to solids contents ranging between 6 and 7 Wt%. The results also illustrated that the feed ash content varied slightly more significantly (26.0-27.3 Wt%) over the same 30 minute time period.

This exercise was again repeated during the final commissioning tests (DT #1), and the results are listed in the lower part of Table 21. Once again, the solids content held fairly tightly to the 6.0 Wt% targets, but the ash contents ranged more dramatically (28.0-29.8 Wt%). It was also interesting to note that the ash content for this later testing, done with the second lot of feed coal, was considerably higher than the ash content in the earlier tests, which were done with the first lot of feed coal.

Table 21
FEED VARIABILITY
QA/QC RESULTS
Upper Freeport Seam Commissioning Tests
(Dry Basis, Except Solids)

Test	Feed Samples (5 Minutes Apart)	Sample Analyses	
		Solids (Wt%)	Ash (Wt%)
CT#1	Feed #1	6.42	25.94
CT#1	Feed #2	6.16	26.22
CT#1	Feed #3	6.46	26.89
CT#1	Feed #4	6.98	27.28
CT#1	Feed #5	6.13	27.33
CT#1	Feed #6	5.87	26.50
DT#1	Feed #1	6.04	28.88
DT#1	Feed #2	6.23	27.96
DT#1	Feed #3	6.25	28.46
DT#1	Feed #4	6.21	29.79
DT#1	Feed #5	6.28	29.17

Table 22 contains the feed lot sample compositions for the five feed lots tested during the Upper Freeport Seam Coal commissioning and multivariable testing. The feed lot analyses were obtained from head samples collected over the entire period when the 1/4" x 0 six-ton lots were fed into the CPPRF system. The "individual test feed sample analysis" represent the average, minimum analyses, and maximum analyses from the various test samples obtained with each feed lot.

From the results, it can be observed that Feed Lot #2 did indeed contain a considerably higher feed ash content (29.23 Wt%) than the other feed lots, which generally ranged within ± 1.0 Wt% ash of 26.5 Wt% ash. This variation in the feed lots head composition was a slight concern. However, the major concern was the extreme range of ash content obtained for the individual tests, as witnessed by range of 24.0-36.0 Wt% ash that was obtained for Feed Lot #4, and 24.0-37.5 Wt% ash that was obtained for Feed Lot #5. These uncontrollable feed variations made evaluation of the impacts of test variables extremely difficult, especially since the column concentrate quality and yield, was so dependent on column feed quality. PTI, PETC and Gilbert Commonwealth staff worked on improving the CPPRF blending and mixing systems to try to reduce the variability of test feed samples for, not only the Upper Freeport Seam testing, but also for the Pittsburgh No. 8 Seam testing (Coal #2). However, it can be seen from the range of Feed Lot #4 and Feed Lot #5 analyses, which were utilized for the later portions of the Upper Freeport testing, that the homogenizing strategies were not very successful for the Upper Freeport Seam Coal. The homogenizing problems may have been due to the fact that the Upper Freeport Feed Sample was a mixture of natural fines and processed coarse coal. This unnatural combination of particles may have been easily segregated and did not lend itself to good homogenization.

Table 22
**FEED LOT SAMPLE COMPARISON
 AND TEST SAMPLE VARIABILITY**
 Upper Freeport Seam Raw Coal
 (Results Are Dry Basis)

	Feed Lot Analysis	Average Analysis	Minimum Analysis	Maximum Analysis
<u>Feed Lot #1</u>				
Ash (Wt%)	25.94	26.85	25.77	29.90
Sulfur (Wt%)	2.49	—	—	—
Pyritic Sulfur (Wt%)	1.90	—	—	—
Heating Value (Btu/lb.)	11292	—	—	—
MAF Heating Value (Btu/lb.)	15248	—	—	—
<u>Feed Lot #2</u>				
Ash (Wt%)	29.23	29.40	26.74	32.58
Sulfur (Wt%)	2.68	—	—	—
Pyritic Sulfur (Wt%)	2.04	—	—	—
Heating Value (Btu/lb.)	10745	—	—	—
MAF Heating Value (Btu/lb.)	15182	—	—	—
<u>Feed Lot #3</u>				
Ash (Wt%)	27.21	27.64	24.97	30.94
Sulfur (Wt%)	2.57	2.55	2.45	2.63
Pyritic Sulfur (Wt%)	2.03	2.07	1.96	2.21
Heating Value (Btu/lb.)	11118	—	—	—
MAF Heating Value (Btu/lb.)	15274	—	—	—
<u>Feed Lot #4</u>				
Ash (Wt%)	26.88	28.37	24.10	36.25
Sulfur (Wt%)	2.56	2.52	2.00	2.81
Pyritic Sulfur (Wt%)	1.97	1.99	1.50	2.35
Heating Value (Btu/lb.)	11160	—	—	—
MAF Heating Value (Btu/lb.)	15262	—	—	—
<u>Feed Lot #5</u>				
Ash (Wt%)	26.57	27.76	24.37	37.53
Sulfur (Wt%)	2.54	2.64	2.38	3.40
Pyritic Sulfur (Wt%)	1.92	2.13	1.85	2.86
Heating Value (Btu/lb.)	11207	—	—	—
MAF Heating Value (Btu/lb.)	15262	—	—	—

Another facet of the testing method QA/QC was to determine the stabilization period required for the column to stabilize prior to sampling the column for a given test. Table 23 shows the results from samples of concentrate and tailings that were taken at 10 minute increments after a column operating variables adjustment was made. It can be observed from Table 23 that the yield and product quality stabilized at 45 ± 1.0 Wt% and 11.7 ± 0.2 Wt%, respectively, after approximately a 15-25 minute stabilization period. Based on these results, PTI utilized a 25 minute stabilization period (approximately three column retention times) during the testing to ensure that the column had stabilized prior to any test sampling.

Table 23
COLUMN STABILIZATION TIME STUDY
QA/QC RESULTS
Upper Freeport Seam Commissioning Tests
(Dry Basis, Except Solids)

Test	Time After Change In Test Conditions	Yield (Wt%)	Concentrate		Tailings	
			Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
CT#2	5 Minutes	41.6	4.49	11.72	3.39	37.96
CT#2	15 Minutes	43.3	4.38	11.57	3.37	38.85
CT#2	25 Minutes	45.8	4.20	11.83	3.43	39.91
CT#2	35 Minutes	43.8	4.32	11.67	3.42	39.00
CT#2	45 Minutes	45.2	4.35	11.89	3.37	39.55
CT#2	55 Minutes	44.5	4.28	11.76	3.41	39.28

The final aspect of the testing method QA/QC program was to check the back-to-back sample repeatability and back-to-back test repeatability to observe the stability and reproducibility of the testing results. Table 24 contains the results of the sample repeatability testing, where back-to-back samples of concentrate, tailings and feed were taken for given test conditions. Table 15 illustrates that the results were fairly consistent, provided the feed content did not vary significantly (see test CT #5). However, when the feed ash content varied significantly, the yields and qualities for the back-to-back samples were prone to vary to a greater degree (see test DT #4).

In a similar fashion, the test repeatability results in Table 25 represent duplicate tests run back-to-back at exactly the same test conditions. As with the sample repeatability tests, the test repeatability results in Table 25 did not change dramatically for tests where the feed composition did not change dramatically (see PT #23 vs. PT #24 and FT #33 vs. FT #34). The yields and product qualities matched fairly well for these tests where the feed composition remained consistent. However, as the feed composition varied more for the individual tests (see FT #23 vs. FT #24), the yields and product qualities also varied more dramatically.

Table 24
BACK-TO-BACK SAMPLE REPEATABILITY
QA/QC RESULTS
Upper Freeport Seam Commissioning Tests

Test Number	Date	Time	Feed Sample				A.B. Yield	Concentrate Sample				Tailings Sample			
			Solids (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)		Solids (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)	Solids (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
CT#5	2/11	1740	6.13	26.76	2.52	—	43.5	4.18	13.17	2.12	1.40	3.65	37.26	—	—
CT#5	2/11	1740	5.68	26.37	2.50	—	45.1	4.15	13.40	2.20	1.48	3.71	37.02	—	—
DT#4	2/23	1357	6.12	33.99	2.65	2.25	12.1	2.99	13.90	2.00	1.32	4.20	36.76	—	—
DT#4	2/23	1357	5.98	32.37	2.59	2.20	19.1	2.86	14.21	2.02	1.38	4.11	36.67	—	—

Table 25
BACK-TO-BACK TEST REPEATABILITY
QA/QC RESULTS
Upper Freeport Seam Multivariable Tests
(Dry Basis, Except Solids)

Test Number	Date	Time	Feed Sample				A.B. Yield	Concentrate Sample				Tailings Sample			
			Solids (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)		Solids (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)	Solids (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
PT#23	3/04	1105	7.88	28.82	2.63	2.11	53.6	3.62	13.06	2.03	1.39	3.80	47.04	3.14	2.57
PT#24	3/04	1151	7.32	28.13	2.63	2.21	56.4	3.69	12.89	2.02	1.30	3.40	48.08	—	—
FT#23	3/16	1213	8.77	26.03	2.56	1.96	62.0	4.40	11.89	1.99	1.37	3.45	49.45	—	—
FT#24	3/16	1311	8.67	32.32	2.73	2.35	53.1	4.32	13.42	2.11	1.48	3.36	53.74	—	—
FT#33	3/17	1350	8.01	27.36	2.54	—	60.5	4.14	14.02	2.12	—	3.43	47.79	—	—
FT#34	3/17	1435	8.69	28.40	2.81	—	58.6	4.02	15.16	2.13	—	3.59	47.14	—	—
FT#43	3/18	1648	8.24	26.13	—	—	70.3	4.40	12.95	2.12	1.42	3.14	57.39	—	—
FT#44	3/18	1733	7.76	24.28	2.20	1.75	74.4	4.49	12.16	2.12	1.37	2.87	59.56	—	—
FT#60	3/23	1440	7.84	26.03	2.43	1.98	76.9	4.88	14.66	2.27	1.60	2.64	63.78	—	—
FT#61	3/23	1520	7.81	26.00	2.47	1.93	72.8	4.87	15.28	2.29	1.56	2.78	54.68	—	—
FT#62	3/23	1625	8.39	28.28	—	—	62.4	4.56	16.87	2.08	—	3.34	47.25	—	—
FT#63	3/23	1715	7.86	30.46	2.70	2.11	61.6	4.60	17.92	2.26	—	3.50	50.55	—	—

For FT #23 and FT #44, where feed ash contents varied by approximately 6.0 Wt% (26.03 vs. 32.32 Wt%), the yield difference became approximately 9 Wt% (62.0 vs. 53.1 Wt%) and the concentrate quality difference became greater than 1.0 Wt% (11.69 vs. 13.42 Wt%). This data illustrates that it was difficult to draw conclusions about the impact of process variables unless the feed compositions for the comparative tests were very similar, because the levels of yield and concentrate quality were so dependent on feed composition.

SECTION 4.11.1.4 - ASTM ANALYSES REPEATABILITY AND REPRODUCIBILITY

The final aspect of PTI's QA/QC testing was to assess the repeatability and reproducibility of PTI's laboratory analyses. Table 26 shows the results from comparative compositional analyses done on test sample obtained during the Upper Freeport Seam multivariable testing. The table includes a comparison of the ash analysis results for the circuit samples done at the test site (DOE's LECO analyzer) and at PTI's Calumet facilities (where compositional checks were performed). Table 26 also contains a comparison of duplicate aliquots that were analyzed for ash, sulfur and pyritic sulfur at PTI's Calumet facilities. The ash content, sulfur content and pyritic sulfur content comparisons were all within ASTM limits for repeatability (within a lab) and reproducibility (between labs) as shown in Table 28. The only analysis that had slightly higher variability than allowed was the concentrate pyritic sulfur content for test PT #24, which varied by approximately 0.17 Wt%.

The second aspect of the laboratory QA/QC program involved sending duplicate sample splits of feed and concentrate samples to other laboratories to compare to PTI's analytical analyses results. Table 27 shows the results from eight samples that were sent to Standard Laboratories and Geochemical, as well as analyzed by PTI's Calumet facilities. The samples included separate aliquots of two feed samples (FT #10 and Ft #27) which were approximately 25.0 and 28.0 Wt% ash, respectively, and two aliquots of concentrate samples (FT #12 and FT #10) that were approximately 11.7 and 14.5 Wt% ash, respectively. All three laboratories analyzed both aliquots of the given samples and PTI also performed duplicate analyses for each aliquot. From the results in Table 27, it can be observed that PTI's repeatability of the analyses for a given aliquot, as well as the duplicate aliquot, is well within ASTM Standards (see Table 28). PTI's analyses also closely matched Standard Laboratories' and Geochemical's results for moisture, ash and sulfur to well within ASTM reproducibility limits (see Table 28). The only concern was the difference in pyritic sulfurs between PTI's results and Standard Laboratories' results which were sometimes outside of the limits of ASTM reproducibility (0.3 Wt% for less than 2 Wt% pyritic sulfur content). Fortunately, PTI's pyritic sulfurs did closely match Geochemical's analyses, so it was assumed that Standard Laboratories results were the source of the reproducibility problem.

Overall, the results of the QA/QC testing illustrated that there were not any significant problems with PTI's sampling methods, with PTI's ASTM analyses, or with the accuracy of the instrumentation within the circuit. The major concern arising from the QA/QC testing was the feed sample variability, which occurred during the testing (particularly for the Upper Freeport Seam Coal). PTI, PETC and Gilbert Commonwealth staff took special precautions to try to improve the blending of the feed within the CPPRF handling systems. However, the data evaluation for the process variable impacts was very difficult, particularly for the Upper Freeport Seam Coal, due to the feed ash composition variability from test-to-test.

Table 26
COMPOSITION COMPARISONS
QA/QC RESULTS
DOE'S LECO FURNACE VS PTI'S CALUMET LAB
Upper Freeport Seam Multivariable Testing
(Dry Basis)

Test Number	Laboratory	Aliquot	A.B. Yield (Wt%)	Feed			Concentrate			Tailings Ash (Wt%)
				Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	
PT#9	DOE LECO	Main Sample	58.1	25.19	—	—	11.72	—	—	43.83
PT#9	PTI Calumet	Main Sample	57.7	25.40	2.54	—	11.67	1.98	—	44.11
PT#9	PTI Calumet	Dup #1 (Unpulv.)	56.7	25.27	2.53	—	11.35	1.97	—	43.50
PT#9	PTI Calumet	Dup #2 (Pulv.)	56.2	25.38	2.53	—	11.25	2.02	—	43.52
PT#24	DOE LECO	Main Sample	56.4	28.13	—	—	12.69	—	—	48.08
PT#24	PTI Calumet	Main Sample	55.3	28.63	2.63	2.21	12.90	2.02	1.30	48.12
PT#24	PTI Calumet	Dup #1 (Unpulv.)	55.8	28.54	2.67	2.23	12.81	2.04	1.34	48.42
PT#24	PTI Calumet	Dup #2 (Pulv.)	55.2	28.30	2.71	2.27	12.84	2.05	1.47	47.38

Notes: - Main sample of tailings and feed were pulverized before analysis. Main sample of concentrate was analyzed unpulverized.

