BITUMINOUS COAL RESEARCH, INC.

CCR-SPONSORED
GAS GENERATOR RESEARCH AND DEVELOPMENT

Progress Report No. 13-A
(BCR Report L-487)

I. INTRODUCTION

This report summarizes progress during September, 1972, on a part of the general program, "Gas Generator Research and Development," being conducted by Bituminous Coal Research, Inc., for the Office of Coal Research. This represents that portion of progress under Contract No. 14-32-0001-1207 being solely sponsored by the Office of Coal Research.

The overall objective of the program continues to be to develop processes for gasifying coal with emphasis on the production of a fuel gas. Laboratory-scale coal gasification experimentation is to be continued, together with process and equipment development.

A. Monthly Progress Charts

Monthly progress charts reflecting proposed rate of effort and expenditures on projects sponsored solely by the Office of Coal Research are shown in Appendixes A-1 and A-2.

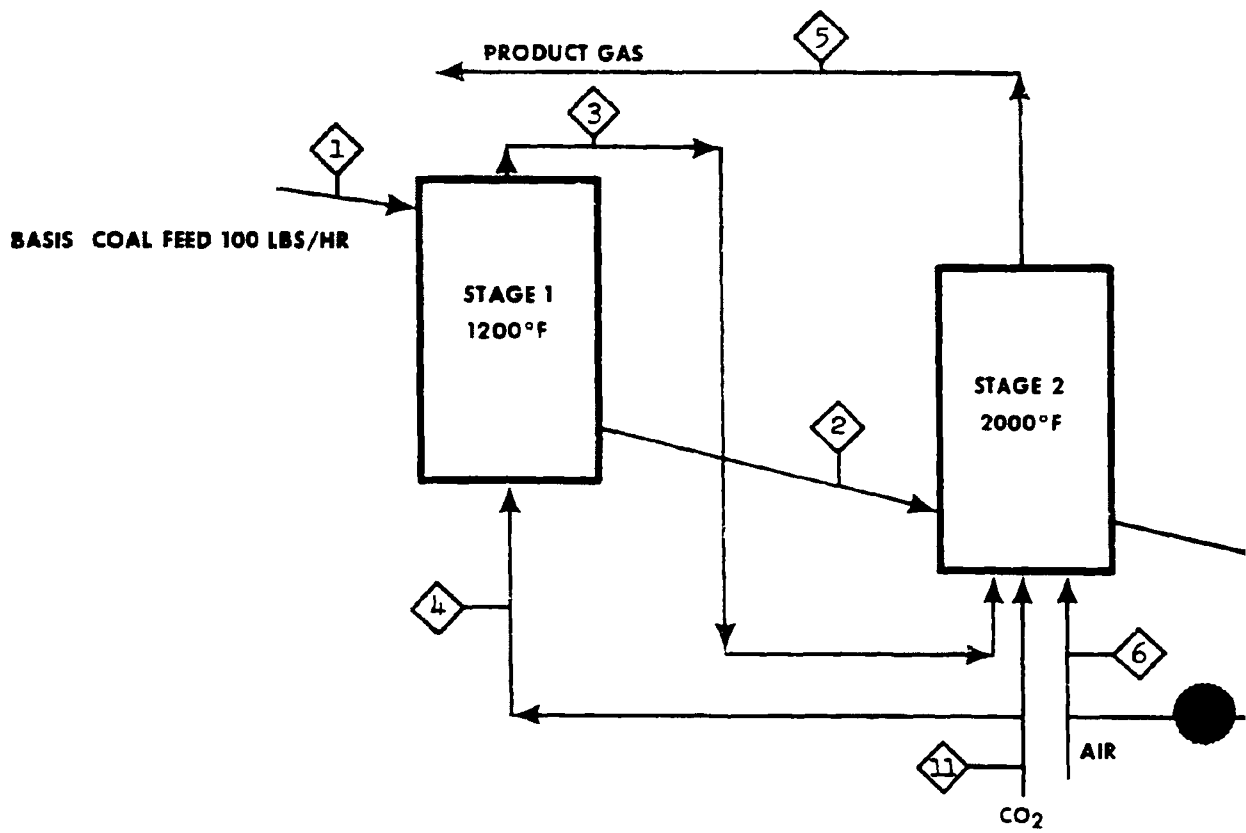
II. PROGRESS ACHIEVED DURING THE MONTH ENDING SEPTEMBER 25, 1972

A. Fluidized-bed Gasification Studies (J. T. Stewart)

Design work on the fluidized-bed gasification PEDU progressed in accordance with the time schedule given in Figure 19, Progress Report No. 12-A. Fluidized-bed batch reactor tests simulating the PEDU Stage 2 reactor were completed and compared with TGA results.

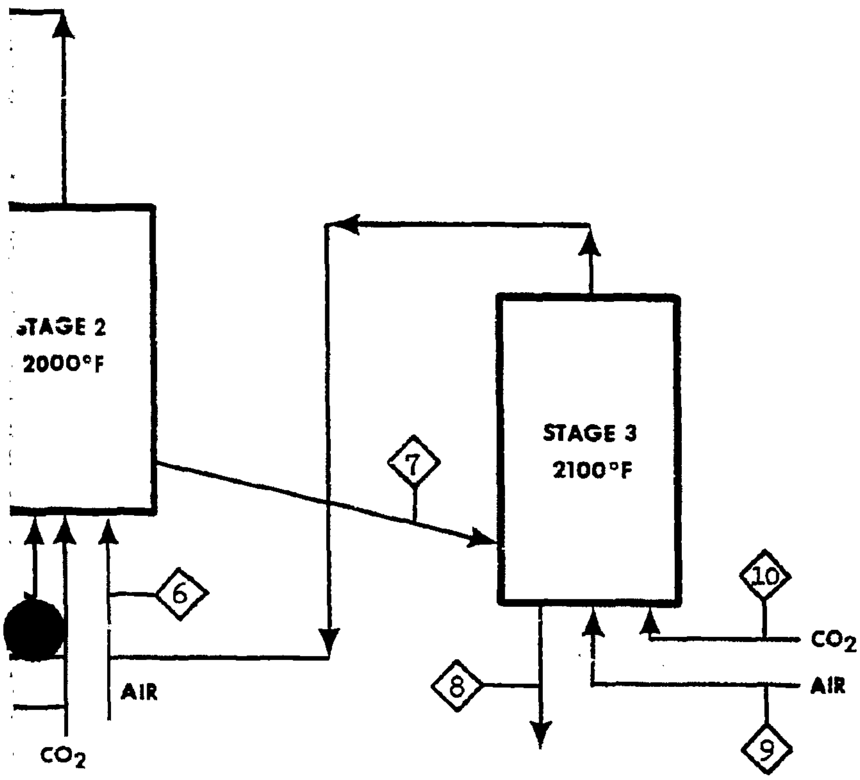
1. Fluidized-bed PEDU: The material balance for the air-steam gasification of Pittsburgh seam coal in the fluidized-bed PEDU was given in last month's report. Figure 22 of this report is the material balance received from Foster Wheeler for the air-carbon dioxide gasification of the same coal to produce a carbon monoxide-rich fuel gas. Drawings and vessel specifications received during the month were as follows:

Drawing Number	Title
OP-721-427	Materials of Construction
OP-724-839	Coal Feed Hopper D-101
OP-724-840	Coal Lock Hopper D-102
OP-724-841	Ash Lock Hopper D-103
OP-724-842	Char Fines Hold Bin D-104
OP-724-843	Stage One Reactor R-101
OP-724-844	Stage Two Reactor R-102
OP-724-845	Stage Three Reactor R-103



STREAM NO.	1		2		3		4		5		6
STREAM	COAL FEED		CHAR FROM STAGE 1		STAGE 1 FLUE GAS		STAGE 3 FLUE GAS		PRODUCT GAS		AIR TO STAGE 2
	LBS	WT, %	LBS	WT, %	MOLS	VOL, %	MOLS	VOL, %	MOLS	VOL, %	MOLS
COAL (ASH FREE)	93.8	93.8	72.6	92.1							
ASH	6.2	6.2	6.2	7.9							
H_2									1.74	7.8	
CO					2.30	37.0	2.30	44.7	7.65	34.2	
CO_2					0.41	6.6	0.41	8.0	2.00	8.9	
H_2O									0.96	4.3	
N_2					2.44	39.3	2.44	47.3	10.0	44.6	
H_2S									0.05	0.2	
STAGE 1 OFF GAS					1.06	17.1					
TOTAL	100.0	100.0	78.8	100.0	6.21	100.0	5.15	100.0	22.4	100.0	9.52
AVG MOL WT					27.7		29.3		27.0		29
TEMP, °F	77		1200		1200		2100		2000		1000
PRESS, PSIA					250		250		250		300
SCFM					39.2		32.5		141.5		60.1
ACFM					7.4		9.4		39.4		8.3

Figure 22. Material Balance for Gasification of Pittsburgh Seam



	6	7		8		9	10	11
…T GAS	AIR TO STAGE 2	CHAR FROM STAGE 2		CHAR FROM STAGE 3		AIR TO STAGE 3	STEAM TO STAGE 3	STEAM TO STAGE 2
…OL, %	MOLS	LBS	WT, %	LBS	WT, %	MOLS	MOLS	MOLS
		26.4	81	3.6	37			
		6.2	19	6.2	63			
7.8								
34.2								
8.9								
4.3								
44.6								
0.2								
100.0	9.52	32.6	100	9.8	100	3.14	0.91	2.55
.0	29					29	44	44
	1000	2000		2100		1000	1000	1000
	300	250				300	300	300
.5	60.1					19.8	5.7	16.1
.4	8.3					2.7	0.78	2.2

2

Bituminous Coal Research, Inc. 8014G38

Pittsburgh Seam Coal with Air and Carbon Dioxide

The PEDU design engineering package will be completed by the end of October. Contingent upon OCR acceptance of the PEDU design and authorization to proceed, detail engineering and solicitation of bids for long delivery items could begin in November. Following this schedule, the PEDU construction would be completed before the end of 1973.

2. Laboratory Investigations: Kinetic studies of the devolatilized coal, air, and carbon dioxide gasification reactions continued, using both the TGA and the fluidized-bed batch reactor (FBBR). The results of both sets of data, taken together, help define the experimental conditions where the reaction rate-controlling step changes.

a. Char Reactivity Studies: Twenty-four tests were made in the TGA during the month with various mixtures of air and carbon dioxide as the reacting gas. An FMC char, BCR Lot No. 2455, and a Consol char, BCR Lot No. 2469, were chosen to simulate the devolatilized coal that will leave the PEDU Stage 1 reactor to be gasified in Stage 2.

TGA studies conducted over the past several months have produced rate equations which accurately describe the char-carbon dioxide and the char-steam reactions. (Progress Report 9-A, Appendix A). These equations specifically apply only at reaction temperatures between 1600 F and 2100 F, and at a particle Reynolds number greater than 0.01. A Reynolds number of 0.01 corresponds, in the FBBR, to an average velocity of 0.025 feet per second. Below this velocity, mass transfer from the bulk gas phase to the particle surface becomes important.

The minimum fluidizing velocity of the devolatilized coal is approximately 0.08 ft/sec at an average particle diameter of 210 μ. However, as the density of the coal decreases with carbon burn-off, the minimum fluidizing velocity drops to as low as 0.02 ft/sec. Thus, the low carbon content, low density stages in the PEDU can be operated in the fluidized regime with either mass transfer or surface reaction as the rate-controlling step for the carbon-steam or the carbon-carbon dioxide reaction. The carbon-oxygen reaction, however, is mass transfer-controlled under all conditions existing in the PEDU.

Figure 23 is a plot of the reaction rate coefficient, k, versus reciprocal absolute temperature. This reaction rate coefficient is an effective value which describes the sum of the carbon-oxygen and carbon-carbon dioxide reactions. It is obtained by measuring the initial slope of the TGA weight-loss curves, as shown in Figure 24.

The slope of the curves in Figure 23 is the activation energy. Above 1000 C, the activation energy is approximately 25 kcal/mole; below 1000 C it is 12 kcal/mole. Below 1000 C, the carbon-carbon dioxide reaction rate is very slow compared to the carbon-oxygen reaction rate. Most of the weight loss can be attributed to the oxygen reaction, with a correspondingly low activation energy indicative of a mass transfer-controlled rate. Above 1000 C, the weight loss attributed to the carbon-carbon dioxide reaction increases, with a corresponding increase in activation energy associated with a chemical reaction-controlled rate.

