BITUMINOUS COAL RESEARCH, INC.

OCR-SPONSORED
GAS GENERATOR RESEARCH AND DEVELOPMENT

Progress Report No. 16-A
(BCR Report L-502)

I. INTRODUCTION

This report summarizes progress during December, 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 sponsored solely 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 DECEMBER 25, 1972

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

1. Fluidized-bed PEDU: The design engineering package for the fluidized-bed coal gasification PEDU was delivered to OCR on December 13, 1972. The contents of the package were outlined in Progress Report No. 15-A.

The PEDU process design provides for a flexible system that will permit a broad experimental program on fluidized-bed gasification. The system was kept as simple as possible without sacrificing research capability. A unique feature of the PEDU is that it was designed to optimize both air - steam gasification, and air + carbon dioxide gasification. Thus, the same equipment will provide experimental data for the generation of low-Btu fuel gas, as well as a low hydrogen, carbon monoxide-rich gas that could be used in an MHD generator.

A successful three-stage process will depend upon success in at least two major areas: (1) the ability to decake highly caking coals in the first stage fluidized bed, and (2) complete carbon utilization in the third stage, operating in either an agglomerating or non-agglomerating mode. The PEDU has been designed specifically for research in these areas.

The fluidized-bed gasification program calls for the study of coals of various rank. In addition, the coal will be gasified with different reactants in the following order.

1. Gasification with air and steam to produce low-Btu fuel gas suitable for firing in conventional boilers or in gas turbines.

2. Gasification with air and carbon dioxide to produce a carbon monoxide-rich gas for use in MHD power generation.

3. Gasification with oxygen and steam to produce a synthesis gas to be used as a basis for chemical by-products, or for further processing into pipeline gas.

Gasification with air and steam has the highest priority. The experimental program will begin with the gasification of a non-caking coal to produce fuel gas. Stage 1 will be operated first. Simulated Stage 3 flue gas to Stage 1 will be generated by the incomplete combustion of natural gas. After the operation of Stage 1 has been mastered, Stages 2 and 3 will, in turn, be brought on stream. Approximately six months will be allotted to the air-blown gasification of non-caking coals. The next six to twelve months would be devoted to the air-blown gasification of caking coals. The schedule is very flexible, contingent upon the success of the original design and the need to optimize mechanical features such as the location of feed nozzles, grid plate design, etc.; as well as the optimization of operating parameters.

2. Laboratory Investigations: No laboratory studies were conducted during the month.

3. Future Work: The PEDU process design will be discussed with OCR at their request. Quotes for the PEDU detail engineering and construction can be solicited immediately upon receipt of authorization from OCR to proceed.

Laboratory cold model studies will resume. Work will begin on a computer program modeling the three-stage fluidized-bed gasifier, based on the kinetic models developed in earlier laboratory and bench-scale investigations.

F. Brigham Young University

The project entitled "Study of High Rate, High Temperature Pyrolysis of Coal," with joint funding by Brigham Young University and OCR, is now in its twenty-first month. Figure 33, Monthly Progress Chart, Expenditures, shows the current budget status. The letter report of progress made during December is as follows:

Nine test runs were made with the 2-inch diameter reactor to further check overall material balance calculations and to provide char samples for analysis by BCR. All of these runs were made with feed rates within the ranges previously tested. The run times were extended to increase the recovery of char over that achieved in prior runs. Tables 26 and 27 present the feed rates, gas analysis, and char analysis data for eight of the runs, and Table 28 presents material balance data. The analysis of the ninth run, Run No. 12-27 which was made with a different coal, is not completed. The data for this run will be presented in the January report.

Run No. 12-11 was the longest duration run which has been made to date. The reactor was operated for 34 minutes for this run. The quench water and char were collected in two tanks and the run was continuous except for a brief shutdown to switch the collection tanks at the midway point. Four gas samples were taken during the run, the samples being taken at intervals of approximately 8 minutes. The reactor temperature was observed to increase gradually during the run. The gas analysis shows higher conversion to acetylene with increasing temperature, as previously found.