Table 27
LABORATORY ANALYSES REPEATABILITY AND REPRODUCIBILITY
QA/QC RESULTS
PTI VS STANDARD LABS AND GEOCHEMICAL
Upper Freeport Seam Multivariable testing
(Dry Basis, Except Moisture)

Sample Number	Description	PTI		PTI		PTI		PTI		Standard Labs				Geochemical			
		Moisture (Wt%)		Ash (Wt%)		Sulfur (Wt%)		Pyr. S. (Wt%)		H2O	Ash	Sulfur	Pyr. S.	H2O	Ash	Sulfur	Pyr. S.
		Ind.	Avg.	Ind.	Avg.	Ind.	Avg.	Ind.	Avg.	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)	(Wt%)
1	FT#10, Feed A	0.66/0.55	0.61	24.86/24.85	24.85	2.24/2.34	2.29	1.80/1.79	1.80	0.85	24.45	2.33	1.53	0.68	24.40	2.42	1.88
2	FT#10, Feed B	0.57/0.56	0.57	24.71/24.77	24.74	2.30/2.26	2.28	1.79/1.80	1.80	0.79	24.42	2.30	1.50	0.71	24.63	2.31	1.89
3	FT#14, Feed A	0.41/0.43	0.42	28.26/28.21	28.24	2.54/2.53	2.53	2.08/2.10	2.10	0.87	27.85	2.53	1.70	0.72	27.63	2.55	2.10
4	FT#14, Feed B	0.63/0.75	0.69	27.98/28.12	28.05	2.52/2.52	2.52	2.12/2.17	2.14	0.96	28.00	2.53	1.71	0.66	27.24	2.52	2.14
5	FT#12, Conc. A	0.72/0.66	0.69	11.69/11.65	11.67	1.95/1.96	1.96	1.37/1.35	1.36	0.88	11.52	1.93	1.19	0.66	11.49	1.96	1.37
6	FT#12, Conc. A	0.69/0.69	0.69	11.62/11.62	11.62	1.97/1.97	1.96	1.32/1.37	1.35	0.82	11.50	1.93	1.16	0.64	11.42	1.94	1.36
7	FT#10, Conc. B	0.55/0.59	0.57	14.50/14.55	14.53	2.08/2.07	2.08	1.58/1.48	1.53	0.82	14.40	2.03	1.21	0.63	14.18	2.06	1.49
8	FT#10, Conc. B	0.59/0.51	0.55	14.56/14.47	14.50	2.02/2.05	2.04	1.48/1.56	1.52	0.87	14.43	2.05	1.22	0.68	14.34	2.03	1.51

Notes: - Ind. - Individual Analysis

Table 28
ASTM STANDARDS FOR
COAL SAMPLE ANALYSES

Analysis	Coal Type	ASTM Allowable Differences on Duplicate Samples	
		Repeatability Within Lab	Reproducibility Between Labs
Moisture	Any	0.30 Wt%	0.50 Wt%
Ash	Raw Coal	0.50 Wt%	1.00 Wt%
	Clean Coal	0.20 Wt%	0.30 Wt%
	Refuse Coal	1.00 Wt%	2.00 Wt%
Btu/lb.	Any	50 Btu/lb.	100 Btu/lb.
Sulfur	<2.0% Sulfur Coal	0.05 Wt%	0.10 Wt%
	>2.0% Sulfur Coal	0.10 Wt%	0.20 Wt%
Pyritic Sulfur	<2.0% Pyritic Sulfur Coal	0.05 Wt%	0.30 Wt%
	>2.0% Pyritic Sulfur Coal	0.10 Wt%	0.40 Wt%

SECTION 4.11.2 - UPPER FREEPORT SEAM TESTING RESULTS

The following discussion focuses on the 12" diameter x 14' high KEN-FLOTE™ Column testing results for the Upper Freeport Seam. The discussion also compares the 12" plant column performance to results obtained at PTI's laboratories with a 2" laboratory column, as well as the feed coal washability and release analyses obtained with the same Upper Freeport Seam Coal. The discussion begins with background information obtained from the 2" laboratory column tests.

SECTION 4.11.2.1 - 2" LABORATORY KEN-FLOTE™ COLUMN TEST RESULTS

During the period from October through December, 1992, PTI conducted a series of 2" laboratory column tests with the Upper Freeport Seam coal to determine the anticipated behavior of the plant column for the Upper Freeport Seam Coal, as well as the anticipated

product quality and yield. The initial 2" column test results indicated that yields in the range of 75-85 Wt% could be expected at product qualities of 11.0-13.0 Wt% ash for the Upper Freeport Seam Coal. The testing also determined the optimum ranges of reagent additions, air rates, froth wash and froth heights which were then scaled up to provide test ranges for the upcoming bench-scale testing. The 2" column tests were performed using a nominal 100M topsize grind, which was obtained using a dry grinding pulverizer at PTI's Calumet laboratories.

During the bench-scale commissioning tests for the Upper Freeport Seam Coal, PTI determined that MIBC frother provided higher yields and better product quality, at lower reagent additions, than the Betz M-150 frother used for all the 2" laboratory column tests. Since the low level of yields and less than optimum separation performance were a concern for the bench-scale circuit, PTI switched to the MIBC frother for all the plant testing. PTI also decided to conduct a short series of additional 2" column tests with the Upper Freeport Seam Coal during the February and March, 1993, time frame, to compare the various frothers in the laboratory environment. The testing was done with feed obtained from PTI's laboratory dry grind, as well as samples of the finer feed size consist which resulted from the PETC CPPRF open-loop grinding circuit. The results from the initial 2" laboratory column tests (conducted in October through December, 1992, with M-150 frother) and the final 2" laboratory column tests (conducted in February and March, 1993, with the various frothers) are listed in the tables in Appendix C.

The results in Appendix C are rather voluminous and difficult to quantify. For the basis of comparison, Table 29 contains results from certain optimum 2" lab column tests with the various frothers for the Upper Freeport Seam Coal. From the results, it can be observed that, as in the plant, the MIBC frother promoted high yield (76-83 Wt%) at lower reagent dosages (0.45 #/ton) than the Betz M-150 and CM-670 frothers (0.60 #/ton). The tailings ash contents of approximately 82.0 Wt% for the MIBC frother were also much higher than the 64-67 Wt% tailings ash content obtained with the Betz frothers (see Table 29). Therefore, the results seem to verify that PTI made a sound choice in switching to the MIBC frother in the plant tests.

Table 30 contains a comparison of the size distribution obtained with PETC's CPPRF dry grind (open loop) and PTI's laboratory dry grind (a closed system, including a 28M screen). It can be noted that there is a greater proportion of undesirable plus 50M (1.2 Wt% vs. 0.2 Wt%) created by PETC's dry grind. The PETC dry grind also created a higher percentage of undesirable 400M x 0 extreme fines than the PTI dry grind (77.1 Wt% vs. 45.5 Wt%). Ideally, it is best to select a grinding circuit prior to flotation that maximizes the amount of 100M x 400M present in the feed coal, as flotation is most efficient for that size range. Table 30 illustrates that PETC's grind only resulted in 19.3 Wt% of the feed being broken into the 100M x 400M size fraction, whereas, the PTI dry grind created 45.0 Wt% within that fraction.

The small proportion of 100M x 400M in the PETC grind led to reduced flotation efficiency for the bench-scale testing circuit (as compared to the 2" laboratory column tests), and also led to more variability in column performance caused by changes in feed composition. Table 31 contains a comparison of the Optimum 2" Laboratory Column Results obtained with PTI's laboratory dry grind, and PETC's plant grind. In all cases, MIBC was used as the frother and

Table 29
OPTIMUM 2" LAB COLUMN RESULTS
PTI LABORATORY DRY GRIND
(Upper Freeport Seam Raw Coal)

Batch Number	Test Number	Appendix C Table Number	Frother Dosage		Collector Dosage		Sample	Actual Solids Content (Wt%)	Total Flow Rate (g/min)	Solids Flow Rate (g/min)	Column Performance (Dry Basis)			
			Type	#/T	Type	#/T					Yield (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)
1	3	18.C.16	M-150	0.60	Fuel Oil	0.60	Recon. Feed	5.76	819	47.2	100.0	23.70	1.93	—
							Product	24.39	148	36.9	78.1	12.41	1.98	—
							Tailings	1.18	871	10.3	21.9	63.98	1.75	—
5	4	18.C.20	CM-670	0.60	Fuel Oil	0.60	Recon. Feed	5.74	843	47.9	100.0	25.84	2.12	—
							Product	40.11	92	36.9	77.0	13.44	2.25	1.40
							Tailings	1.17	942	11.0	23.0	67.34	1.70	—
4	3	18.C.19	MIBC	0.45	Fuel Oil	0.60	Recon. Feed	5.69	832	47.3	100.0	23.78	2.02	—
							Product	28.69	137	39.3	83.1	11.92	2.12	1.34
							Tailings	0.89	895	8.0	16.9	82.07	1.52	—
4	5	18.C.19	MIBC	0.45	Fuel Oil	0.60	Recon. Feed	5.73	866	49.6	100.0	29.54	2.35	1.83
							Product	33.45	113	37.8	76.2	12.93	2.41	1.73
							Tailings	1.24	953	11.8	23.8	82.70	2.18	2.17

Notes: - All tests performed in 2" diameter by 6' high column, with nominal 100M grind feed coal.

- All tests done with 200 ml/min. froth wash, 14" froth thickness, and 1.5-2.0 CFM air rate @ 40 PSI.

Table 30
 SIZE DISTRIBUTION COMPARISON
 PETC AND PTI DRY GRINDS
 Upper Freeport Seam Raw Coal
 (Dry Basis)

Size Fraction (USA Mesh)	PETC Dry Grind		PTI Dry Grind	
	Direct (Wt%)	Cum. Passing (Wt%)	Direct (Wt%)	Cum. Passing (Wt%)
Top x 30M	0.2	99.8	0.0	100.0
30M x 50M	1.0	98.8	0.2	99.8
50M x 70M	1.0	97.8	3.1	96.7
70M x 100M	1.4	96.4	6.2	90.5
100M x 200M	6.3	90.1	22.1	68.4
200M x 400M	13.0	77.1	22.9	45.5
400M x 0	77.1	0.0	45.5	0.0
	100.0		100.0	

Table 31
OPTIMUM 2" LAB COLUMN RESULTS
PTI LABORATORY GRIND VS PETC/CPPRF PLANT GRIND
(Upper Freeport Seam Raw Coal)

Batch Number	Test Number	Appendix C Table Number	Grind Method	Frother Dosage		Collector Dosage		Sample	Actual Solids Content (Wt%)	Total Flow Rate (g/min)	Solids Flow Rate (g/min)	Column Performance (Dry Basis)			
				Type	#/T	Type	#/T					Yield (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)
1	4	18.C.8	PTI's Lab	MIBC	0.45	Fuel Oil	0.60	Recon. Feed	5.35	822	44.0	100.0	26.20	—	—
								Product	44.18	79	34.9	79.3	12.41	—	—
								Tailings	0.97	943	9.1	20.7	79.05	—	—
1	5	18.C.8	PTI's Lab	MIBC	0.45	Fuel Oil	0.60	Recon. Feed	5.76	772	46.2	100.0	25.10	2.12	1.60
								Product	36.47	102	37.2	80.6	12.00	2.30	1.55
								Tailings	1.03	870	9.0	19.4	79.70	1.24	—
2	4	18.C.11	PETC/CPPRF	MIBC	0.30	Fuel Oil	0.50	Recon. Feed	6.20	836	51.8	100.0	26.04	2.42	—
								Product	21.07	169	35.6	68.7	12.08	2.21	1.60
								Tailings	1.68	967	16.2	31.3	56.67	2.88	—
2	5	18.C.11	PETC/CPPRF	MIBC	0.30	Fuel Oil	0.50	Recon. Feed	6.46	835	53.9	100.0	26.48	2.50	—
								Product	20.64	188	38.8	72.0	12.90	2.27	1.69
								Tailings	1.78	847	15.1	28.0	61.39	3.09	—

Notes: - All tests performed in 2" diameter by 6" high column, with nominal 100M grind feed coal.
- All tests done with 200 ml/min. froth wash, 14" froth thickness, and 1.5-2.0 CFM air rate @ 40 PSI.

#2 Fuel Oil as the collector. For coals containing approximately the same feed ash content (25-26 Wt%), yields approximately 10 Wt% higher (80 Wt%) could be obtained at 12 -13 Wt% product ash contents for PTI's laboratory ground coal, as compared to yields of 70 Wt% for the PETC ground coal. The finer PETC grind apparently caused separation efficiency problems, as well as causing the solids contents in the froth to be much lower than the coarser PTI laboratory grind (approximately 20 Wt% vs. 36-44 Wt%). This explains the reason why PTI was experiencing difficulties obtaining yields above 75 Wt% for the multivariable tests done at PETC's CPPRF. A more detailed discussion of the multivariable testing results is detailed later in the discussion.

Table 32 includes a comparison of the performance results, by size, for the Optimum 2" Laboratory Separation for both PTI's laboratory grind and PETC's plant grind. The results illustrated a lower yield was obtained in the plus 200M and 200M x 400M size fractions for the finer PETC ground feed coal. Despite the improved quality of the coarser size fractions of the PETC ground concentrate, the overall concentrate was higher ash content (12.8 Wt%) than for the PTI grind (12.5 Wt%) due to the large proportion of higher ash content 400M x 0 fines which were present within the PETC groundconcentrate. Table 32 illustrates the disadvantage of the extremely fine PETC grind for obtaining reasonable yield (greater than 75 Wt%), while still achieving acceptable concentrate qualities (12-13 Wt%).

SECTION 4.11.2.2 - 12" PLANT COLUMN MULTIVARIABLE TESTING RESULTS

The following discussion summarizes the impact evaluation for various levels of process operating variables obtained from the Upper Freeport Seam Coal multivariable testing. The discussion also quantifies the optimum plant KEN-FLOTE™ Column results, by size, for the various stages of the multivariable testing. Due to the fact that flotation feed compositions varied randomly, and sometimes very severely, from test to test during the Upper Freeport Seam multivariable testing, it was very difficult to do a statistics-based approach to the operating variable impacts evaluation. However, PTI feels it is still worthwhile to compare some of the test results individually for tests where the impact of process variables can be directly compared (i.e., tests occurring in the same time frame with similar feed compositions).