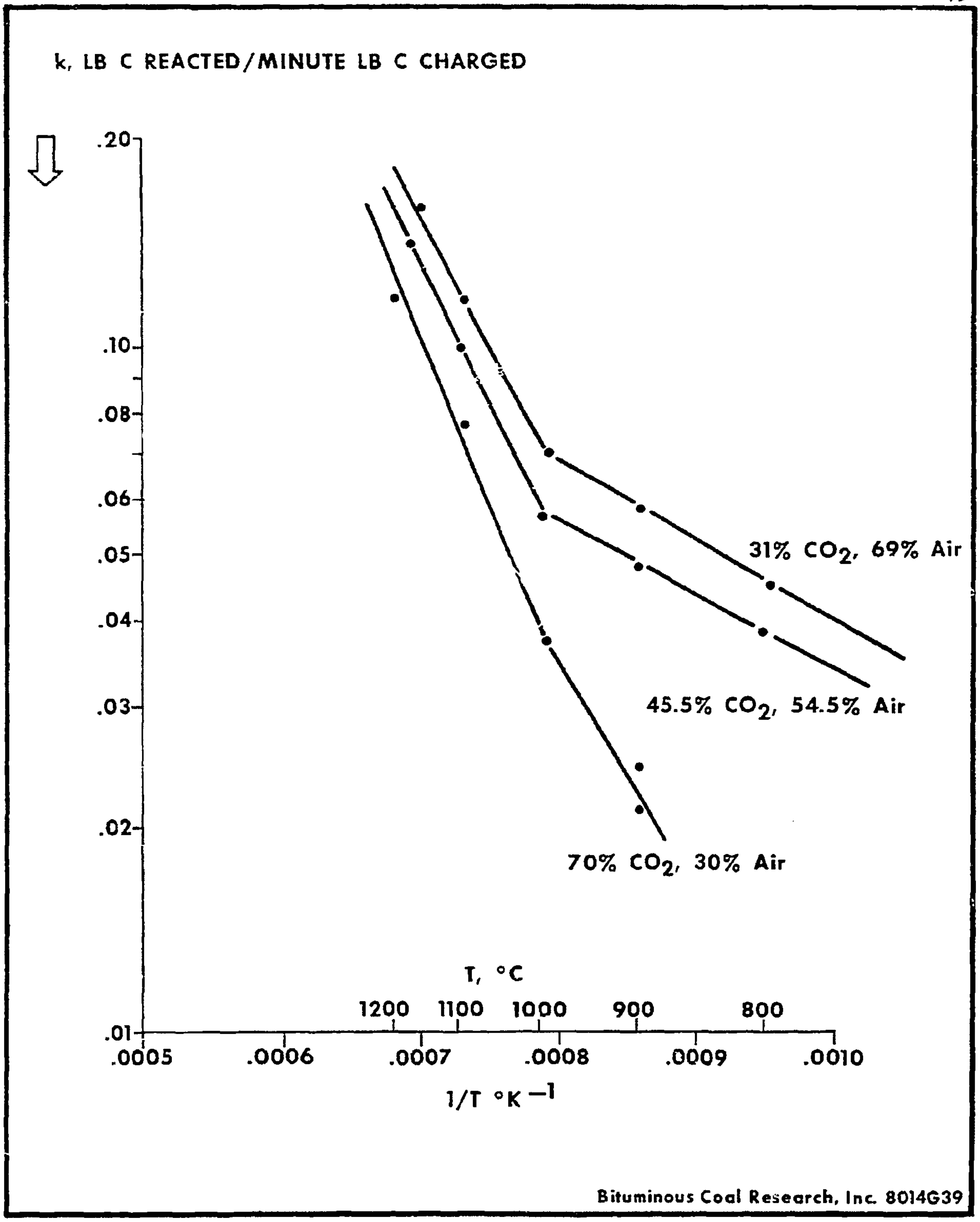


Figure 23. Arrhenius Plot of TGA Derived k Values for FMC Char

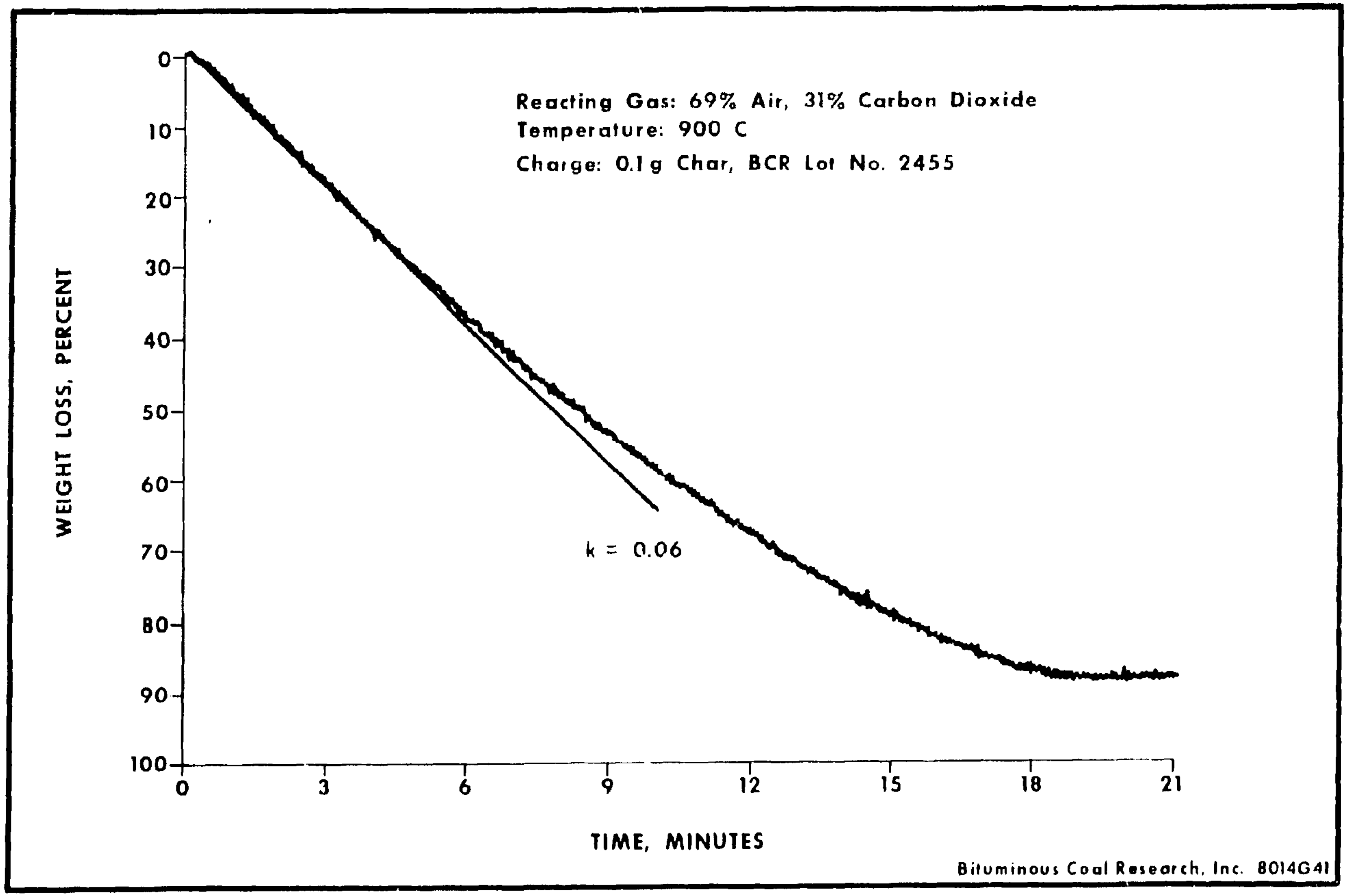


Figure 24. Typical Weight-loss Curve Used in Defining Effective k Values

The actual transition from mass transfer to chemical reaction rate control is not abrupt. In the fluidized-bed PEDU both resistances will be of importance. The chemical reaction rate will be most important under the conditions of high steam or carbon dioxide utilization imposed on Stage 2. The higher temperatures and lower velocities in Stage 3 may lead to mass transfer control. The important point is, however, that data easily obtained from the TGA tests can be extrapolated to predict performance in the fluidized bed. For example, with a reacting gas of 54.5 percent air and 45.5 percent carbon dioxide, the TGA results give a reaction rate of 0.05 lb C reacted/minute/lb C charged. FBBR results (Progress Report 12-A, Tests 3-8) ranged from 0.02 to 0.06 lb C reacted/minute/lb C charged.

b. Fluidized-bed Gasification Batch Reactor: Because of the number of FBBR tests made during the last report period, no tests were made this month pending correlation with the TGA results. Since test results have now confirmed the design basis chosen for Stages 2 and 3 of the fluidized-bed PEDU, the FBBR system is being modified to simulate the coal devolatilization step in the PEDU Stage 1 reactor.