The material balance data for this run, listed in Table 28, shows that 469 grams of coal were fed and that 192 grams of char were filtered from the quench water. An additional 20 grams were collected from the gas filter and from the quench pipe. Thus, at least 45.2 percent of the coal fed was converted to char. This implies that 54.8 percent was converted to gas, however the calculated conversion to gas based on the ash analysis of the coal and char was 48.72. Part of the difference between these figures may be attributed to material dissolved in the quench water. The water was observed to have a gray color. The fraction of carbon gasified, based on the gas analysis data and the volume of gas produced, was calculated to be 45 percent.

Char samples from Runs 12-11, 12-19-3, 12-19-7, and 12-27, along with a sample of the coal, have been shipped to BCR for analysis.

Material and energy balance calculations have been made for a gasification process which would utilize recycle fuel gas rather than pure hydrogen. The carbon dioxide, hydrogen sulfide, and acetylene were assumed to be removed prior to recycling a portion of the gas. The following assumptions were made concerning the equilibria and conversions in the coal reactor: (1) The conversion of coal to either methane, ethylene, and acetylene is a function only of reactor temperature, the function being represented by a smooth curve drawn through the conversion data shown in the Third Semi-Annual Report; (2) The shift reaction and the steam carbon reaction are in quasi-equilibrium, the quasi-equilibrium K_p's being given as a function of reactor temperature by the data shown in the Third Semi-Annual Report; (3) The recycle gas and oxygen are fed at 530°K and the coal and steam are fed at 420°K; (4) The reactions