The first variable of interest was the comparison of fresh city water to process water that had been recirculated through DOE's thickener and had residual flocculant and reagent. Table 33 contains the results from a comparative test that was performed during the multivariable testing (PT #4 and PT #5). For identical test conditions, the process water caused much higher concentrate ash content (26.7 Wt% vs. 14.1 Wt%) and considerably lower tailings ash content (33.1 Wt% vs. 37.4 Wt%) than the city water. The flotation performance deterioration caused by the recirculating process water was more pronounced than what occurs in an operating plant due to the fact that the CPPRF thickener is a high rate thickener and requires much higher flocculant dosage than a normal thickener. This resulted in much higher quantities of residual flocculant being recirculated within the circuit. After test PT #5, the decision was made to conduct all remaining tests with fresh city water and have a one-pass system through the CPPRF, where the clarified water was routed to local water treatment facility.

Table 32
OPTIMUM 2" COLUMN TESTS, SIZE ANALYSIS RESULTS
COMPARING PETC AND PTI DRY GRINDS
(Upper Freeport Seam Raw Coal)

Feed Grind System	Size Fraction USA Mesh	Reconstituted Feed			Actual Feed				Concentrate					Tailings		
		Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Yield (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)
PTI	Top x 30M	0.0	—	—	0.0	—	—	—	—	0.0	—	—	—	0.0	—	—
PTI	30M x 50M	0.1	—	—	0.1	—	—	—	100.0	0.1	—	—	—	0.0	—	—
PTI	50M x 100M	7.8	—	—	7.8	—	—	—	77.1	7.5	—	—	—	9.3	—	—
PTI	100M x 200M	21.5	—	—	21.7	—	—	—	83.9	22.5	—	—	—	17.3	—	—
PTI	Top x 200M	29.4	26.7	—	29.6	27.3	2.20	1.67	82.1	30.1	13.4	2.04	1.20	26.6	87.7	2.21
PTI	200M x 400M	24.6	19.0	—	24.6	20.1	2.75	2.15	90.3	27.7	11.7	2.77	2.06	12.1	87.0	1.44
PTI	400M x 0	<u>46.0</u>	<u>28.7</u>	—	<u>45.8</u>	<u>27.8</u>	<u>2.05</u>	<u>1.62</u>	<u>73.6</u>	<u>42.2</u>	<u>12.4</u>	<u>2.36</u>	<u>1.65</u>	<u>61.3</u>	<u>74.0</u>	<u>0.93</u>
PTI	Total	100.0	25.7	—	100.0	25.7	2.27	1.77	80.2	100.0	12.5	2.38	1.63	100.0	79.2	1.33
PTI	Heads	100.0	25.1	2.10	100.0	25.1	2.12	1.60	80.6	100.0	12.0	2.30	1.55	100.0	79.7	1.24
PETC	Top x 30M	0.0	—	—	0.1	—	—	—	0.0	0.0	—	—	—	0.1	—	—
PETC	30M x 50M	0.5	—	—	0.5	—	—	—	14.1	0.1	—	—	—	1.5	—	—
PETC	50M x 100M	1.9	—	—	2.1	—	—	—	26.0	0.7	—	—	—	4.7	—	—
PETC	100M x 200M	5.3	—	—	5.5	—	—	—	49.2	3.7	—	—	—	8.9	—	—
PETC	Top x 200M	7.7	33.8	2.65	8.2	34.6	2.71	2.15	41.2	4.5	7.9	1.59	0.95	15.2	52.0	3.39
PETC	200M x 400M	12.7	27.4	3.16	12.3	27.4	3.31	2.82	69.9	12.6	9.2	1.79	1.19	13.0	69.7	6.33
PETC	400M x 0	<u>79.6</u>	<u>25.3</u>	<u>2.24</u>	<u>79.5</u>	<u>25.1</u>	<u>2.24</u>	<u>1.80</u>	<u>73.4</u>	<u>82.9</u>	<u>13.6</u>	<u>2.23</u>	<u>1.61</u>	<u>71.8</u>	<u>57.6</u>	<u>2.26</u>
PETC	Total	100.0	26.2	2.39	100.0	26.2	2.41	1.95	70.5	100.0	12.8	2.15	1.53	100.0	58.3	2.96
PETC	Heads	100.0	25.9	2.34	100.0	25.9	2.43	1.91	71.1	100.0	12.8	2.12	1.47	100.0	58.3	2.87

Table 33
CITY WATER VERSUS PROCESS WATER COMPARISON

Test Number	Feed Rate (#/hr)	Water Type	Yield (Wt%)	Feed		Concentrate		Tailings	
				Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
PT#4	300	Process	30.0	7.25	31.19	5.47	26.73	5.85	33.10
PT#5	300	City	23.2	7.80	32.00	4.87	14.12	5.89	37.39

As witnessed by the low yields shown in Table 33, PTI was struggling early in the commissioning and multivariable testing to obtain higher yield and acceptable product qualities for the testing circuit. During the preliminary multivariable testing, PTI decided to compare MIBC frother performance to the Betz M-150, which was the initial frother selected for the testing. Table 34 shows a comparison of the testing results for two of the multivariable tests. Although the separation efficiencies were rather poor for both tests, in Table 34, due to the fact that recirculated process water was being used, the results did show a higher yield being obtained with the MIBC frother (47 Wt% vs. 30 Wt%) at a better product quality (21.6 Wt% ash vs. 26.7 Wt% ash) than for M-150 frother at the same reagent dosage. This, coupled with the improved results in the 2" laboratory column separations, caused PTI to switch to MIBC frother for the remainder of the bench-scale testing program.

Table 34
MIBC FROTHER VS. BETZ M-150 FROTHER COMPARISON

Test Number	Feed Rate (#/hr)	Frother	Yield (Wt%)	Feed		Concentrate		Tailings	
				Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
PT#4	300	M-150	30.0	7.25	31.19	5.47	26.73	5.85	33.10
PT#6	300	MIBC	47.4	7.65	32.32	5.50	21.57	5.83	42.01

One of the secondary research goals of the project was to test the use of a dual-cylinder sleeve that PTI invented and tested during earlier laboratory column experiments. Various dual-cylinder column sleeves were tested during the later stages of the Upper Freeport Seam multivariable testing (see tests FT #64 through FT #87 in Appendix A). In all cases, the dual-cylinder sleeve caused lower yields and poorer product qualities than were obtained for the standard 12" diameter KEN-FLOTE™ Column without the sleeve. The deterioration in performance was likely caused by short circuiting of coal through the bubble-free zone outside of the inner sleeve. Due to the poor separation performance, the dual-cylinder column sleeves were not used during the Upper Freeport Seam control testing. Based on the tighter testing schedule for the Pittsburgh No. 8 Seam Coal, where the test matrix needed to be condensed, the dual-cylinder column sleeve approach was also not utilized for that portion of the testing.

Another secondary research goal that was evaluated during the project was the use of polyacrylic acid as a pyrite depressant. The multivariable testing results for the Upper Freeport Seam Coal (see Appendix A) proved inconclusive, in terms of improved sulfur and/or pyritic sulfur removal occurring due to the polyacrylic acid addition. This was also the case for the 2" laboratory column tests conducted with the Upper Freeport Seam Coal discussed earlier. Due to the lack of any significant or noticeable impact of the polyacrylic acid on circuit performance, it was also not utilized during the Upper Freeport Seam Coal control testing, or the Pittsburgh No. 8 Seam testing.

There were a number of key primary variables that impacted performance to varying extents, one of the process variables that could be used for Upper Freeport Seam control testing was the quantity of froth wash water. PTI intended to target a product quality of approximately 13 Wt% ash in the Upper Freeport Seam control testing. The testing proved that this product composition could be achieved at relatively high yields (70-75 Wt%) when the feed was in the range of 24-26 Wt% ash, regardless of the froth washing quantity. However, as the feed ash content increased, as witnessed by Table 35 a high dosage of froth wash was required to clean up the concentrate and give the desired ash content range (12-14 Wt%). For this reason, PTI decided to use a feed rate of approximately 5.5 GPM during the Upper Freeport Seam control testing, and a high froth wash of 3.5 GPM to ensure positive bias, and that the froth was adequately cleaned for situations where the feed ash content increased above 27 Wt%.

Table 35
FROTH WASH IMPACT

Test Number	Feed Rate (#/hr)	Feed Rate (GPM)	Froth Wash (GPM)	Yield (Wt%)	Feed		Concentrate		Tailings	
					Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
FT#41	250	8.1	1.0	70.2	6.20	27.95	4.73	15.44	2.76	57.35
FT#42	250	6.1	3.0	68.0	8.33	27.50	4.35	12.44	3.06	59.44

The second operating variable that had a consistent impact on yield and product quality during the Upper Freeport Seam Coal multivariable testing was air rate to the column aspirators. Table 36 illustrates some of the more representative results, which occurred for two back-to-back tests with similar feed ash contents. The only major difference between the two tests was the variation in air rate to the aspirators. In general, a higher air rate promoted higher yield with slightly poorer product quality. Based on these results, PTI decided that air rate to the aspirators would be the primary control variable for the Upper Freeport Seam Control testing as a means of altering concentrate ash content and maximizing product yield for varying feed conditions. During the control testing, the air rate was adjusted between 1.0 and 2.0 CFM (at 50 PSI). If adjustment within this range were not adequate to maintain circuit performance at the desired level, secondary and tertiary control variables (froth height and reagent dosages) were then altered.

Table 36
AIR RATE IMPACT

Test Number	Air Rate 50 PSI (CFM)	Yield (Wt%)	Feed		Concentrate		Tailings	
			Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
PT#14	2.0	59.7	8.30	28.82	4.25	12.67	3.11	52.76
PT#15	1.5	55.6	8.25	28.51	4.17	11.42	3.34	49.94

Note: - Both tests were fed at 250 #/hr., 7.5 Wt% solids, and 6.5 GPM, using 1.00 #/T MIBC and 2.00 #/T No. 2 Fuel Oil, with 36" froth height, 3.0 GPM froth wash and 3.5 GPM launder water.

As mentioned, the secondary control variable within the Upper Freeport Seam control testing was froth height. In general, the impact of froth height on circuit performance was not as consistent and recognizable as the impact of air rate. However, increasing the froth height did seem to slightly improve the quality of the product at the expense of concentrate yield, as witness by the back-to-back test data shown in Table 37. PTI set the froth height at approximately 32" during the Upper Freeport Seam control testing. If the primary control adjustments (air rate adjustments) were not adequate to obtain the desired yield and concentrate quality, PTI adjusted froth height to between 26" and 38" to allow for an additional yield and concentrate quality compensation.

Table 37
FROTH HEIGHT IMPACT

Test Number	Froth Thickness	Yield (Wt%)	Feed		Concentrate		Tailings	
			Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
PT#26	20	43.8	5.79	27.80	3.44	12.15	2.89	39.88
PT#27	28	39.7	5.07	28.55	3.34	11.98	3.19	39.44

The final (tertiary) control variable that was utilized during the Upper Freeport Seam control testing was reagent dosage. As with froth height, the reagent dosage impact (shown in the test results in Appendix A) was less consistent and of lower magnitude than the air rate impact for the Upper Freeport Seam Coal. In general, minor changes in reagent dosage did not seem to have a major impact on yield and product quality when the feed was less than 28 Wt% ash content (FT#43 and FT#45). However, as feed ash content increased, it seemed that higher reagent dosage was required to obtain reasonable yields (greater than 60 Wt%). Table 38 illustrates that situation for two tests with similar circuit conditions (FT#26 and FT#49), with the exception of different reagent addition dosages. Both tests also had fairly high feed ash contents (29.9-30.9 Wt%) thereby verifying the conclusion made above.

From the results in Table 38 it can be observed that, for the high ash content feed, the high reagent dosages promoted much higher yield, while not significantly deteriorating the concentrate quality (which remained at approximately 14.5 Wt% ash). PTI ran with reagents at approximately 1.0 #/ton MIBC and 2.0 #/ton fuel oil during the Upper Freeport Seam control testing, and only adjusted those reagents in cases where the air rate control loop and froth height control loop reached minimum or maximum endpoints, beyond which the control algorithms would not exceed. The upcoming discussion summarizes the approach to the Upper Freeport Seam control testing, including a discussion of the control testing results.

Table 38
REAGENT DOSAGE IMPACT

Test Number	MIBC (#/T)	Fuel Oil (#/T)	Yield (Wt%)	Feed		Concentrate		Tailings	
				Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)	Solids (Wt%)	Ash (Wt%)
FT#43	0.90	2.00	70.3	8.23	26.13	4.40	12.95	3.14	57.39
FT#45	1.20	2.00	73.4	9.14	26.11	4.68	12.09	2.57	64.82
FT#26	1.20	2.00	69.4	8.04	29.94	4.41	14.76	3.04	64.44
FT#49	0.80	1.60	51.5	8.13	30.87	4.42	14.46	4.03	47.79

Note: - All tests were fed at 250 #/hr, 8.0 Wt% solids, and 6.1 GPM, using 1.5 CFM air rate, 24" froth height, 3.0 GPM froth wash, and 3.5 GPM launder water.

The Upper Freeport Seam multivariable testing was performed in two stages:

- Preliminary Multivariable Testing (PT#1-PT#33), which occurred in early March, 1993.
- Primary Multivariable Testing (FT#1-FT#87), which occurred in the latter part of March, 1993.

Table 39 contains the separation performance, by size, for two of the earlier optimum tests, occurring during the preliminary multivariable test matrix for the Upper Freeport Seam Coal. Whereas, Table 40 contains the same performance, by size, for some of the later optimum tests, occurring during the primary multivariable testing matrix.

From comparing the results from FT#45 (Table 40) to the results for PT#8 and PT#32 (Table 39), it can be observed that much higher yield was obtained in the primary multivariable testing. This higher yield was caused by a number of changes in operating conditions utilized for the primary multivariable testing, which included:

- Higher Reagent Dosages for FT#45 (1.2 #/ton MIBC and 2.0 #/ton Fuel Oil as compared to 0.8 #/ton and 1.2 #/ton Fuel Oil for PT#8 and PT#32).
- Higher Froth Wash Water Addition for FT#45 (3.5 GPM as compared to 2.5 GPM for PT#8 and PT#32).
- Slightly Higher Feeds Solids Content for FT#45 which resulted in lower column feed rate (GPM) and higher retention time for similar solids feed rate (250 #/hr.).