The new reactor, made from type 310 stainless steel, has been completed and pressure tested. Figure 25 is a plot of pressure drop versus velocity obtained in the new reactor with a charge of 20 grams of char. The sharp break at the minimum fluidizing velocity of 0.08 feet/second and the constant pressure drop up to several times the minimum velocity indicate that the bed is well fluidized and that no appreciable slugging or channeling is occurring.

3. Future Work: Design work on the fluidized-bed PEDU should be completed by the end of October. The FBBR will be used to simulate the PEDU Stage 1 reactor.

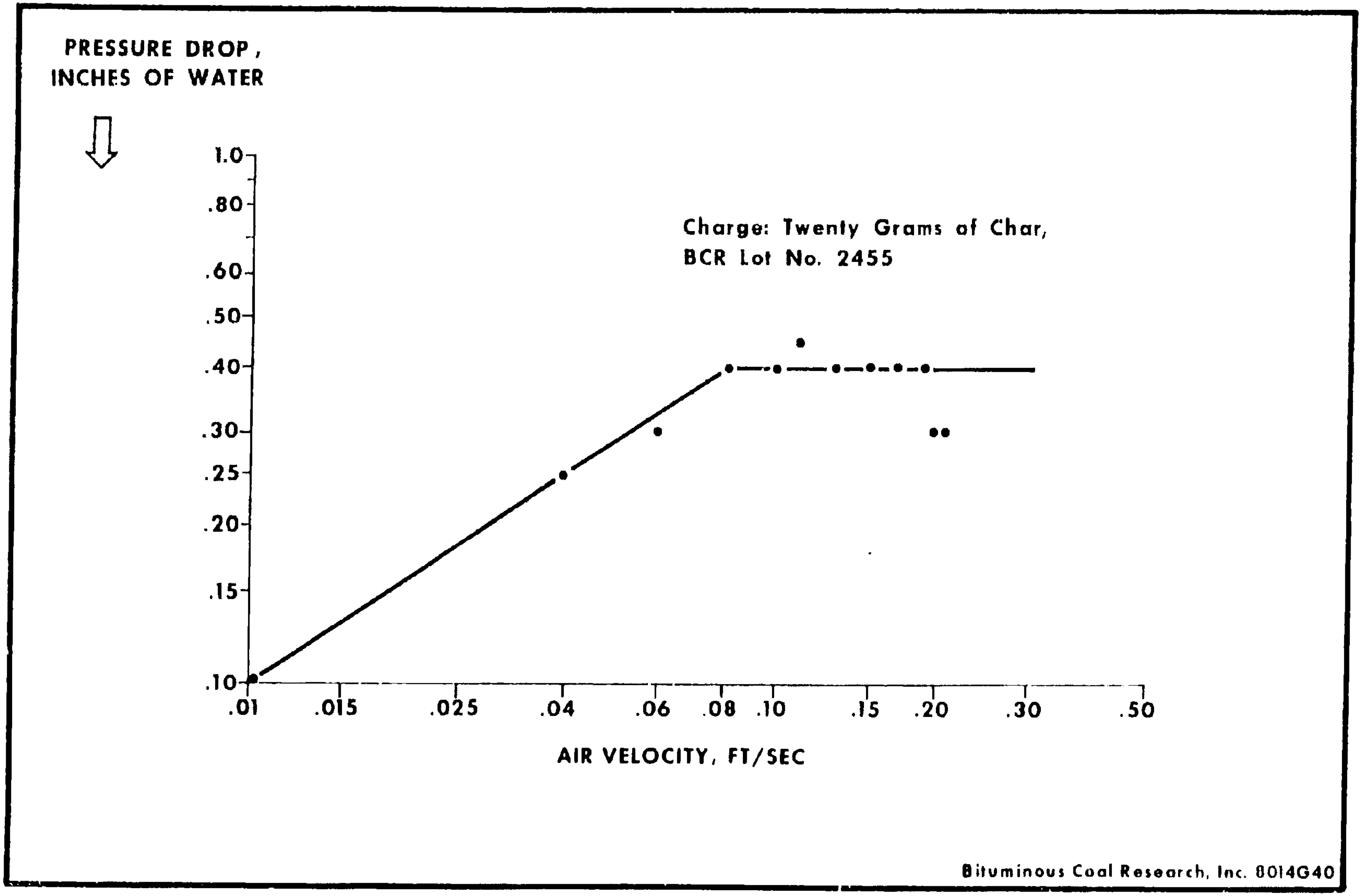


Figure 25. Fluidization Curve Obtained in Fluidized-bed Batch Reactor

B. Brigham Young University

The project entitled "Study of High Rate, High Temperature Pyrolysis of Coal" with joint funding by Brigham Young University and BCR is now in its eighteenth month. Figure 26, Monthly Progress Chart, Expenditures, shows the current budget status. The letter report of progress made during September is as follows:

Three additional test runs were completed using the 2-inch diameter reactor. The objective of these runs was to obtain yield data at lower residence times than previously obtained with this reactor size. Since data obtained during August with smaller diameter reactors indicated that residence time had only a minor effect on yields, it was of interest to determine if these results could be confirmed with the 2-inch diameter reactor. The lower residence times were achieved by increasing the feed rates to the reactor.

Coal feed rates for these runs were 4.1 pounds per hour, approximately twice the maximum feed rate that had been employed with this reactor previously. Data obtained from these tests are presented in Table 24. Comparison of the yields from these tests with prior results at lower feed rates but at the same oxygen/coal ratio showed that the amount of carbon monoxide and carbon dioxide produced per pound of coal was substantially higher and that the yield of hydrocarbon gases was lower. This was attributed to incomplete reaction of the hydrogen and oxygen combustion gases prior to mixing with the coal. It was concluded that a larger volume combustion chamber was required upstream of the mixing zone before satisfactory data could be obtained with feed rates of this magnitude.

The balance of the effort for this period was devoted to analysis and correlation of the data accumulated over the past four months. The objective of this analysis is to obtain correlations of the gasification yields as a function of reactor temperature, reactor residence time, and average concentrations of hydrogen and steam in the reactor. A computer program which will provide optimized correlations of the data in terms of these parameters is being prepared.