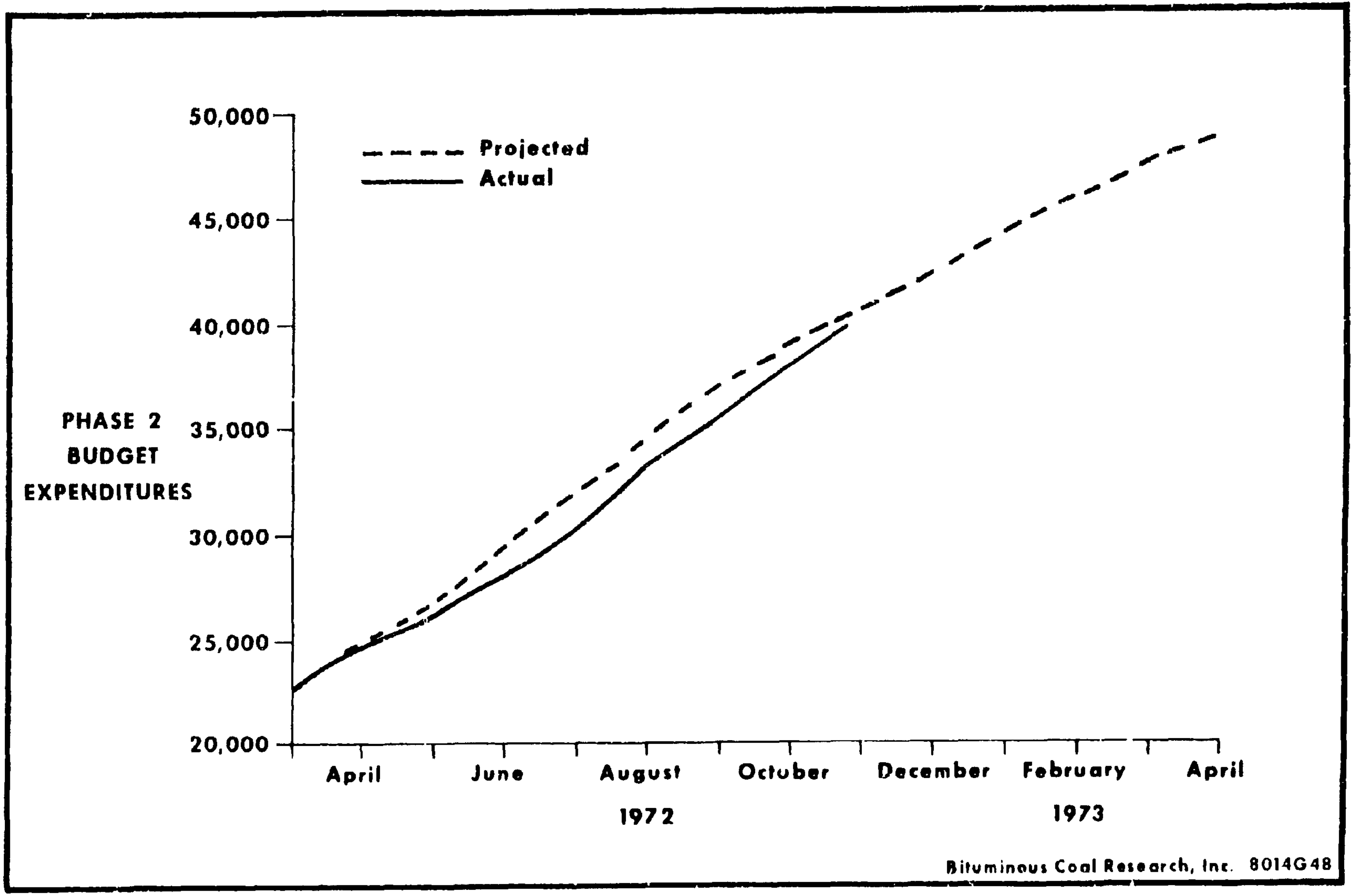


Figure 33. Monthly Progress Chart, Expenditures, Brigham Young University

TABLE 26. DATA FROM 2-INCH DIAMETER REACTOR TEST

Run No.	12-11			
Feed Rates, lbs/hr				
Coal	1.84			
Hydrogen Carrier	0.082			
Hydrogen Combustion	0.162			
Oxygen	1.28			
Oxygen/Coal Ratio	0.70			
Uncorrected Gas Composition, Vol. Percent	Sample 1	Sample 2	Sample 3	Sample 4
Hydrogen	67.26	67.23	66.07	64.22
Oxygen	2.00	1.10	0.89	0.80
Nitrogen	2.99	1.02	0.87	3.33
Methane	5.97	5.35	5.26	4.21
Carbon Monoxide	18.84	20.81	21.94	23.11
Ethane	0.03	0.02	0.02	0.01
Ethylene	0.59	0.50	0.53	0.26
Carbon Dioxide	1.43	2.87	3.27	2.76
Acetylene	0.89	1.10	1.15	1.31
Product Gas Volumetric Flow Rate, scf/hour	51.17		53.44	
Reactor Temp., F	2228	2279	2318	2356
Char Collection, lbs Char/100 lb Coal	40.35		41.44	
Ash in Char, Percent	15.50		15.83	