Table 39
PRELIMINARY MULTIVARIABLE TEST MATRIX
OPTIMUM TESTS, SIZE ANALYSIS RESULTS
(Upper Freeport Seam Coal)

Test Number	Size Fraction USA Mesh	Reconstituted Feed			Actual Feed				Concentrate					Tailings		
		Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Yield (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)
PT#8	Top x 30M	0.5	—	—	0.7	—	—	—	0.0	0.0	—	—	—	1.0	—	—
PT#8	30M x 50M	1.2	—	—	1.5	—	—	—	4.8	0.1	—	—	—	2.8	—	—
PT#8	50M x 100M	2.8	—	—	3.0	—	—	—	14.5	0.7	—	—	—	5.7	—	—
PT#8	100M x 200M	5.4	—	—	5.6	—	—	—	28.9	2.7	—	—	—	9.2	—	—
PT#8	Top x 200M	9.9	35.6	3.52	10.8	38.6	3.80	3.52	20.4	3.5	9.5	1.47	0.73	18.7	42.3	4.05
PT#8	200M x 400M	14.9	26.0	3.38	14.6	26.6	3.59	3.21	54.7	14.1	9.5	1.90	1.22	16.0	45.9	5.16
PT#8	400M x 0	<u>75.2</u>	<u>26.6</u>	<u>2.35</u>	<u>74.6</u>	<u>26.0</u>	<u>2.36</u>	<u>1.82</u>	<u>63.3</u>	<u>82.4</u>	<u>14.1</u>	<u>2.13</u>	<u>1.57</u>	<u>65.3</u>	<u>48.2</u>	<u>2.73</u>
PT#8	Total	100.0	27.4	2.62	100.0	27.4	2.70	2.21	57.8	100.0	13.3	2.07	1.49	100.0	46.7	3.37
PT#8	Heads	100.0	26.2	—	100.0	26.2	2.55	2.11	59.7	100.0	13.0	2.09	1.33	100.0	45.9	—
PT#32	Top x 30M	0.2	—	—	0.2	—	—	—	0.0	0.0	—	—	—	0.4	—	—
PT#32	30M x 50M	1.0	—	—	1.3	—	—	—	6.2	0.1	—	—	—	2.6	—	—
PT#32	50M x 100M	3.3	—	—	3.2	—	—	—	18.7	1.0	—	—	—	7.0	—	—
PT#32	100M x 200M	6.5	—	—	6.4	—	—	—	38.0	4.0	—	—	—	10.5	—	—
PT#32	Top x 200M	11.0	43.3	2.84	11.1	49.1	3.20	3.01	28.7	5.1	13.4	1.65	0.99	20.5	55.4	3.32
PT#32	200M x 400M	15.2	27.4	3.00	15.5	28.9	3.55	3.26	60.2	14.8	10.8	1.98	1.31	16.0	52.6	4.55
PT#32	400M x 0	<u>73.8</u>	<u>24.8</u>	<u>2.16</u>	<u>73.4</u>	<u>23.7</u>	<u>2.22</u>	<u>1.68</u>	<u>67.1</u>	<u>80.1</u>	<u>13.6</u>	<u>2.04</u>	<u>1.45</u>	<u>63.5</u>	<u>47.7</u>	<u>2.39</u>
PT#32	Total	100.0	27.3	2.36	100.0	27.3	2.53	2.07	61.8	100.0	13.2	2.01	1.40	100.0	50.1	2.93
PT#32	Heads	100.0	25.6	—	100.0	25.6	2.47	1.98	65.8	100.0	12.9	1.98	1.25	100.0	50.1	—

Table 40
PRIMARY MULTIVARIABLE TEST MATRIX
OPTIMUM TESTS, SIZE ANALYSIS RESULTS
(Upper Freeport Seam Coal)

Test Number	Size Fraction USA Mesh	Reconstituted Feed			Actual Feed				Concentrate					Tailings		
		Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Yield (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)
FT#45	Top x 30M	0.1	—	—	0.1	—	—	—	0.0	0.0	—	—	—	0.3	—	—
FT#45	30M x 50M	0.9	—	—	0.6	—	—	—	15.9	0.2	—	—	—	2.8	—	—
FT#45	50M x 100M	3.1	—	—	2.6	—	—	—	41.6	1.8	—	—	—	6.5	—	—
FT#45	100M x 200M	7.6	—	—	7.8	—	—	—	62.5	6.8	—	—	—	9.7	—	—
FT#45	Top x 200M	11.7	32.7	2.64	11.1	27.0	2.11	1.61	53.9	8.8	9.9	1.75	1.05	19.2	59.4	3.68
FT#45	200M x 400M	17.4	23.2	2.57	17.4	26.4	2.90	2.21	74.2	18.0	9.2	1.86	1.19	15.7	63.4	4.60
FT#45	400M x 0	<u>70.9</u>	<u>27.4</u>	<u>2.35</u>	<u>71.5</u>	<u>27.5</u>	<u>2.42</u>	<u>1.98</u>	<u>74.0</u>	<u>73.2</u>	<u>13.6</u>	<u>2.32</u>	<u>1.86</u>	<u>65.1</u>	<u>66.7</u>	<u>2.45</u>
FT#45	Total	100.0	27.3	2.42	100.0	27.3	2.47	1.98	71.7	100.0	12.5	2.19	1.67	100.0	64.8	3.02
FT#45	Heads	100.0	26.1	2.37	100.0	26.1	2.38	2.00	73.4	100.0	12.1	2.12	1.51	100.0	64.8	3.05
FT#47	Top x 30M	0.2	—	—	0.6	—	—	—	0.0	0.0	—	—	—	0.5	—	—
FT#47	30M x 50M	1.5	—	—	1.4	—	—	—	17.9	0.4	—	—	—	3.8	—	—
FT#47	50M x 100M	4.3	—	—	3.6	—	—	—	32.9	2.1	—	—	—	8.8	—	—
FT#47	100M x 200M	7.8	—	—	7.5	—	—	—	46.6	5.4	—	—	—	12.7	—	—
FT#47	Top x 200M	13.8	45.4	4.00	13.1	46.9	4.66	4.18	38.5	7.9	9.5	1.63	0.97	25.8	67.9	5.49
FT#47	200M x 400M	14.2	28.2	3.64	14.0	30.4	3.74	3.12	67.3	14.2	11.1	2.33	1.81	14.2	63.3	6.35
FT#47	400M x 0	<u>72.0</u>	<u>25.5</u>	<u>2.28</u>	<u>72.9</u>	<u>25.1</u>	<u>2.21</u>	<u>1.82</u>	<u>72.8</u>	<u>77.9</u>	<u>14.8</u>	<u>2.30</u>	<u>1.68</u>	<u>60.0</u>	<u>54.3</u>	<u>2.24</u>
FT#47	Total	100.0	28.7	2.71	100.0	28.7	2.74	2.31	67.3	100.0	13.9	2.25	1.64	100.0	59.1	3.66
FT#47	Heads	100.0	28.2	2.68	100.0	28.2	2.75	2.39	67.7	100.0	13.5	2.21	1.68	100.0	58.8	3.65

In addition, a comparison of FT#47 to FT#45 in Table 40 illustrates the drop in yield and deterioration in product quality caused by increased feed ash content. The higher feed ash content for Test FT#47 (28.2 Wt% vs. 26.1 Wt% for Test FT#45) resulted in a dramatic decrease in yield (down to 67.7 Wt% from 73.4 Wt%) and much higher concentrate ash contents (13.5 Wt% up from 12.1 Wt%). This deterioration in performance was principally caused by the lower yield in the Top x 200M and the 200M x 400M size fraction for FT#47, which caused the overall concentrate quality to be shifted higher due to the high magnitude of the 400M x 0 in the flotation concentrate. The size data for FT#47 in Table 40 illustrates the problems that high feed ash contents, coupled with the extremely fine grind, caused during the Upper Freeport Seam control testing.

SECTION 4.11.2.3 - 12" PLANT COLUMN CONTROL TESTING

The Upper Freeport Seam control tests that PTI performed focused on comparing the performance of the circuit when it was merely set at optimum operating conditions to the performance when it was controlled by PTI's On-Line Monitor for various feed conditions. Based on the results from the process variable evaluation and Tables 39 and 40, discussed in the previous section, the optimum setpoint operating conditions for the Upper Freeport Seam Coal were determined to be:

- 5.5 GPM Feed Rate,
- 3.5 GPM Froth Wash,
- 3.5 GPM Launder Water,
- 1.5 CFM @ 50 psi Air Rate,
- 32" Froth Thickness, and
- 1.0 #/ton MIBC and 2.0 #/ton No. 2 Fuel Oil, assuming a 220 #/hr solids feed rate.

During the testing, PTI and DOE staff randomly changed the solids feed rate from the various product bins in the CPPRF circuit between 190 and 250 #/hr. to alter the circuit throughput. PTI and PETC staff also randomly varied the amount of precleaned coal blended into the feed coal (between 0 Wt% and 50 Wt%) to further magnify the feed variations for certain portions of the testing.

On certain days (4 test days) the control testing was done in a regulatory mode (uncontrolled), at the test conditions shown above, to establish a baseline of how circuit performance varied for changing feed conditions when the operating conditions were kept constant. PTI then also ran approximately four days of testing using supervisory testing (controlled mode) to target certain product qualities and yield ranges. The supervisory control focused on varying certain operating conditions based on the quality results from the On-Line Monitor. The three levels of control included:

- Level #1 - Air Rate changes between 1.0 and 2.0 CFM,
- Level #2 - Froth Height changed between 26" and 38", and
- Level #3 - Reagent Dosage changes between 0.75 #/ton and 1.25 #/ton of MIBC, with a constant 2:1 collector-to-frother dosage ratio.

The goal of the testing was to target concentrate quality of 13.0 Wt% ash, while assuring that the yield did not vary beyond a desired range 60-80 Wt%.

During the Upper Freeport Seam control testing, PTI experienced a number of operating problems, which included:

- Extreme variations in feed composition (24 to 38 Wt% ash content), which made it impossible to control the concentrate quality at 13.0 Wt% ash, despite even radical changes in the Level #1 through #3 control variables shown above.
- Excessive concentrate sample foaming within PTI's On-Line Monitor, which made it impossible to obtain reproducible nuclear count numbers to get sound calibration for the ash monitor for concentrate, solids and ash content.
- Inconsistent sample size within the On-Line Monitor, which was also caused by the concentrate foaming problems, which also lead to inconsistent nuclear count information and poor concentrate sample calibrations.

Changing the blending approach for the Pittsburgh No. 8 Seam Coal, as well as adding a defoamer (Nalco 7810 Anti-foaming Reagent) to the On-Line Monitor reduced these problems for the Pittsburgh No. 8 Seam testing, thereby allowing for more conclusive control testing results. However, they did compromised the results from the Upper Freeport Seam control testing. Therefore, no discussion for the Upper Freeport control testing results is included in this final report.

SECTION 4.11.2.4 - COMPARISON OF LABORATORY AND 12" PLANT COLUMN TESTING RESULTS

The remainder of this Upper Freeport discussion focuses on comparison of the 12" plant column results to the laboratory testing results, which included the 2" laboratory column testing, the raw coal washability analysis and raw coal flotation release analysis. Table 41 contains the feed composition analysis, by size, for a composite of the PETC ground Upper Freeport Seam Coal. It can be observed that approximately 80 Wt% of the feed coal was ground into the 400M x 0 size fraction, while 2.7 Wt% remained in the plus 100M size fraction. In general, this grind was considerably finer than a normal nominal 100M x 0 topsize grind. Table 41 also illustrates that the feed was approximately 26.0 Wt% ash, with the coarser size fractions being higher ash content than the finer size fractions.

Table 41
PETC GRIND FEED PARTICLE SIZE ANALYSIS
Upper Freeport Seam Raw Coal, PETC Grind
(Dry Basis)

Size Fraction (USA Mesh)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)
Top x 100M	2.7	39.7	2.40	1.84
100M x 200M	5.5	32.1	2.86	2.30
200M x 400M	12.3	27.4	3.31	2.82
400M x 0	79.5	25.1	2.24	1.80
Total	100.0	26.2	2.41	1.95
Head	100.0	25.9	2.43	1.91

Figure 18 contains the ash versus yield relationship obtained from four different tests done with the PETC composite feed coal. Those tests include:

- The Washability Analysis Results, which defined the actual liberation of impurities from the feed coal and represents the theoretical best yield/ash relationship that can be obtained upon a perfect density separation.
- The Flotation Release Analysis Results, which represents the best separation that can be expected with any flotation process.
- The 2" Laboratory Column Results, which represents the optimum concentrate yield/ash relationship that was obtained under ideal laboratory conditions in PTI's continuous 2" laboratory KEN-FLOTE™ flotation test rig.
- The 12" Plant Column Results, which represent the optimum yield/ash relationship obtained from the multivariable tests performed at PETC's CPPRF with the 12" diameter KEN-FLOTE™ Column.

Only the 2" lab column and 12" plant column tests that had feed compositions that closely matched the PETC grind head sample, used for the washability and release analysis (25-27 Wt% ash) were considered as potential candidates for optimum laboratory and plant column results. All tests with feed ash contents that were outside the desired feed ash content range were not considered. Complete listing for the washability analysis and flotation release analysis for the Upper Freeport Seam Coal are included in Appendix E.

Figure 18
ASH VS. YIELD PERFORMANCE COMPARISONS
WASHABILITY, RELEASE ANALYSIS, AND CONTINUOUS COLUMN TESTS
Upper Freeport Seam Raw Coal, PETC Grind
(Dry Basis)

The following observations can be made based on the results in Figure 18:

- There is progressive deterioration in efficiency upon going from the washability analysis to release analysis and finally to the continuous column tests, as would be expected.
- The 12" plant column results lie on approximately the same curve as the 2" laboratory column results, indicating that there was no significant deterioration in column performance observed upon column scale-up.

The gradual break in the curves for the continuous column tests, which occurs at approximately 13 Wt% ash and 75 Wt% yield, also illustrates why PTI targeted 13.0 Wt% ash as the target concentrate composition during the Upper Freeport control testing.

Table 42 contains a comparison of the optimum 2" laboratory and 12" plant KEN-FLOTE™ Column results for the Upper Freeport Seam Coal. As was shown in Figure 18, Table 42 also illustrates that approximately the same yield (71.1 vs. 73.4 Wt%) and product quality were (12.1 to 12.8 Wt%) were obtained in the optimum 2" laboratory and 12" plant column tests for approximately 26 Wt% ash content feed. The main difference upon scale-up of the column was the difference in concentrate solids content, where the 2" column had a much higher concentrate ash content (19.14 Wt%) than the 12" plant column (7.47 Wt%). Although the low concentrate solids content for the plant column did not significantly impair the ash/yield relationship, it did have negative ramifications on column operations and accuracy of PTI's On-Line Monitor.

For example, the low concentrate solids content in the plant column lead to extremely high froth wash water requirements to obtain a positive bias within the column (net downward flow). This reduces column retention time, and has a negative impact on column throughput. The low concentrate solids content also limited the accuracy of the On-Line Monitor readings for the concentrate sample, where high concentrate solids contents are desired to improve the sensitivity of the On-Line Monitor reading to changes in concentrate ash content. The low solids content of the concentrate samples (3-5 Wt% when launder water were included) made determination of accurate calibration relationships for concentrate ash content very difficult for the Upper Freeport Seam Coal. The ramifications of the low concentrate solids content and methods for improving concentrate solids content in the future are discussed in more detailed during the Pittsburgh No. 8 Seam Coal testing evaluation.