C. Engineering Design and Evaluation

1. OCR/BCR Gasification--Power Generation: As instructed in OCR letter dated August 30, 1972, we have cooperated with Foster Wheeler and Pittsburg and Midway in their work on the design of a 50 ton/hr air-blown, two-stage coal gasifier by making our computer program available to them for kinetic calculations and material balances. On September 13, 1972, personnel from Foster Wheeler visited BCR to obtain this information; additional clarifying information was transmitted to them on September 21, 1972.

D. Literature Search (V. E. Gleason)

There were no literature references completed this month.

E. Other

1. Patent Matters: Worthwhile ideas continue to be written as invention disclosures for submission to OCR for consideration. Status of invention disclosures is as follows:

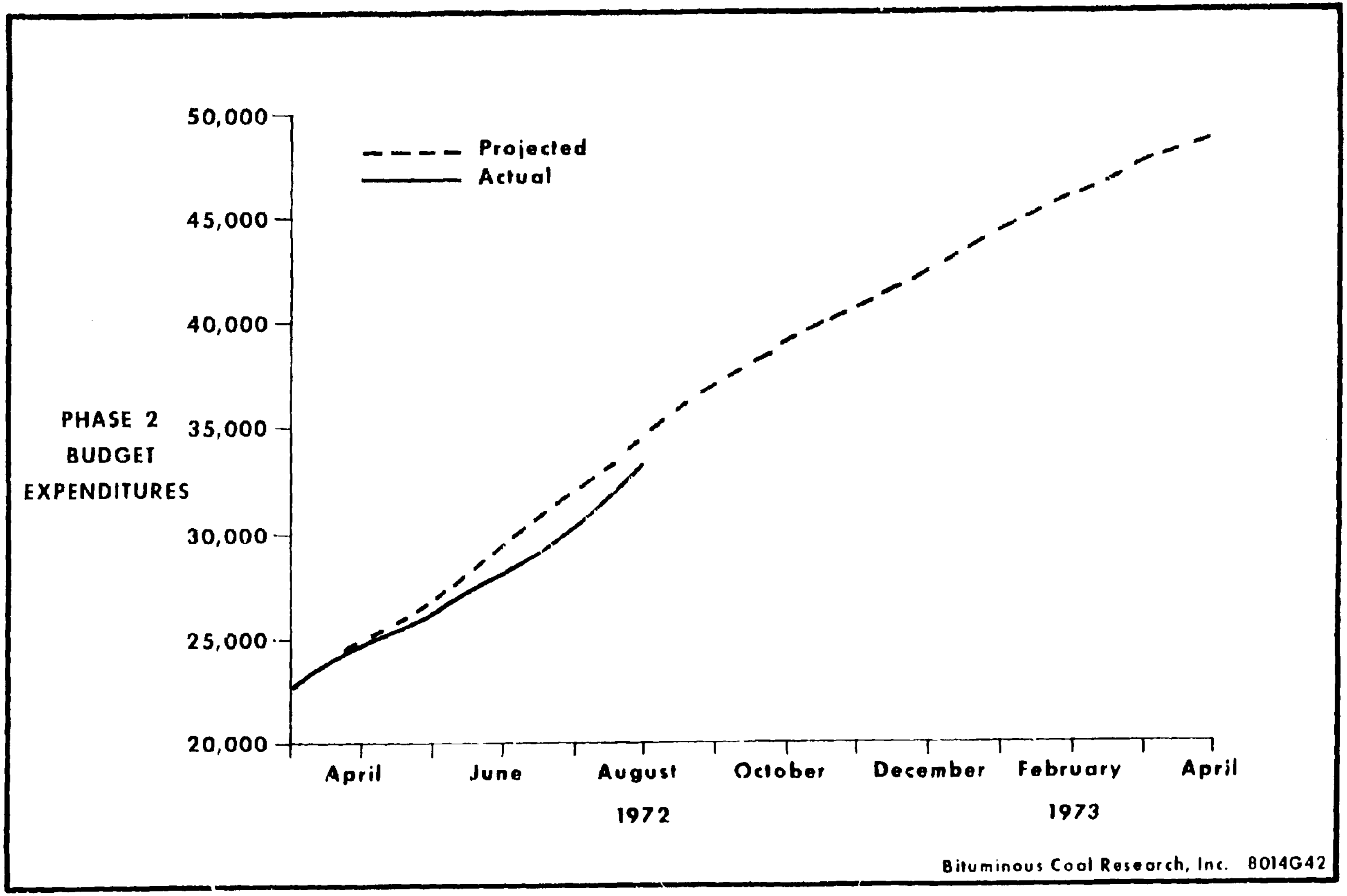


Figure 26. Monthly Progress Chart, Expenditures, Brigham Young University

TABLE 24. DATA OBTAINED WITH 2-INCH DIAMETER REACTOR

Run No.	9-6-1	9-6-2	9-6-3
Feed Rates, lbs/hr			
Coal	4.07	4.07	4.07
Hydrogen Carrier	0.082	0.082	0.082
Hydrogen Combustion	0.373	0.373	0.208
Oxygen	2.435	2.435	1.645
Oxygen/Coal Ratio	0.598	0.598	0.404
Uncorrected Gas Composition Volume Percent			
Hydrogen	56.12	52.28	24.05
Oxygen	0.35	0.29	11.50
Nitrogen	0.92	1.10	47.74
Methane	2.39	1.41	2.73
Carbon Monoxide	34.06	34.65	10.68
Ethane	0.00	0.00	0.03
Ethylene	0.26	0.10	0.58
Carbon Dioxide	3.92	8.88	2.15
Acetylene	1.94	1.25	0.51
Product Gas Volumetric Flow Rate, SCF/hour	108.6	85.2	67.1
Reactor Temperature, °F	2497	2497	1872
Char Collection, lbs. Char/100 lbs. coal	35.38	28.00	39.31
Percent Ash in Char	15.01	16.02	11.24

a. Invention Disclosure--Brigham Young University: During the course of work under Subcontract No. 3, Professor R. L. Coates, Brigham Young University, developed a new concept of pyrolyzing coal which may be patentable.

An Invention Disclosure (Form DI 1217) entitled "Process for High Temperature Pyrolysis of Coal," was submitted to OCR for consideration on January 6, 1972. By letter dated January 26, 1972, OCR acknowledged receipt of this disclosure and forwarded it for processing.

F. Visitors During September, 1972

September 7, 1972

Mr. Paul E. Arbogast
Mr. Calvin N. Walker
Lord Electric Company, Inc.
2 Gateway Center
Pittsburgh, Pennsylvania 15222

September 13, 1972

Mr. Maynard R. Born
Mr. J. T. McMain
Mr. Robert Quade
Mr. E. L. Heller
Gulf General Atomic Company
P. O. Box 608
San Diego, California 92112

Mr. Duane J. Hartline
Mr. R. J. McCallister
Foster Wheeler Corporation
110 S. Orange Avenue
Livingston, New Jersey

III. WORK PLANNED FOR OCTOBER, 1972

The work planned for October will basically be a continuation of the on-going program which has been underway for the past few months.