TABLE 27. DATA FROM 2-INCH REACTOR TESTS

Run No.	12-19-1	12-19-2	12-19-3	12-19-4	12-19-5	12-19-6	12-19-7
Feed Rates, lb/hr							
Coal	1.62	1.62	1.62	1.62	1.62	1.62	1.62
Hydrogen Carrier	0.082	0.082	0.082	0.082	0.082	0.082	0.082
Hydrogen Combustion	0.1673	0.1673	0.1673	0.148	0.148	0.1275	0.1214
Oxygen	1.345	1.345	1.345	1.18	1.18	1.01	0.915
Nitrogen	0.00	0.145	0.00	0.544	0.00	0.00	0.00
Oxygen/Coal Ratio	0.83	0.83	0.83	0.69	0.69	0.62	0.56
Uncorrected Gas Composition, Volume percent							
Hydrogen	63.27	62.84	62.06	57.28	62.33	60.22	57.11
Oxygen	2.51	1.01	0.86	1.48	0.96	2.25	4.97
Nitrogen	8.13	7.39	3.43	18.19	3.95	10.41	16.43
Methane	2.99	2.64	2.19	2.80	2.60	2.72	3.77
Carbon Monoxide	19.60	20.51	27.86	15.57	26.19	19.73	13.11
Ethane	0.02	0.01	0.00	0.02	0.01	0.01	0.05
Ethylene	0.43	0.36	0.20	0.46	0.35	0.50	0.76
Carbon Dioxide	2.07	3.98	2.29	3.38	2.53	2.89	3.22
Acetylene	0.98	1.25	1.10	1.13	1.08	1.27	0.58
Product Gas Volumetric Flow Rate, scf/hour	50.35	55.58	52.30	53.66	47.40	43.42	42.70
Reactor Temperature, F	2355	2355	2420	2330	2355	2241	2118
Char Collection, lbs Char/100 lb Coal	38.12	41.12	36.99	41.12	40.01	38.77	40.64
Ash in Char, percent	16.97	16.90	16.52	15.50	15.07	14.40	14.33

TABLE 28. MATERIAL BALANCE DATA

Run No.	12-11	12-19-1	12-19-2	12-19-3	12-19-4	12-19-5	12-19-6	12-19-7
Run Time, min.	34	11	10	9.25	10	7	7	7
Coal Feed Rate, g/min.	13.88	12.26	12.26	12.26	12.26	12.26	12.26	12.26
Total Fed, g.	469	135	123	113	123	86	86	86
Total Char Collected, g.	192*	51.4	50.4	41.9	50.4	34.3	33.2	34.8
Char Yield, percent	40.9	38.1	41.1	37.0	41.1	40.0	38.8	40.6
Ash in Coal, percent	8.03	8.03	8.03	8.03	8.03	8.03	8.03	8.03
Ash in Char, percent	15.66	16.97	16.90	16.52	15.50	15.07	14.40	14.33
Coal Gasified, percent 100(1-Coal Ash/Char Ash)	48.72	52.68	52.48	51.39	48.19	46.72	44.24	43.96
Char Yield + Coal Gasified, percent	89.61	90.77	93.57	88.36	89.28	86.72	82.99	84.59

* An additional 20 grams of char were recovered from the gas filter and quench piping. Including this char raises the char yield to 45.2 percent.

occur adiabatically. The results of a calculation based on feeds of 0.6 pounds of oxygen and 0.7 pounds of steam per pound of coal, with 60 percent of the product gas being recycled, are presented in Figure 34. The adiabatic reactor temperature corresponding to these feed conditions was computed to be 1503°K or 2246°F.

Calculations such as these are being made to guide redesign of the reactor for testing with gas mixtures simulating use of recycle gas. Further work towards redesigning the reactor is planned for January.

Five revised copies of the Third Semi-Annual Report, and five copies of the final draft of the paper prepared for the ACS Symposium on Coal Gasification were forwarded to BCR.

C. Engineering Design and Evaluation

1. OCR/BCR Gasification--Power Generation: On December 5, 1972, representatives from Westinghouse and Combustion Engineering met with BCR staff. Both organizations were supplied with the necessary materials and instructions for using BCR's BI-GAS computer program as an aid in their OCR-sponsored projects. Similar information was transmitted to Ralph M. Parsons Company on December 5, 1972, in accordance with their request and OCR approval. Westinghouse requested additional information which was transmitted on December 14, 1972.

D. Literature Search (V. E. Gleason)

No literature references were added to the abstract file in December.