In conclusion, Table 43 contains the performance comparison (by size) for the optimum 2" laboratory and 12" plant column tests shown in Table 42. As with Table 42, the results illustrate the similarity between the yield and quality, by size, for the two different size columns when treating a feed of similar size consist and composition. The slightly better results for the 12" diameter plant column test can be attributed to the lower proportion of the 400M x 0 present in the plant column feed (approximately 70 Wt%) as compared to the 2" lab column test (approximately 80 Wt%).

Table 42
 SCALE-UP PERFORMANCE COMPARISON
 OPTIMUM 2" LABORATORY AND 12" PLANT COLUMN RESULTS
 Upper Freeport Seam Raw Coal

Column Size (D x H)	Sample	Solids (Wt%)	Dry Basis Analyses			
			Yield (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
2" x 6'	Feed	6.19	100.0	25.9	2.43	1.91
	Concentrate	19.14*	71.1	12.8	2.12	1.47
	Tailings	1.61	28.9	58.3	2.87	2.76
12" x 14'	Feed	9.24	100.0	26.1	2.37	1.91
	Concentrate	7.47*	73.4	12.1	2.12	1.51
	Tailings	4.76	26.6	64.8	3.05	3.00

Notes: - * - Prior to launder water addition.

- Optimum 2" laboratory KEN-FLOTE™ Column test conditions and results are for Batch #3, Test #4B, summarized in Table 18.C.26 of Appendix C.
- Optimum 12" Plant KEN-FLOTE™ Column test conditions and results are for multivariable test FT#45, summarized in Appendix A.

Table 43
SCALE-UP PERFORMANCE COMPARISON, BY SIZE
OPTIMUM 2" LABORATORY AND 12" PLANT COLUMN RESULTS
Upper Freeport Seam Raw Coal

Column Size (D x H)	Size Fraction USA Mesh	Reconstituted Feed			Actual Feed				Concentrate					Tailings		
		Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Yield (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)
2" x 6"	Top x 30M	0.0	—	—	0.1	—	—	—	0.0	0.0	—	—	—	0.1	—	—
2" x 6"	30M x 50M	0.5	—	—	0.5	—	—	—	14.1	0.1	—	—	—	1.5	—	—
2" x 6"	50M x 100M	1.9	—	—	2.1	—	—	—	26.0	0.7	—	—	—	4.7	—	—
2" x 6"	100M x 200	5.3	—	—	5.5	—	—	—	49.2	3.7	—	—	—	8.9	—	—
2" x 6"	Top x 200M	7.7	33.8	2.65	8.2	34.6	2.71	2.15	41.2	4.5	7.9	1.59	0.95	15.2	52.0	3.39
2" x 6"	200M x 400	12.7	27.4	3.16	12.3	27.4	3.31	2.82	69.9	12.6	9.2	1.79	1.19	13.0	69.7	6.33
2" x 6"	400M x 0	<u>79.6</u>	<u>25.3</u>	<u>2.24</u>	<u>79.3</u>	<u>25.1</u>	<u>2.24</u>	<u>1.80</u>	<u>73.4</u>	<u>82.9</u>	<u>13.6</u>	<u>2.23</u>	<u>1.61</u>	<u>71.8</u>	<u>57.6</u>	<u>2.26</u>
2" x 6"	Total	100.0	26.2	2.39	100.0	26.2	2.41	1.95	70.5	100.0	12.8	2.15	1.53	100.0	53.3	2.96
2" x 6"	Heads	100.0	25.6	2.34	100.0	25.9	2.43	1.91	71.1	100.0	12.8	2.12	1.47	100.0	58.3	2.87
12" x 14"	Top x 30M	0.1	—	—	0.1	—	—	—	0.0	0.0	—	—	—	0.3	—	—
12" x 14"	30M x 50M	0.9	—	—	0.6	—	—	—	15.9	0.2	—	—	—	2.8	—	—
12" x 14"	50M x 100M	3.1	—	—	2.6	—	—	—	41.6	1.8	—	—	—	6.5	—	—
12" x 14"	100M x 200	7.6	—	—	7.8	—	—	—	62.5	6.8	—	—	—	9.7	—	—
12" x 14"	Top x 200M	11.7	32.7	2.64	11.1	27.0	2.11	1.61	53.9	8.8	9.9	1.75	1.05	19.2	59.4	3.68
12" x 14"	200M x 400	17.4	23.2	2.57	17.4	26.4	2.90	2.21	74.2	18.0	9.2	1.86	1.19	15.7	63.4	4.60
12" x 14"	400M x 0	<u>70.9</u>	<u>27.4</u>	<u>2.35</u>	<u>71.5</u>	<u>27.5</u>	<u>2.42</u>	<u>1.98</u>	<u>74.0</u>	<u>73.2</u>	<u>13.6</u>	<u>2.32</u>	<u>1.66</u>	<u>65.1</u>	<u>66.7</u>	<u>2.45</u>
12" x 14"	Total	100.0	27.3	2.42	100.0	27.3	2.47	1.98	71.7	100.0	12.5	2.19	1.67	100.0	64.8	3.02
12" x 14"	Heads	100.0	26.1	2.37	100.0	26.1	2.38	2.00	73.4	100.0	12.1	2.12	1.51	100.0	64.8	3.05

SECTION 4.11.3 - PITTSBURGH No. 8 SEAM TESTING RESULTS

The following discussion focuses on the Pittsburgh No. 8 Seam multivariable and control testing results for the 12" KEN-FLOTE™ Column installed at PETC's CPPRF. It also summarizes the 2" laboratory column results, washability analysis and flotation release analysis results for the Pittsburgh No. 8 Seam Coal conducted at PTI's Calumet laboratories. The discussion is broken down into a number of subsections, which include:

- 2" Laboratory Column Results, including comparisons of different frothers and improvements caused by the polyacrylic acid depressant.
- 12" Bench-Scale Column Multivariable Testing Results, including feed coal variability and operating variable impact evaluation.
- Comparison of Laboratory and 12" Plant Column Testing Results, to determine the scale-up efficiency of the flotation column technology.
- Control Testing Approach for 12" Bench-Scale Column.
- Control Testing Results for 12" Bench-Scale Column.

Since the results for the Upper Freeport Seam Coal (first coal tested) were not as conclusive as the results for the Pittsburgh No. 8 Seam Coal (second coal tested), the results discussed in the remainder of this section will also form the basis for the Technical and Economic Evaluation Sections at the end of this report.

SECTION 4.11.3.1 - 2" LABORATORY COLUMN TESTING RESULTS

Appendix D contains the results from the 2" laboratory tests that were performed during February and March, 1993, with the Pittsburgh No. 8 Seam Coal. The main focus was to determine the anticipated reagent addition dosages and product qualities that could be obtained with this coal at a nominal 100M Topsize grind. In addition to those main testing goals, secondary goals were to evaluate the comparative performance of three frothers (MIBC, Betz M-150 and Betz CM-670), and to also determine whether the polyacrylic acid depressant had any impact on improving pyritic sulfur removal in the continuous laboratory application.

The results in Appendix D are very voluminous and difficult to decipher. Because of this certain optimum data has been transferred into Table 44, for the basis of comparison. The first three rows of data in Table 44 compare the optimum separations for the three frothers, with frother dosages of 0.45 #/ton for all three different frothers and fuel oil collector dosages of 0.6 #/ton for all three tests. For the Pittsburgh No. 8 Seam Coal the M-150 and MIBC frothers performed very similar, giving yields in the range of 76-78 Wt% and product qualities of approximately 11 Wt% ash for feeds ranging from 25-26 Wt% ash. The CM-670 frother was less selective giving a higher concentrate ash content (14.3 Wt%) while only promoting the same tailings ash content as the other two frothers (approximately 76 Wt%).

The pyritic sulfur and total sulfur removals were also in the same range for the MIBC and M-150 frothers. However, the CM-670 was, once again, less selective. One small advantage of the MIBC frother was that it provided a higher solids content in the concentrate than the M-150 frother (42 Wt% vs. 33 Wt%). This was of particular importance for the bench-scale testing where the low solids content of the concentrate presented some logistical problems for

Table 44
OPTIMUM 2" LAB COLUMN RESULTS
PTI LABORATORY DRY GRIND
Pittsburgh No. 8 Seam Raw Coal

Batch Number	Test Number	Appendix D Table Number	Frother Dosage		Collector Dosage		Poly. Acid Dosage		Sample	Actual Solids Content (Wt%)	Total Flow Rate (g/min)	Solids Flow Rate (g/min)	Column Performance (Dry Basis)			
			Type	#/T	Type	#/T	Type	#/T					Yield (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. Sulfur (Wt%)
7	3	18.D.8	MIBC	0.45	Fuel Oil	0.60	—	—	Recon. Feed	5.95	800	47.6	100.0	25.12	4.45	2.49
									Product	42.39	88	37.3	78.4	10.92	4.57	2.24
									Tailings	1.13	912	10.3	21.6	76.65	4.02	3.40
11	3	18.D.12	M-150	0.45	Fuel Oil	0.60	—	—	Recon. Feed	6.26	836	52.3	100.0	26.19	4.53	2.76
									Product	32.89	121	39.8	76.1	10.92	4.71	2.33
									Tailings	1.37	915	12.5	23.9	74.80	3.96	4.13
13	3	18.D.14	CM-670	0.45	Fuel Oil	0.60	—	—	Recon. Feed	6.10	816	49.8	100.0	25.29	4.63	2.72
									Product	19.95	205	40.9	82.1	14.32	4.93	2.66
									Tailings	1.10	811	8.9	17.9	75.58	3.28	3.01
8	3	18.D.9	MIBC	0.45	Fuel Oil	0.60	Pure	0.80	Recon. Feed	6.00	793	47.6	100.0	25.48	4.60	2.65
									Product	43.45	84	36.5	76.7	11.39	4.67	2.33
									Tailings	1.22	909	11.1	23.3	71.86	4.36	3.70
12	3	18.D.13	M-150	0.45	Fuel Oil	0.60	Pure	0.80	Recon. Feed	6.15	806	49.6	100.0	24.82	4.52	2.50
									Product	35.09	112	39.3	79.2	11.66	4.75	2.31
									Tailings	1.15	894	10.3	20.8	74.94	3.63	3.22

Notes: - All tests performed in 2" diameter by 6' high column, with nominal 100M grind feed coal.
- All tests done with 200 ml/min. froth wash, 14" froth thickness, and 1.5-2.0 CFM air rate @ 40 PSI.

the Upper Freeport Seam testing. Therefore, the decision was made to continue to use the MIBC frother for the Pittsburgh No. 8 Seam multivariable and control testing performed in the bench-scale testing circuit at the CPPRF.

The lower part of Table 44 contains additional testing results done with the polyacrylic acid depressant, using both MIBC and M-150 frothers. When the results for MIBC and M-150 in the lower part of Table 44 are compared to the corresponding results in the upper part of Table 44, it can be observed that there are no significant improvements in pyritic sulfur removal resulting from the polyacrylic acid depressant addition. This, coupled with the inability of the polyacrylic acid depressant to promote improved pyritic sulfur removal during the Upper Freeport Seam bench-scale testing, led to the decision to drop the polyacrylic acid depressant addition from the testing matrix for the Pittsburgh No. 8 Seam Coal multivariable testing. The dual-cylinder column option was also dropped from the Pittsburgh No. 8 Seam Coal multivariable testing, due to the poor results obtained with the sleeves for the Upper Freeport Seam Coal multivariable testing.

SECTION 4.11.3.2 - 12" PLANT COLUMN MULTIVARIABLE TESTING RESULTS

Appendix G contains the test results and conditions for the 46 multivariable tests that were performed using the 12" diameter column, bench-scale testing circuit. Each 45-minute test included a 25-35 minute stabilization period followed by a 15-20 minute sampling and ash monitor counting period. The sampling period encompassed collecting samples of concentrate, tailings and feed for both a bypass sample bucket (for lab analysis) and a split to the On-Line Monitor for nuclear counts. The goal of the multivariable testing was to determine the optimum test conditions for reasonable column performance, as well as to determine the impact of some key process variables on column performance. The variables that gave the best sensitivity were then to be used to control the column performance in the control testing, which was done during the month of June, 1993.

During the multivariable testing for the Pittsburgh No. 8 Seam Coal, a different 6-ton lot of feed coal was brought over from Dillner Storage for each two-week testing period. During the weekly testing the feed lot was gradually fed from the product bin to the circuit and individual multivariable tests were run over 45-minute time increments. During the one-month multivariable testing period for the Pittsburgh No. 8 Seam Coal (May 3 through May 28, 1993) two feed lots were utilized for the testing. Table 45 contains a comparison of the two feed lots utilized for the Pittsburgh No. 8 Seam Coal multivariable testing. The first column of the table contains the feed lot analysis obtained from a composite sample collected as the coal was charged into the CPPRF system. The remaining columns contain the individual feed sample analysis from each of the 46 multivariable test (VT#1-VT#46) occurring during the one-month duration of the Pittsburgh No. 8 Seam Coal multivariable testing. The table includes the average feed sample analysis, as well as the minimum and maximum analyses obtained for the various feed samples, indicating the range of feed composition.

Table 45
FEED LOT AND TEST FEED
SAMPLE VARIABILITY
Pittsburgh No. 8 Seam Raw Coal
(Dry Basis)

	Feed Lot Analysis	Individual Test Feed Samples		
		Average Analysis	Minimum Analysis	Maximum Analysis
<u>Feed Lot #1 (VT#1-VT#35)</u>				
Ash (Wt%)	24.45	23.12	17.22	27.64
Sulfur (Wt%)	4.55	4.41	4.00	5.38
Pyritic Sulfur (Wt%)	2.77	2.75	2.30	3.82
Heating Value (Btu/lb.)	10955	---	---	---
MAF Heating Value (Btu/lb.)	14500	---	---	---
<u>Feed Lot #2 (VT#36-VT#46)</u>				
Ash (Wt%)	23.27	23.24	21.48	26.31
Sulfur (Wt%)	4.64	4.76	4.07	5.56
Pyritic Sulfur (Wt%)	2.57	2.87	2.26	3.65
Heating Value (Btu/lb.)	11138	---	---	---
MAF Heating Value (Btu/lb.)	14516	---	---	---

Table 45 illustrates that the two feed lots had fairly similar compositions, with feed ash contents of only 24.5 Wt% and 23.3 Wt%. The feed lot samples for the individual tests varied fairly significantly (17.2 Wt% to 27.6 Wt% ash) for the Feed Lot #1 testing. However, for the second feed lot (Tests VT#36-VT#46), the project team altered the feeding approach to try to maintain the product bins at about half full. This reduced the variation in feed composition to only 21.5 Wt% to 26.3 Wt% ash variation from test to test. This allowed for better evaluation of the impact of process variables on column performance during the tests performed using the second feed lot (VT#36-VT#46).