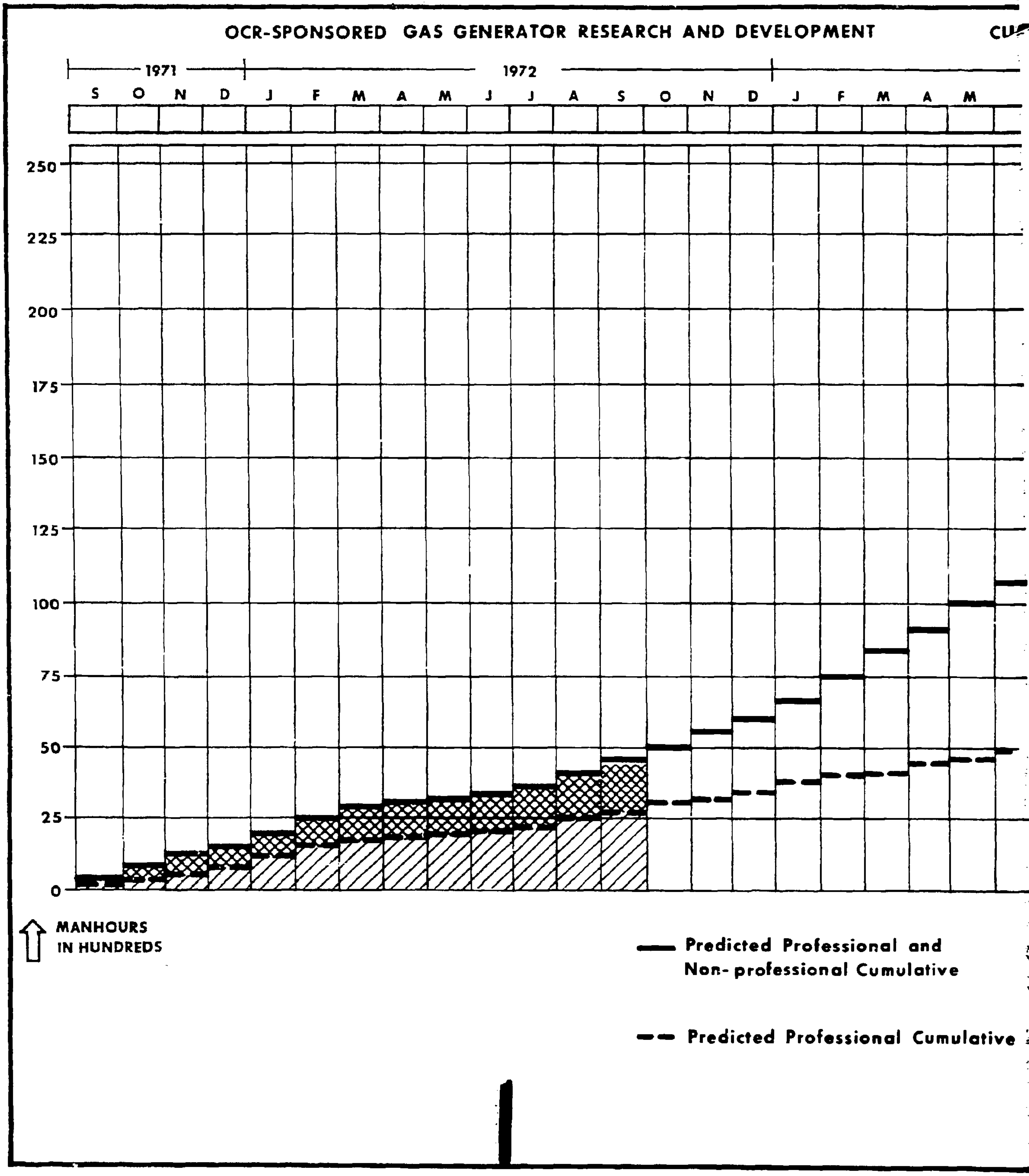
Design work on the fluidized-bed PEDU should be completed by the end of the month. Laboratory work will continue using the fluidized-bed batch reactor to study air-blown gasification with different chars.

Brigham Young will conduct additional tests at higher feed rates in the two-inch diameter reactor to verify the small residence time effects noted previously.

Discussions concerning power generation using the BCR/OCR gasifier will continue as requested.