Based on the results from the multivariable testing with the first feed lot (VT#1-VT#35), PTI determined that it was best to use a 1/4" screen and 4912 RPM in PETC's hammermill to minimize the amount of 400M x 0 size fraction present in the column feed. PTI also determined that the column could be operated efficiently at solids feed rates of 200-300 #/hr., provided that the feed solids content was kept fairly high (7-10 Wt%) to allow for reasonable column retention time (6-10 minutes). Optimum froth wash and launder water additions were found to be approximately 3.5 and 3.0 GPM, respectively for column feed rates in the range of 5-8 GPM.

During the multivariable testing for the second feed lot, PTI conducted an eight test matrix to determine the relative impact of the three main column performance variables that seemed to have the greatest impact on column performance. They included:

- Reagent Dosages, varying both MIBC frother and No. 2 Fuel Oil collector.
- Froth Thickness, in inches from the top of the column.
- Air Rate, through the static aspirator determined in CFM @50 psi.

Table 46 contains the results from the eight test matrix (VT#39-VT#46), which was performed during the Lot #2 testing. Note that there were still some feed composition variations which make the evaluation of the results somewhat difficult. However, in general, it can be observed that the largest difference in yield and composition was caused by the change in reagent dosage from 0.7 #/ton MIBC and 1.4 #/ton fuel oil to 1.3 #/ton MIBC and 2.6 #/ton fuel oil. The higher reagent dosages in VT#43-VT#46, led to significantly higher yields and concentrate ash contents. The other two changes (froth thickness changes from 30" to 18") and air rate changes (from 1.7 CFM to 2.3 CFM) had a less significant and consistent impact on yield and product quality. Lower froth thickness and higher air rates lead to slightly higher yields and concentrate ash contents, for similar feed conditions.

Based on the results from the multivariable testing, PTI decided that the principle variables that would be used to control column performance in the Pittsburgh No. 8 Seam control testing would be MIBC frother and No. 2 Fuel Oil collector addition rates. The decision was made to keep these reagents at a 1:2 ratio of MIBC-to-Fuel Oil for the control testing, and adjust them up or down, proportionally. The second and third level variables, which would be altered in the case where MIBC and Fuel Oil reach maximum or minimum acceptable dosages, would be air rate and froth thickness, respectively. The logic and approach used in the control testing strategy is discussed in more detail in a later subsection.

As part of the multivariable testing, PTI also conducted size analysis on the feed, concentrate and tailings samples from one of the optimum separations occurring during the multivariable testing. Table 47 contains the performance and quality results for this optimum test (VT#23) which was performed at the following test conditions:

- 300 #/hr. Solids Feed Rate,
- 6.5 GPM Column Feed Rate at 9.0 Wt% Solids,
- 18" Froth Thickness and 1.8 CFM Air Rate @ 50 Psi,
- Froth Wash and Launder Water Additions of 3.0 GPM,
- MIBC Frother Dosage of 1.0 #/ton and No. 2 Fuel Oil Collector Dosage at 2.0 #/ton, and
- 1/4" Screen in the Hammermill Operated at 4912 RPM.

More details on VT#23 test conditions and results are included in Appendix G.

Table 47 illustrates the low yield occurring in the Top x 30M and 30M x 50M size fraction where approximately 3.0 Wt% of the feed coal is lost to tailings. The results in Table 47 also show that the yield of approximately 77.3 Wt% could be obtained at 10.0-10.5 Wt% ash for the 23 Wt% feed coal, despite the loss of 3.0 yield units in the coarse size fraction. The high ash content of 13.5 Wt% for the 400M x 0 size fraction of the concentrate also illustrates why it is important to keep the proportion of 400M x 0 to a reasonable amount (preferably less than 50 Wt%) when trying to obtain acceptable concentrate qualities (less than 12.0 Wt% ash). The upcoming subsection compares some of the optimum multivariable test results obtained with the 12" diameter bench-scale column to the laboratory column testing results, including the 2" laboratory column results, washability analysis and release analysis for similar size consists and feed composition samples of Pittsburgh No. 8 Seam Raw Coal.

Table 46
DETAILED TEST RESULTS
Pittsburgh No. 8 Seam Multivariable Testing
(Dry Basis)

Test Number	Reagents (#/T)		Froth Thickness (Inches)	Air Rate @ 50 Psi (CFM)	Actual Feed Sample			Concentrate Sample					Tailings Sample		
	MIBC	No. 2 F.O.			Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)	Yield (Wt%)	Comb. Rec. %	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
VT#39	0.70	1.40	30	1.7	23.50	4.99	3.13	62.3	75.7	7.07	3.92	1.73	50.63	4.90	—
VT#40	0.70	1.40	30	2.3	24.29	4.44	2.44	64.4	78.3	7.94	3.99	1.84	53.83	5.36	—
VT#41	0.70	1.40	18	1.7	22.72	4.07	2.26	67.0	78.9	8.96	3.73	1.68	50.66	3.81	—
VT#42	0.70	1.40	18	2.3	24.95	4.57	2.91	65.5	78.5	10.06	3.93	1.99	53.27	4.80	—
VT#43	1.30	2.60	30	1.7	24.79	4.87	3.12	74.5	89.3	9.84	4.46	2.36	68.34	4.29	3.55
VT#44	1.30	2.60	30	2.3	21.98	4.71	2.63	78.3	90.6	9.71	4.42	2.24	66.20	4.91	—
VT#45	1.30	2.60	18	1.7	22.22	4.86	2.81	79.9	91.0	11.43	4.58	2.38	65.15	4.70	3.96
VT#46	1.30	2.60	18	2.3	26.31	5.56	3.65	73.3	86.2	13.37	4.89	2.88	61.85	5.72	—

Notes: - Comb. - Combustibles

- Yields are based on ash balance from feed, concentrate, and tailings samples.
- All tests performed targeting 250 #/Hr. feed rate and 25.0 Wt% feed solids to PTI's feed sump (undiluted).
- All tests performed with column feed rate of 6.1 GPM at 8.0 Wt% solids with no inner sleeves or polyacrylic acid addition.
- All tests performed with Hammermill set at 4912 RPM with 1/4" screen.
- All tests performed with froth wash bar set at 12", 3.5 GPM froth wash and 3.0 GPM launder water wash.

Table 47
OPTIMUM TEST PARTICLE SIZE ANALYSIS RESULTS
Pittsburgh No. 8 Seam Multivariable Testing
(Dry Basis)

Test Number	Size Fraction USA Mesh	Reconstituted Feed			Actual Feed Sample				Yield (Wt%)	Concentrate Sample				Tailings Sample		
		Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)		Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)
VT#23	Top x 30M	0.5	—	—	0.6	—	—	—	0.0	0.0	—	—	—	2.2	—	—
VT#23	30M x 50M	3.0	—	—	3.4	—	—	—	28.1	1.1	—	—	—	9.1	—	—
VT#23	50M x 100M	8.5	—	—	8.9	—	—	—	67.6	7.5	—	—	—	11.8	—	—
VT#23	Top x 100M	12.0	18.31	4.24	12.9	17.26	4.80	2.99	54.9	8.6	6.96	3.54	1.12	23.1	32.12	5.10
VT#23	100M x 200	15.5	13.74	4.40	16.8	14.36	4.50	2.53	85.5	17.3	7.58	3.76	1.67	9.6	50.08	8.20
VT#23	200M x 400	22.8	14.47	5.30	24.1	13.88	5.01	2.99	88.7	26.4	7.97	4.48	2.31	11.2	65.48	11.77
VT#23	400M x 0	49.7	31.11	4.07	46.2	32.66	3.95	2.56	73.5	47.7	13.52	4.40	2.50	56.1	79.90	3.18
VT#23	Total	100.0	23.09	4.42	100.0	23.07	4.41	2.71	76.6	100.0	10.46	4.24	2.19	100.0	64.39	5.08
VT#23	Heads	100.0	22.37	4.43	100.0	22.38	4.33	2.67	77.3	100.0	10.02	4.21	2.22	100.0	64.44	5.18

SECTION 4.11.3.3 - COMPARISON OF LABORATORY AND 12" PLANT COLUMN TESTING RESULTS

PTI collected a composite of the CPPRF ground feed coal over the entire duration of the Pittsburgh No. 8 multivariable testing (Lot #1 and Lot #2). Table 48 contains the size analysis of the composite sample, whose composition closely matched the average composition of the Feed Lot #1 and Feed Lot #2 samples (see Table 45). Once again, Table 48 illustrates that less than 50 Wt% of the feed coal was ground to 400M x 0 size fraction for the Pittsburgh No. 8 Seam Coal. This compares to approximately 80 Wt% 400M x 0 size fraction that was present during the Upper Freeport Seam testing. The move to this coarser grind had the advantage of reducing the dependency of column performance on feed composition, which dramatically deterred the conclusiveness of the Upper Freeport Seam control testing. However, there was a significant loss in yield (approximately 3 Wt%) due to the inability of the column to efficiently recover the 4.3 Wt%, Top x 50M that was present in the feed coal. This compromise was illustrated in Table 47, discussed within the previous section. In actual plant applications the plus 50M would be removed from the flotation circuit and treated in some other unit operation (water-only cyclones or spirals). However, that approach was not available at the CPPRF, due to the limitations of PETC's open-loop dry grinding circuit.

Table 48
FEED PARTICLE SIZE ANALYSIS
Pittsburgh No. 8 Seam Raw Coal, PETC Grind
(Dry Basis)

Size Fraction (USA Mesh)	Weight (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
Top x 30M	1.0	28.68	5.19	3.10
30M x 50M	3.3	28.68	5.19	3.10
50M x 70M	3.5	21.50	4.64	2.59
70M x 100M	5.4	18.74	4.74	2.89
100M x 200M	16.0	14.98	5.00	2.96
200M x 400M	22.6	14.08	5.25	3.49
400M x 0	48.2	32.43	3.83	2.45
TOTAL	100.0	24.21	4.47	2.82
HEAD	100.0	23.40	4.51	2.69

The composite ground feed sample that was subjected to the size analysis in Table 48 was also the sample used for the feed coal washability and release analysis performed with the Pittsburgh No. 8 Seam Coal. Figure 19 contains the ash vs. yield performance comparison for a number of different tests performed with the Pittsburgh No. 8 Seam Feed Coal obtained from PETC's grinding circuit. The tests illustrated in the graph include:

- The Washability Analysis Results, which defines the actual liberation of impurities from the feed coal, and represents the theoretical best yield/ash relationship that can be obtained upon a perfect density separation.
- The Flotation Release Analysis Results, which represents the best separation that can be expected with any flotation process.
- The 2" Laboratory Column Results, which represents the optimum concentrate yield/ash relationship that was obtained under ideal laboratory conditions in PTI's continuous 2" laboratory KEN-FLOTE™ flotation test rig.
- The 12" Plant Column Results, which represent the optimum concentrate yield/ash relationship obtained from the multivariable tests performed at PETC's CPPRF with the 12" diameter KEN-FLOTE™ Column.

Only the 2" laboratory column tests and 12" plant column tests that had feed compositions closely matched feed compositions utilized for the washability and release analysis (23-25 Wt%) were considered as potential candidates for the optimum lab and plant results in Figure 19. Any test that had feed ash contents outside the range of 23-25 Wt%, were disregarded and not considered as optimum test candidates for the graph. Appendix F contains the complete feed coal washability and release analysis results for the Pittsburgh No. 8 Seam Coal, as well as the procedures utilized for the release analysis work.

Figure 19
ASH VS. YIELD PERFORMANCE COMPARISONS
WASHABILITY, RELEASE ANALYSIS AND CONTINUOUS COLUMN TESTS
Pittsburgh No. 8 Seam Raw Coal, PETC Grind
(Dry Basis)

The following observations can be made based on the results shown in Figure 19:

- There is progressive deterioration in efficiency upon going from the washability analysis to release analysis and finally to the continuous column tests, as would be expected. However, the difference in performance between the washability and the various flotation separations was of lesser magnitude for the Pittsburgh No. 8 Seam Coal than for the Upper Freeport Seam Coal (see Figure 18) due to the coarser grind that was utilized for the Pittsburgh No. 8 Seam Coal.
- The 2" lab column obtained higher yields at when low ash contents products were required (less than 10.0 Wt%). However, the difference between the 2" laboratory column and 12" plant column were of much lesser magnitude, if even significant, for tests yielding ash contents in the range of 10-12 Wt%.

It is also worth noting that the curve connecting the optimum test results for the 12" plant column began to break and flatten out at approximately 10.0 Wt% ash content. Therefore, a target of approximately 10.0 Wt% ash content was set for the control testing performed later with the Pittsburgh No. 8 Seam Coal. Hopefully, yields in the range of 70-80 Wt% could still be achieved at this optimum concentrate solids content setting.

As a further comparison of scale-up column performance, Table 49 contains a comparison of the optimum column results for the Pittsburgh No. 8 Seam Coal for both the 2" laboratory and 12" plant column tests. For feed coals with similar ash contents (22.0-22.5 Wt%), the yields and product ash content for the 2" diameter lab column and 12" diameter plant column were very similar, with only a slight decrease in yield being observed upon scale-up to the 12" diameter column (approximately 3 Wt%). The main difference between the results was that the 2" diameter column gave a much higher concentrate solids content (28.0 Wt%) than the 12" diameter column (12.8 Wt%) for the same size consist of feed. This may be somewhat due to scale-up dynamics that occur on larger columns. However, PTI also feels that the air distribution and air aspirator system used in the 12" diameter column may also have something to do with the observed drop in concentrate solids content. The 12" diameter bench-scale column had a lower aspirator cross-sectional area to column cross-sectional area ratio than the 2" diameter laboratory column, and therefore had higher air velocities required to meet the air volume targets. This may have contributed to the lower concentrate solids content. This is a phenomena that PTI desires to research further in the future, as it leads to some detrimental side affects such as requiring much higher froth wash water to obtain a positive bias in the column. It also causes difficulty in obtaining accurate calibrations for concentrate ash content within PTI's On-Line Monitor, due to lower nuclear count sensitivity occurring for the low solids content, concentrate samples.

Table 49
SCALE-UP PERFORMANCE COMPARISON
OPTIMUM 2" LABORATORY AND 12" PLANT COLUMN RESULTS
Pittsburgh No. 8 Seam Coal

Column Size (D x H)	Sample	Solids (Wt%)	Dry Basis Analyses			
			Yield (Wt%)	Ash (Wt%)	Sulfur (Wt%)	Pyr. S. (Wt%)
2" x 6'	Feed	5.9	100.0	22.1	3.99	2.30
	Concentrate	28.0*	80.3	10.3	4.25	2.27
	Tailings	1.1	19.7	69.9	2.92	2.42
12" x 14'	Feed	9.1	100.0	22.4	4.43	2.74
	Concentrate	12.8*	77.3	10.0	4.21	2.22
	Tailings	2.2	22.7	64.4	5.18	4.52

Notes: - * -Prior to launder water addition.

- Optimum 2" Laboratory KEN-FLOTE™ Column test conditions and results are for Batch #14, Test #3, summarized in Table 18.D.16 of Appendix D.
- Optimum 12" Bench-Scale KEN-FLOTE™ Column test conditions and results are for multivariable test VT#23, summarized in Table 18.G.6 of Appendix G.

Despite the solids content concerns, the optimum 12" diameter plant column results for the Pittsburgh No. 8 Seam Coal seemed to closely match the 2" diameter laboratory column results. Concentrate ash contents of approximately 10.0 Wt% were achieved at both scales, with the 12" plant column leading to only slightly lower yields than the 2" lab column (77.3 Wt% versus 80.3 Wt%). One final observation worth noting in Table 49 is that the 12" diameter column seemed to have better sulfur and pyritic sulfur removals than the 2" diameter laboratory column. This behavior was also observed for the Upper Freeport Seam Coal testing, and may be due to the fact that the greater froth wash required in the plant column enhanced the removal of entrained pyrite. This behavior will also need to be researched further in future scale-up testing.

SECTION 4.11.3.4 - CONTROL TESTING APPROACH (PITTSBURGH NO. 8 SEAM COAL)

During the period from June 1 through June 16, 1993, PTI's bench-scale testing efforts focused on conducting the Pittsburgh No. 8 Seam control testing. PTI conducted ten extended control testing runs (WT #1-Wt #10) with a duration of 6-10 hours for each test. The tests were either done in a regulatory mode (uncontrolled) where reagents, air rate and froth height were merely held constant, or in a supervisory mode (controlled) where the computer control algorithms altered those variables to target concentrate ash contents of 10.0 Wt%. The control testing results are summarized in Appendix H.

Table 50 contains a listing of the control testing approach for the two types of tests that were performed (regulatory tests and supervisory tests). As with the Upper Freeport Seam control testing, the column feed rate, launder wash water rate and froth wash water rate were all held constant at desired optimums for both types of tests. Gilbert Commonwealth personnel also randomly varied the feed composition and solids feed rate by altering the weigh belt feeder settings from the two product bins, which fed the CPPRF's existing dry grinding circuit. One product bin contained raw coal and the other product bin contained a raw/precleaned coal mix (50/50 Wt%), so the subsequent feed coal ash content could be varied to the circuit by changing the blend from the product bins.

Table 50 also illustrates that, for the regulatory tests, the reagent dosages, air rates and froth thicknesses were all held constant at the levels at optimum levels. However, in the supervisory tests, the reagent dosages, air rates and froth thicknesses were altered to target setpoint concentrate quality (10.0 Wt% ash) and column yield (65-85 Wt%). The methodology of the supervisory control is discussed later in this section.

As mentioned, Gilbert Commonwealth personnel used a blending strategy from the two bins to attempt to simulate random changes in feed rate and feed composition to PTI's column flotation circuit. Table 51 shows the blending approach for the 6-hour run schedule that was used during the testing. For tests that lasted longer than six hours, the schedule shown in Table 51 was merely repeated. The approach shown in Table 51 allowed for feed rate variations between 220 and 280 lb/hr and in feed ash content ranges which often varied from 20-30 Wt% ash, partly due to variations that also occurred within the bins themselves.

Lastly, Table 52 contains a simplified version of the control logic used for the supervisory (controlled) testing. During the control testing, the multiplexer and On-Line Monitoring System were used to collect concentrate and tailing samples on 20-minute increments. The On-Line Monitor predicted solids and ash contents (obtained from existing calibration relationships) were then compared to the concentrate ash content target (10.0 Wt%) and yield target range (65-85 Wt%). The control software then made step-changes in the control variables (reagents, air rates and froth thicknesses) based on the difference between the measured circuit performance and the desired setpoints, as shown in Table 52. The control would nominally target 10.0 Wt% ash concentrates, except when the yield varied outside the range of 65 Wt% to 85 Wt%, the Control Logic would override the main control variable, and control the circuit to at least maintain a minimum yield of 65 Wt% or not exceed a maximum yield of 85 Wt%. The yields were determined from a flow balance based on the measured magnetic flowmeter flow rates and the concentrate and tailings solids contents (predicted from On-Line Monitor).

Table 50
CONTROL TESTING APPROACH
Pittsburgh No. 8 Seam Coal

	Regulatory Tests	Supervisory Tests
Column Feed Rate	Constant, 6.1 GPM	Constant, 6.1 GPM
Launder Wash Water	Constant, 3.0 GPM	Constant, 3.0 GPM
Froth Wash Water	Constant, 3.5 GPM	Constant, 3.5 GPM
Raw/Precleaned Mix	G/C Vary, 100/0 - 50/50 Wt%	G/C Vary, 100/0 - 50/50 Wt%
Solids Feed Rate	G/C Vary, 220-280 #/hr.	G/C Vary, 220-280 #/hr.
Frother (MIBC)	Constant, 1.0 #/T	Level #1 Control, 0.7-1.3 #/T
Collector (No. 2 Fuel Oil)	Constant, 2.0 #/T	Level #1 Control, 1.4-2.6 #/T
Air Rate (50 PSI)	Constant, 2.0 CFM	Level #2 Control, 1.7-2.3 CFM
Froth Thickness	Constant, 24"	Level #3 Control, 30"-18"

Table 51
FEED COMPOSITION AND FEED RATE VARIATIONS
Pittsburgh No. 8 Seam Coal
(6 Hour Schedule)

Run Hour	Bin #1 Raw/Precleaned Mix Average 19 Wt% Ash (Feed Rate, #/hr.)	Bin #2 Raw Coal Average 25 Wt% Ash (Feed Rate, #/hr.)
1	0	250
2	0	280
3	220	0
4	280	0
5	0	220
6	0	250

** Repeat If Necessary **

Table 52
 SUPERVISORY CONTROL LOGIC (SIMPLIFIED)
 Pittsburgh No. 8 Seam Coal
 (Step Changes on 20-Minute Intervals)

Control Variable	Low	Med. Low	Target	Med. High	High
Main: Conc. Ash Content (Wt%)	<8.5	8.5-9.5	9.5-10.5	10.5-11.5	>11.5
#1 Override: Low Yield (Wt%)	<60	60-65	NA	NA	NA
#2 Override: High Yield (Wt%)	NA	NA	NA	85-90	>90
Response	++	+	0	-	--
Level #1: MIBC (0.7-1.3 #/T)	+2	+1	0	-.1	-.2
Level #1: No. 2 F.O. (1.4-2.6 #/T)	+4	+2	0	-.2	-.4
Level #2: Air Rate (1.7-2.3 CFM)	+2	+1	0	-.1	-.2
Level #3: Froth Thickness (30"-18")	-3.0	-1.5	0	+1.5	+3.0

Note: Control Logic also adjusts response based on convergence/divergence.

In the control logic, shown in Table 52, the Level #1 control adjusted both MIBC and fuel oil between the ranges of 0.70-1.30 lb/ton for MIBC and 1.40-2.60 lb/ton for fuel oil. In essence, the fuel oil to MIBC ratio was kept at 2:1 and the two reagents were adjusted upwards or downward proportionally. In cases where the Level #1 control reached the maximum or a minimum value, shown in Table 52, the control system then jumped into Level #2 control to adjust air rates. If the air rate then reached maximum or minimum, the control system jumped into Level #3 (froth thickness control). In the case where the concentrate qualities or yields began to reverse themselves, the control system worked its way out of Level #3 and Level #2 control, sequentially, back into Level #1 control to stabilize the circuit. This approach worked fairly well for the Pittsburgh No. 8 Seam control testing and often led to significant yield improvements as a result of the supervisory control. The next subsection contains a discussion of the calibration results and ash content tracking plots for the Pittsburgh No. 8 Seam control testing, as well as the yield improvements obtained by using the on-line monitoring system.

SECTION 4.11.3.5 - CONTROL TESTING RESULTS (PITTSBURGH NO. 8 SEAM COAL)

Due to drift, which PTI observed in the electronic systems used to make the on-line monitor readings (detectors, preamplifiers and amplifiers), the calibrations relationships determined during the multivariable testing did not hold over the course of the supervisory tests, which were performed in subsequent weeks. For this reason, PTI was required to use the regulatory tests daily runs, to obtain calibration relationships for the supervisory tests, which occurred on subsequent days. Although undesirable, this constant recalibration was required to obtain

accurate monitoring and control of the circuit during the supervisory testing. PTI is working on altering the electronics for future on-line monitors, to ensure better measurement consistency and reproducibility over extended time periods and changing plant environments.

The routine calibration of the on-line monitor involved correlating nuclear count results to actual solids and ash contents of the concentrate and tailings samples. This empirical correlation was then used to develop calibration relationships to predict solids and ash contents during the supervisory testing. During the supervisory testing, the control system would then compare the predicted concentrate ash contents to the target values and alter the circuit operating variables to hone in on the desired concentrate qualities (10.0 Wt% ash). Figures 20 and 21 contain the calibration results for concentrate solids and ash contents, respectively, obtained for one of the later regulatory tests (WT #9) performed during the Pittsburgh No. 8 Seam control testing. The RMS errors of 0.28 Wt% and 0.33 Wt%, respectively, indicate a good correlation between predicted and actual concentrate and solids and ash content results, respectively. PTI normally guarantees RMS errors within 0.5 Wt% for concentrate, solids and ash contents for commercial installations with the On-Line Monitor.

Similarly, Figures 22 and 23 contain the calibration results from WT #9 for tailings solids and ash contents, respectively. For the tailings sample, the RMS errors between predicted and actual solids and ash contents were 0.30 Wt% and 3.49 Wt%, respectively. The RMS error of 3.49 Wt% for the tailings ash content was higher than PTI has experienced in conventional flotation circuits, where PTI generally warrants RMS errors within 2.0 Wt%. This error was probably caused by the interdependency of solids and ash content counts caused by limitations of the single nuclear source approach PTI uses for the On-Line Monitor measurements. PTI also plans to use a blended source in future analyzers to obtain an independent solids content measurement, thereby allowing for more accurate determination of ash contents for streams where solids contents and ash contents do not vary proportionally. This recommendation, as well as the planned changes in nuclear electronics, will be discussed in more detail in the Conclusions and Recommendations section.

Although the tailings ash content RMS errors were excessive and exceeded the RMS errors normally experienced in a conventional flotation circuit, they did not present any major problem in the project, as tailings ash content was not used as a critical variable in the control system logic. In the testing, yields were determined from solids contents and flow rates in the concentrate and tailings streams. Fortunately, tailings solids contents RMS errors were generally within the desired range (± 0.3 Wt%).

Figures 24 and 25 contain a tracking plot for concentrate ash and tailings ash content for two of the later control tests that were conducted during the project (WT #9 and WT #10). Once again, it can be observed that for concentrate stream the predicted ash contents track fairly closely with the actual ash content. However, the magnitude of the differences between the actual and predicted ash contents were much greater for the tailings stream tracking plot (Figure 25). Fortunately, PTI did not utilize the tailings ash content for the yield calculation done within the circuit. However, changes need to be made in PTI's On-Line Monitor's measuring system to obtain more accurate measurements of tailings ash content in the future, because flow rates for concentrate and tailings may not be available in commercial installations, as they were in this tightly controlled bench-scale testing application. In those cases, accurate tailings ash content measurements may be required to obtain a yield estimate.

Figure 20
CONCENTRATE SOLIDS CORRELATION
Pittsburgh No. 8 Seam Coal

WT#9 Results
(6/15/93)

RMS Error
= 0.28 Wt%

Figure 21
CONCENTRATE ASH CORRELATION
Pittsburgh No. 8 Seam Coal

WT#9 Results
(6/15/93)

RMS Error
= 0.33 Wt%

Figure 22
TAILINGS SOLIDS CORRELATION
Pittsburgh No. 8 Seam Coal

WT#9 Results
(6/15/93)

RMS Error
= 0.30 Wt%

Figure 23
TAILINGS ASH CORRELATION
Pittsburgh No. 8 Seam Coal

WT#9 Results
(6/15/93)

RMS Error
= 3.49 Wt%

Figure 24
CONCENTRATE ASH TRACKING PLOT
Pittsburgh No. 8 Seam Coal Control Testing

WT#9 - #10 Results: (6/15/93 - 6/16/93)

Figure 25
TAILINGS ASH TRACKING PLOT
Pittsburgh No. 8 Seam Coal Control Testing

WT#9 - #10 Results: (6/15/93 - 6/16/93)

Table 53
SUMMARY CONTROL TESTING COMPARISONS
Pittsburgh No. 8 Seam Coal

	WT#3 Regulatory Test (6/01/93 - 10 Hr. Run)	WT#5 Supervisory Test (6/07/93 - 6 Hr. Run)
Average Feed Ash (Wt%)	24.3	24.2
Feed Ash Range (Wt%)	21.1-30.7	21.0-29.1
Average Conc. Ash (Wt%)	9.7	9.8
Conc. Ash Range (Wt%)	8.7-11.2	8.6-12.0
Average Yield (Wt%)	70.8	73.6
Yield Range (Wt%)	64.3-75.6	62.8-78.7
Average Comb. Recovery (%)	84.5	87.5
Comb. Recovery Range (%)	79.0-89.4	77.9-90.2

In summation, Table 53 contains a summary comparison between the regulatory mode results and the supervisory mode results two of the tests performed during the Pittsburgh No. 8 Seam control testing (WT #3 and WT #5). These two tests provided a good evaluation of the benefits of the supervisory control (i.e., PTI's On-Line Monitoring System) because they both had about the same average feed ash content (24.2 Wt% vs. 24.3 Wt%) and feed ash content range (21.0-31.0 Wt%). In addition, the average concentrate ash contents of 9.7 to 9.8 Wt% were also very close, and slightly less than, the control testing target (10.0 Wt% ash).

During the supervisory test (WT #5), the control system gradually increased reagents to reach the desired 10.0 Wt% target ash content. Therefore, an approximately 2.8 Wt% yield improvement was observed for the supervisory testing over-and-above the level achieved in the regulatory tests (73.6 Wt% vs. 70.8 Wt%). The average combustibles recovery for the supervisory test was also approximately 3.0% higher (87.5% vs. 84.5%).

Due to difficulty in obtaining comparable tests from day-to-day, particularly consistent feed ash content ranges and concentrate ash content ranges, this improvement in yield could not be verified for some of the later control testing (such as WT#9 and WT#10). However, the results in Table 53 do illustrate the advantage of the supervisory control for obtaining an increased yield and better stabilized circuit operation. It seems feasible that a supervisory control involving PTI's On-Line Monitoring System could lead to increased yields in the range of 2-5 Wt%, provided the on-line monitor readings for concentrate and tailings, solids and ash content are within the acceptable RMS error ranges shown below:

- 0.5 Wt% for concentrate samples solids and ash content,
- 0.5 Wt% for feed sample solids and ash content, and
- 0.5 Wt% and 2.0 Wt% for tailings samples solids and ash contents, respectively.

The on-line monitoring system must provide these accuracies, not only over a short term basis, but also have the consistency to maintain these relationships over a longer term basis, so that the nuisance of constant recalibration can be avoided.