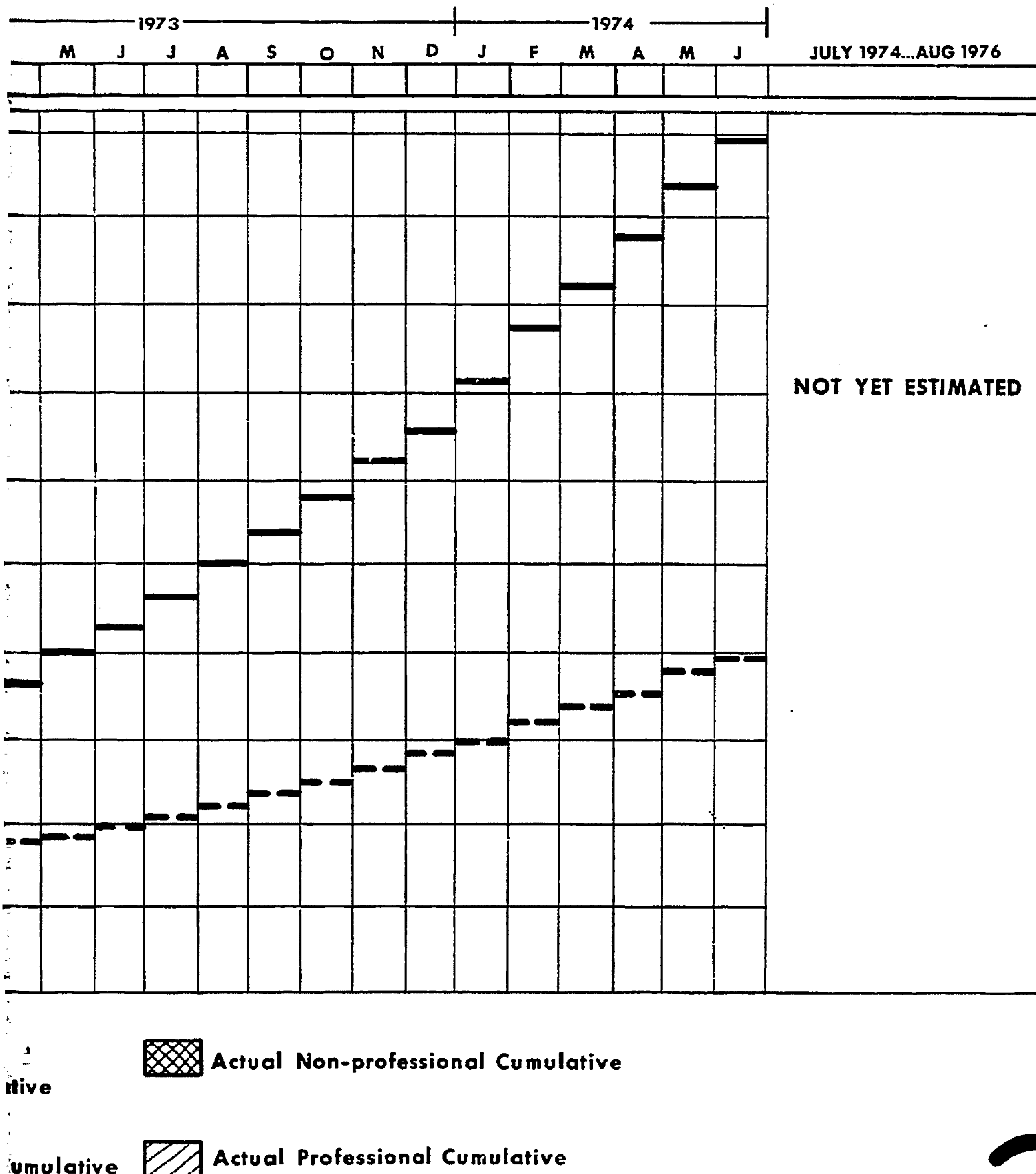
A. Papers to be Presented

October 29-November 1, 1972	Third International Conference on Fluidized Bed Combustion Hueston Woods, Ohio	"Fluidized Bed Gasification--Process and Equipment Development" J. T. Stewart E. K. Diehl



OCR-SPONSORED GAS GENERATOR RESEARCH AND DEVELOPMENT
CU
1971
1972
S O N D J F M A M J J A S O N D J F M A M
250
225
200
175
150
125
100
75
50
25
0
MANHOURS IN HUNDREDS
Predicted Professional and Non-professional Cumulative
Predicted Professional Cumulative

CUMULATIVE MANHOURS



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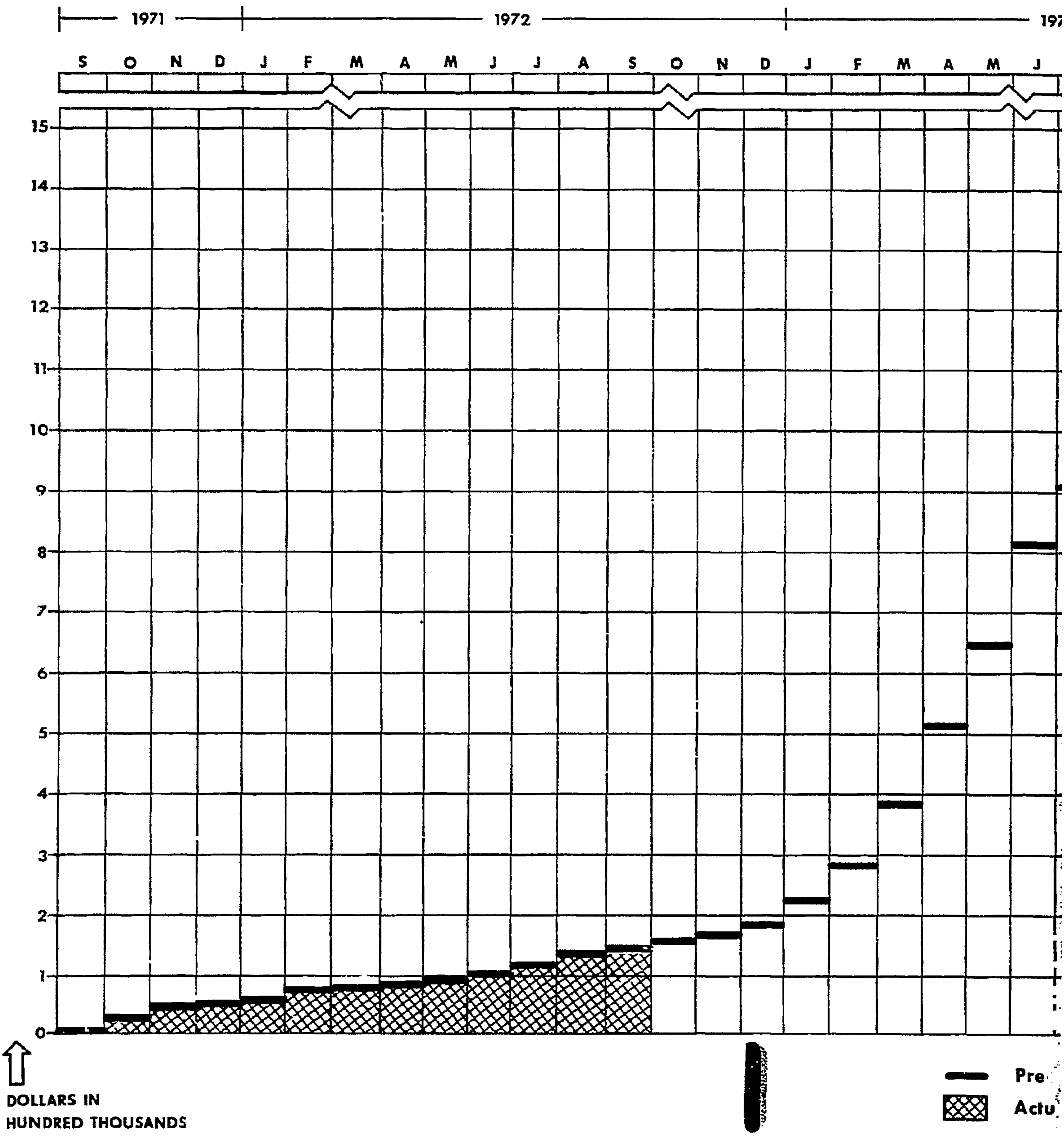
OCR-SPONSORED GAS GENERATOR RESEARCH AND DEVELOPMENT
Schedule of Predicted and Actual Manhours