SECTION 4.11.4 - SECONDARY PROJECT GOAL RESULTS

The previous discussion contained detailed results with respect to PTI's primary project goals. However, only limited discussion was focused toward PTI's secondary project research goals, which involved evaluating the feasibility of the following process options:

- Use of PTI's dual-cylinder flotation column design, which had previously resulted in higher flotation yields than conventional single cylinder columns when low ash content products (less than 10.0 Wt%) were required.
- Use of polyacrylic acid as a pyrite depressant to improve pyritic and total sulfur removal within the flotation column circuit.
- Implementation of an X-Ray Fluorescence (XRF) based system onto PTI's On-Line Quality Monitor to obtain on-line pyritic sulfur readings, as well as on-line solids and ash contents for the various test samples.

Although all of these process options showed promise during Phase I Small Business Innovative Research (SBIR) Projects conducted by PTI or other researchers, these options could not be successfully utilized or implemented for the continuous bench-scale testing performed within this project.

Based on the bench-scale testing results, PTI feels that the first two process options (the dual-cylinder column and polyacrylic acid depressant) are unfeasible and should not be further researched in future projects or commercialization. Use of pyritic sulfur depressants is probably still a feasible approach, but future work should focus on less expensive additives such as pH adjustment (i.e., CaO additions) to provide the proper surface chemistry.

Although the XRF system prototype design included in PTI's On-Line Monitor, used in the bench-scale project, was not able to accurately measure pyritic sulfur in the flotation concentrates stream, PTI still feels that the technology shows considerable promise. Apparently, the detectors and source combination utilized for the prototype design were not sensitive enough to provide the resolution required to obtain measurements for the low solids content (less than 5.0 Wt%) and low pyritic sulfur content (less than 2.0 Wt%, dry basis) present in the concentrate samples obtained during the bench-scale testing. PTI plans to continue work on the XRF System upgrade to PTI's On-Line Quality Monitor for both pyritic sulfur content and total sulfur content through future DOE SBIR projects, as well as through private sponsorship. Future development will need to focus on more sensitive detectors and more intricate designs, but the initial laboratory results to indicate that the approach is sound, from a nuclear physics standpoint. The design must be merely optimized to provide the necessary sensitivity. The market for on-line sulfur and pyritic sulfur measurement is also a strong driving force toward commercialization, particularly with the increased focus on coal sulfur specifications necessitated by the 1990 Clean Air Act.

SECTION 4.11.5 - DEWATERING TEST RESULTS

The University of Kentucky's (UK's) Center for Applied Energy Research (CAER) is the inventor of the KEN-FLOTE™ Column technology utilized during the bench-scale testing project. In 1992, PTI obtained an exclusive, worldwide license to manufacture and sell the KEN-FLOTE™ Column technology to the coal and mineral processing industries.

During the project, PTI subcontracted UK's CAER to provide technical assistance on the design and operation of the 12" diameter x 14' high, bench-scale KEN-FLOTE™ Column, including assisting in development of the testing plan and commissioning of the column circuit. The UK CAER staff spent considerable time at site, during the initial multivariable testing with both coals (Upper Freeport and Pittsburgh No. 8 Seam Coals), assisting PTI in debugging the column and honing in on optimum operating levels for the various process variables.

In addition, the CAER staff also conducted a series of dewatering tests at their Lexington, Kentucky laboratories, using representative samples of the flotation concentrate for both coals. A report detailing the results from this work is included in Appendix I of the Appendices.

The goal of the dewatering studies was to determine the anticipated filter cake moisture content which could be obtained from both vacuum and pressure filtration units for the concentrate slurry samples, as well as the anticipated operating costs of the filtering step. Surfactant and flocculant additions were also tested during the laboratory studies to determine the reductions in cake moisture which could be obtained through relatively inexpensive, low dosage additions of those additives. PTI and UK CAER staff felt this testing was important because of problems obtained with high moisture content products resulting from fine coal cleaning circuits. The flotation control technology being developed by PTI can only be implemented if the available dewatering technologies can make a salable product from the additional fines which are recovered in the fine coal cleaning circuits.

Table 54 contains a summary of the dewatering results (with and without reagents) for both the vacuum filter and pressure filter tests that were performed at UK's CAER. Table 54 contains the moisture contents and project operating costs for systems treating both the Upper Freeport and Pittsburgh No. 8 concentrate samples. In general, moisture contents less than 20 Wt% will probably be required to insure that the fine-coal cleaning circuits being added into the flotation product does not adversely affect the handling characteristics and overall moisture content of the final clean coal product. Table 54 illustrates that acceptable moisture contents can be likely obtained at fairly low operating costs for the Pittsburgh No. 8 Seam Coal using vacuum filtration. However, more expensive pressure filtration will likely be required for the Upper Freeport Seam Coal, due to the much finer size consist. Despite the higher operating costs of the pressure filtration units, the overall economics is still very favorable considering that the final clean coal product can be sold for approximately \$30/ton. This leaves a considerable difference (\$25-28/ton) that can be used to payback capital costs for the flotation and filtration equipment installation.

Table 54
**LABORATORY DEWATERING RESULTS
 AND PROJECTED OPERATING COSTS**
 (Based on 40 TPH Capacity)

Filter Type	Reagents	Upper Freeport Seam Concentrate Sample		Pittsburgh No. 8 Seam Concentrate Sample	
		Moisture (Wt%)	Operating Costs (\$/Ton)	Moisture (Wt%)	Operating Costs (\$/Ton)
Vacuum	None	33.2	1.72	25.2	1.72
Vacuum	Surfactant	27.6	2.34	17.9	2.34
Vacuum	Flocculant	26.8	1.74	16.9	1.75
Pressure	None	11.7	5.00	---	---
Pressure	Surfactant	11.9	5.77	---	---
Pressure	Flocculant	9.4	5.03	---	---

Work being done by UK's CAER and other researchers on novel dewatering equipment, (i.e., such as the pressure filtration technology), shows great promise for producing very low moisture content cakes (often less than 10 Wt% moisture) without the need for expensive thermal drying techniques. These novel mechanical dewatering methods can greatly increase the applicability of fine-coal cleaning to additional coal preparation plants, where moisture increases and handling problems had previously led to feasibility concerns. This will only serve to expand the market for supervisory flotation control systems, based on PTI's On-Line Monitor.

SECTION 5 - COMMERCIAL, ECONOMIC EVALUATION

The economic evaluation for installing the technology demonstrated within this project into an operational coal preparation plant can be looked upon as involving three different steps. Each step involves its own economic evaluation, which can be summarized as follows:

- **Step 1 - Justification For Installation of a Column Flotation Circuit:** During the last 10 years coal preparation plant operators have begun installing column, flotation circuits in existing plants. In some cases the column circuits have been substituted for traditional trough cells, where the increased yield or improved product quality must justify the capital costs to install the columns. In other cases, the column flotation circuit is being added as part of a new fine-coal cleaning installation. In that scenario, the capital and operating cost of the entire fine-coal circuit must be justified by the additional revenues obtained from the fine-coal product, which is usually blended back into the overall cleaning plant product.
- **Step 2 - Justification of Regulatory Control of Flotation Column Operations:** Many plants have begun to use instrumentation tied in to a control room computer (i.e., PLC) to monitor the critical operating variables for the columns (air rate, froth

thickness, feed rate and reagent dosage) and maintain those variables at some desired optimum setpoint. The cost of those instruments must be justified by increased column yield and more consistent concentrate quality. This represents the existing state-of-the-art control for column flotation operations.

- **Step 3 - Justification of PTI's On-Line Monitoring System:** This system consists of PTI's Multiplexer Sampling System, On-Line Quality Monitor and Computer Control Panel to allow for on-line manipulation of the circuit operating conditions to maximize circuit yield while maintaining the desired product quality. The cost of this system must also be justified by the additional revenues (i.e., yield increase) and better product quality consistency promoted by the on-line control.

The focus of this development project is to expand the existing state-of-the-art control methods (Step 1 and 2) by adding PTI's On-Line Control System (Step 3) to the total column flotation system technology. Therefore, the main goal of the control testing portion of the project was to attempt to quantify the benefits obtained by adding the On-Line Monitoring System to an existing regulatory controlled column flotation installation.

Based on the results from the Pittsburgh No. 8 Seam control testing, Table 55 contains an example of the economics for installing a column flotation supervisory control (i.e., PTI's On-Line Monitoring System). The economics assume a plant with four 8' diameter by 22' high flotation columns that are treating 50 TPH of 100M x 0 feed coal slurry. The economics also assume that a yield improvements of 3.0 Wt% (over and above regulatory control alone) can be achieved by adopting the supervisory control. This was approximately the level of yield increase observed in the comparison shown in Table 53.

Table 55
ON-LINE MONITORING SYSTEM ECONOMICS
Comparing Regulatory to Supervisory Control

ASSUMPTIONS

- Plant With Four 8' Diameter x 22' High Columns
- Columns Treat 50 TPH of 100M x 0 Feed Coal Slurry
- Operate 14 Hrs./Day, 5 Days/Wk., 50 Wks./Yr. (3,500 Hrs./Yr.)
- Yield Increase of 3.0 Wt% Due to Supervisory Control (1.5 TPH)
- Clean Coal Price of \$30 Per Ton (Dry Basis)

SUPERVISORY SYSTEM PAYBACK PERIOD

- On-Line Monitoring System Cost \$150K (Including Installation)
- Additional Revenues of \$157K Per Year (1.5 TPH * 3500 Hr/Yr * \$30/Ton)
- Payback Period of One Year

Based on the above estimates, and assuming the operating schedule and clean coal price shown in Table 55, the additional revenues for the supervisory control would be approximately \$157K per year. When these revenues are compared to PTI's On-Line Monitoring System cost of \$150K, which includes purchase and installation of the On-Line Monitor, Computer Control Panel and Multiplexer Sampling System, it follows that the system has a payback period of approximately one

year. Although operating costs are not included in the payback period estimate in Table 55, the approach is still fairly valid since the system has very low operating costs (i.e., minimal operator labor or power requirements). Service contracts also only begin after the first 90 days of operation, and are fairly inexpensive (\$500 to \$750 per month), so they will also have little, if any, effect on the economics.

In past commercial applications where PTI has installed the On-Line Monitoring System in conventional circuits the payback period has usually been shorter (six to nine months) than the estimated one year payback shown in Table 55. The more rapid payback for conventional column circuits is due to the higher capacity and greater inefficiency of the conventional flotation circuits. In summation, the one year payback period in Table 55 seems reasonable. However, keep in mind that the key to achieving the payback on investment is to have high availability of the system and good reliability of the On-Line Monitor measurements (i.e., sound calibrations) so that the yield improvements assumed in Table 55 (3.0 Wt%) can be maintained.

SECTION 6 - CONCLUSIONS AND RECOMMENDATIONS

This bench-scale testing project was broken down into multivariable and control testing stages for each of the two coals tested (Upper Freeport and Pittsburgh No. 8 Seam Coal). The primary goals of the various testing stages were:

- Multivariable Testing Goal #1 - Determine the impact of key process variables on column performance.
- Multivariable Testing Goal #2 - Determine the accuracy of PTI's On-Line Monitor measuring for solids and ash in the concentrate and tailings streams.
- Control Testing Goal #1 - Develop algorithms that alter key column process variables to achieve desired column performance (concentrate ash content and yield).
- Control Testing Goal #2 - Quantify PTI's control system's ability to smooth concentrate quality and increase yield for changing feed conditions.

Operational problems that persisted through the entire bench-scale testing duration for the first coal (Upper Freeport Seam Coal) compromised the ability to accomplish the project goals for the first coal. However, the results presented in the Data Evaluation Section (Section 4) and the Economic Evaluation Section (Section 5) illustrate that the majority of the project goals were accomplished for the second coal (Pittsburgh No. 8 Seam Coal) once some of the major operating problems were overcome (i.e., through coarsening the feed grind and adding defoamer to the concentrate sample). The main shortcoming, with respect to the project goals, for the Pittsburgh No. 8 Seam Coal testing, was the constant recalibration of the On-Line Monitor, which was necessitated due to drift within the On-Line Monitor's nuclear electronics.

The main advantage of the project is that it allowed PTI to gain knowledge and experience about the proper approach, methods and hardware required to properly optimize and control column flotation performance. Many operational problems were incurred during the project, some of that PTI was able to solve during the project, and other that must be overcome as the technology is further developed and commercialized. The key operating problems experienced with the KEN-FLOTE™ Column that must be further researched and overcome include:

- The low concentrate solids content which limited the throughput capacity of the column, due to high froth washing requirements. The low concentrate solids content also lead to difficulty obtaining accurate On-Line Monitor measurements, due to the poor measurement sensitivity obtained with low solids content samples (particularly less than 5.0 Wt%).
- The higher-than-anticipated reagent dosages that undoubtedly contributed to the low solids content listed above, and also caused foaming problems within PTI's On-Line Monitor. A defoaming reagent addition (Nalco 7810) was required to provide consistent sample size and reproducible On-Line Monitor counts for the concentrate samples collected within the circuit.

PTI and UK's CAER staff will continue to research alternative column design, particularly alternative air bubble generation and air distribution systems, to try to maximize column concentrate solids content while reducing reagent dosage requirements. Obtaining those goals should improve not only column performance, but also the accuracy and reliability of PTI's On-Line Monitoring System when it is incorporated with the column technology.

In addition to the KEN-FLOTE™ Column operation there were also a number of hardware problems with PTI's On-Line Quality Monitor that must be remedied for future commercial installations. The required hardware changes include:

- The On-Line Monitor nuclear source presently contains only one radioactive isotope (1 mCi ^{241}Am). PTI proposes to add a second isotope (1 mCi ^{137}Cs). This should allow for an independent solids content measurement using the ^{137}Cs peak, as is done in existing density gauges. The ^{241}Am peaks can then be used to principally determine coal ash content, thereby allowing for separate solids and ash measurements. This should significantly enhance the accuracy of PTI's On-Line Quality Monitor, in cases where changes in slurry solids and ash content are not proportional, and when trying to measure low solids content samples (particularly flotation tailings).
- On all future ash monitors, PTI plans to install new solid state sodium iodide (NaI) crystal detectors instead of the xenon-gas filled, proportional counters presently used. The solid state detectors are not subject to the failure and drift that have persisted with the gas filled detectors, which should lead to more consistent calibration and better reliability of the On-Line Monitor measurements.

The CPPRF bench-scale testing circuit provided the tightly controlled testing environment necessary to quantify the limitations of PTI's existing systems and determine that these changes were indeed warranted and required.

PTI also plans to continue with development of the X-Ray Fluorescence (XRF) System for pyritic sulfur and total sulfur measurement, to be added to PTI's analyzers in the future. Although unsuccessful in the bench-scale testing, this upgrade shows considerable promise and would greatly improve the marketability of PTI's On-Line Monitor.

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