Month	This Month				Cumulative			
	Professional		Non-Professional		Professional		Non-Professional	
	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual
Sept. '71		284.5		239.5		284.5		239.5
Oct. '71		289.5		152.0		574.0		391.5
Nov. '71		231.5		186.5		805.5		578.0
Dec. '71		201.0		91.0		1,006.5		669.0
Jan. '72		244.0		152.5		1,250.5		821.5
Feb. '72		285.0		218.5		1,535.5		1,040.0
Mar. '72		223.0		109.0		1,758.5		1,149.0
Apr. '72		75.0		21.5		1,833.5		1,170.5
May '72		108.0		162.5		1,941.5		1,333.0
June '72		214.0		209.0		2,155.5		1,542.0
July '72		139.5		167.0		2,295.0		1,709.0
Aug. '72	237.0	247.0	248.0	187.0	2,532.0	2,542.0	1,957.0	1,896.0
Sept. '72	238.0	240.0	249.0	160.5	2,770.0	2,782.0	2,206.0	2,056.5
Oct. '72	240.0		251.0		3,010.0		2,457.0	
Nov. '72	240.0		251.0		3,250.0		2,708.0	
Dec. '72	240.0		250.0		3,490.0		2,958.0	
Jan. '73	238.0		557.0		3,728.0		3,515.0	
Feb. '73	238.0		557.0		3,966.0		4,072.0	
Mar. '73	237.0		558.0		4,203.0		4,630.0	
Apr. '73	240.0		566.0		4,443.0		5,196.0	
May '73	240.0		566.0		4,683.0		5,762.0	
June '73	240.0		564.0		4,923.0		6,326.0	
July '73	304.0		581.0		5,227.0		6,907.0	
Aug. '73	304.0		582.0		5,531.0		7,489.0	
Sept. '73	304.0		581.0		5,835.0		8,070.0	
Oct. '73	397.0		589.0		6,232.0		8,659.0	
Nov. '73	397.0		590.0		6,629.0		9,249.0	
Dec. '73	398.0		589.0		7,027.0		9,838.0	
Jan. '74	474.0		933.0		7,501.0		10,771.0	
Feb. '74	475.0		934.0		7,976.0		11,705.0	
Mar. '74	475.0		933.0		8,451.0		12,638.0	
Apr. '74	480.0		949.0		8,931.0		13,587.0	
May '74	480.0		950.0		9,411.0		14,537.0	
June '74	464.0		939.0		9,875.0		15,476.0	
July '74 to Aug. '76	N O T Y E T E S T I M A T E D							

OCR-SPONSORED GAS GENERATOR RESEARCH AND DEVELOPMENT



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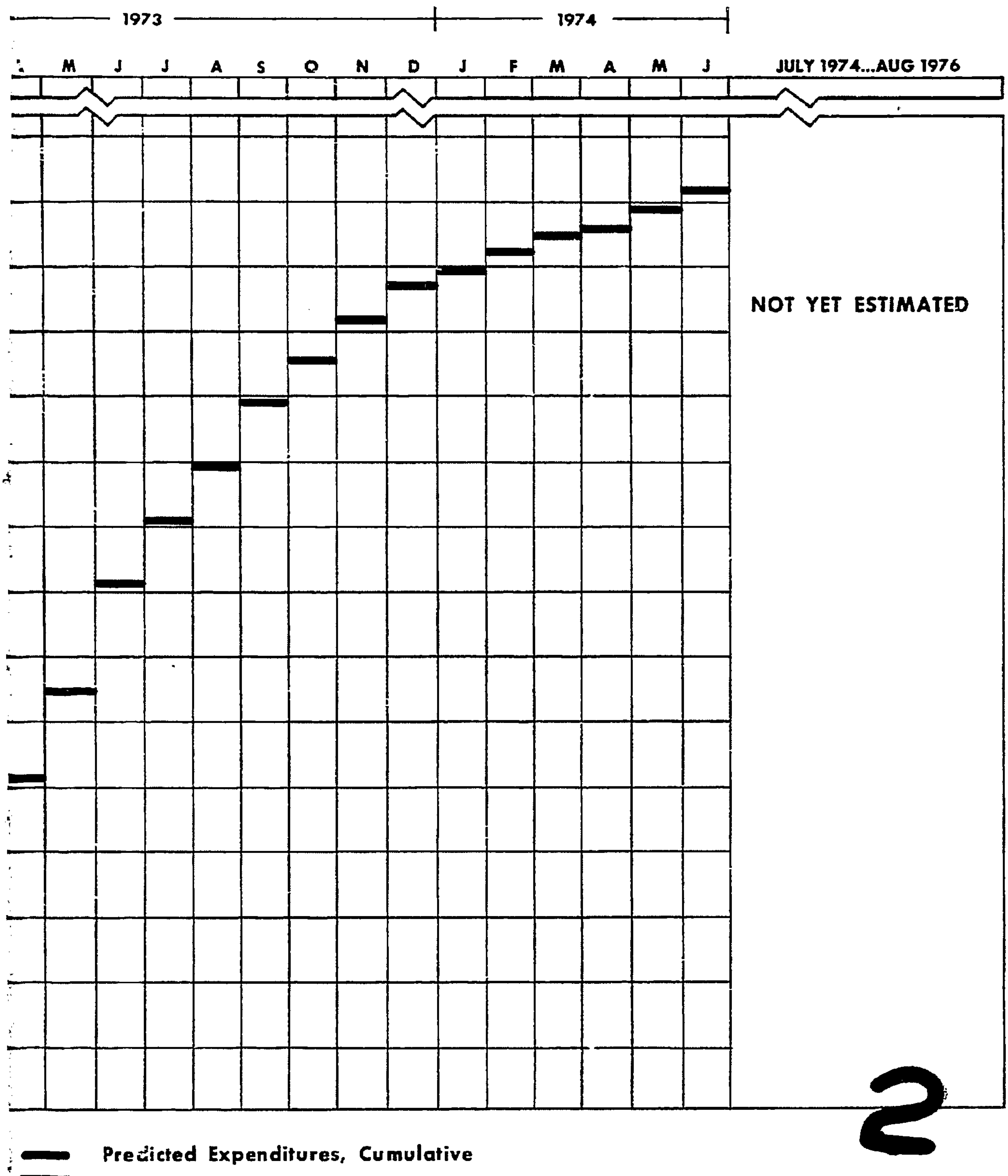
CUMULATIVE EXPENDITURES



Predicted Expenditures, Cumulative

Actual Expenditures, Cumulative

OCR-SPONSORED GAS GENERATOR RESEARCH AND DEVELOPMENT
Schedule of Predicted and Actual Expenditures

	Current Month		Cumulative to Date	
Month	Predicted	Actual	Predicted	Actual
1971				
Sept.		5,710		5,709
Oct.		22,720		28,429
Nov.		17,751		46,180
Dec.		6,161		52,340
1972				
Jan.		7,986		60,327
Feb.		15,328		75,655
March		16,354		92,009
April		3,432		95,441
May		4,352		99,793
June		8,080		107,873
July		6,189		114,062
Aug.	13,840	8,115	135,553	122,177
Sept.	13,840	12,747	149,393	134,924
Oct.	10,980		160,373	
Nov.	10,980		171,353	
Dec.	10,980		182,333	
1973				
Jan.	46,060		228,393	
Feb.	56,060		284,453	
March	102,560		387,013	
April	128,694		515,707	
May	128,693		644,400	
June	167,693		812,093	
July	93,077		905,170	
Aug.	93,077		998,247	
Sept.	93,076		1,091,323	
Oct.	61,410		1,152,733	
Nov.	61,410		1,214,143	
Dec.	61,410		1,275,553	
1974				
Jan.	22,810		1,298,363	
Feb.	22,809		1,321,172	
March	22,810		1,343,982	
April	22,694		1,366,676	
May	22,693		1.389,369	
June	22,693		1,412,062	
July to Aug. '76	N O T	Y E T	E S T I M A T E D	