E. Other

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

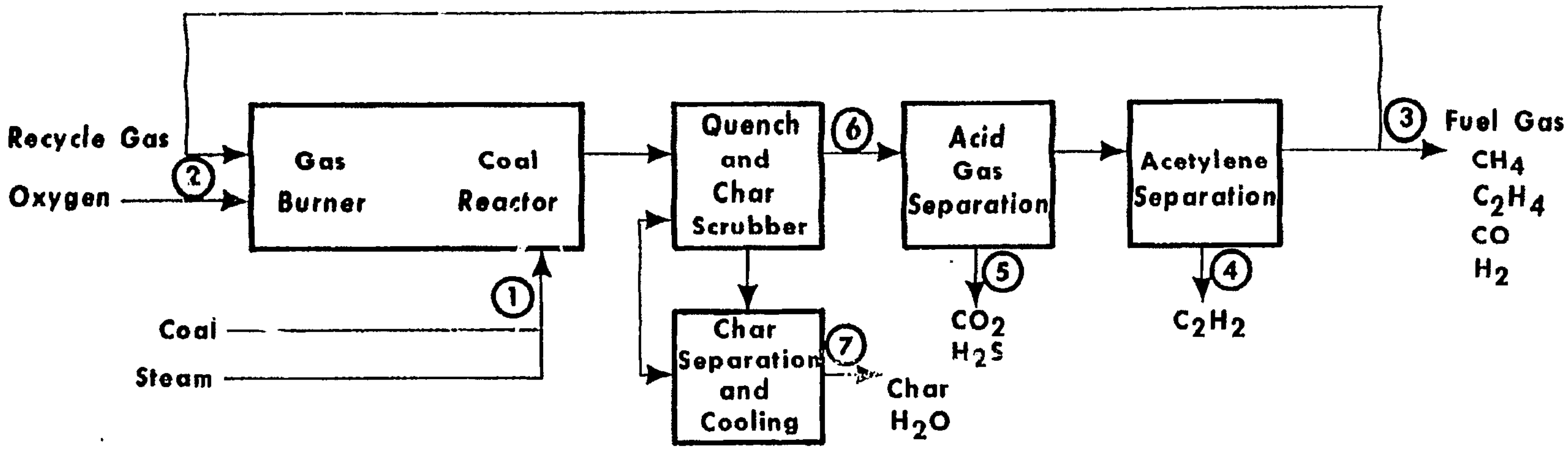
a. Invention Disclosure--Brigham Young University: During the course of work under Subcontract No. 3, Professor R. L. Coates, Brigham Young University, developed a new concept of pyrolyzing coal which may be patentable.

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 December, 1972

December 5, 1972

Mr. Jamin Chen, Staff Engineer
Combustion Engineering
Lummus Company
1515 Broad Street
Bloomfield, New Jersey 07003



Component \ Station	1 MOL	1 LB	2 MOL	2 LB	3 MOL	3 LB	4 MOL	4 LB	5 MOL	5 LB	6 MOL	6 LB	7 MOL	7 LB
Coal		1000												
O_2			19	600										
H_2O	39	700											36	647
H_2			25	51	17	34					42	84		
CH_4			2	31	1	21					3	52		
C_2H_4				6		4						10		
C_2H_2							2	47			2	47		
CO			28	781	19	521					47	1302		
CO_2									14	624	14	624		
H_2S										7		7		
Char														327
Total	39	1700	74	1469	37	580	2	47	14	631	108	2126	36	974

Bituminous Coal Research, Inc. 8016BG2

Figure 34. Simplified Material Balance

Mr. J. P. Hamm, Fellow Engineer
Mr. E. J. Vidt, Sr. Research Scientist
Mr. Donald P. Wei, Manager, Analysis & Programming
Mr. Harry S. Wilson, Program Manager
Mr. Cyrus F. Wood, Manager, Problem Analysis
Westinghouse Electric Corporation
R. & D. Center
Beulah Road
Pittsburgh, Pennsylvania 15235

G. Trips During December, 1972

None

III. WORK PLANNED FOR JANUARY, 1973

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

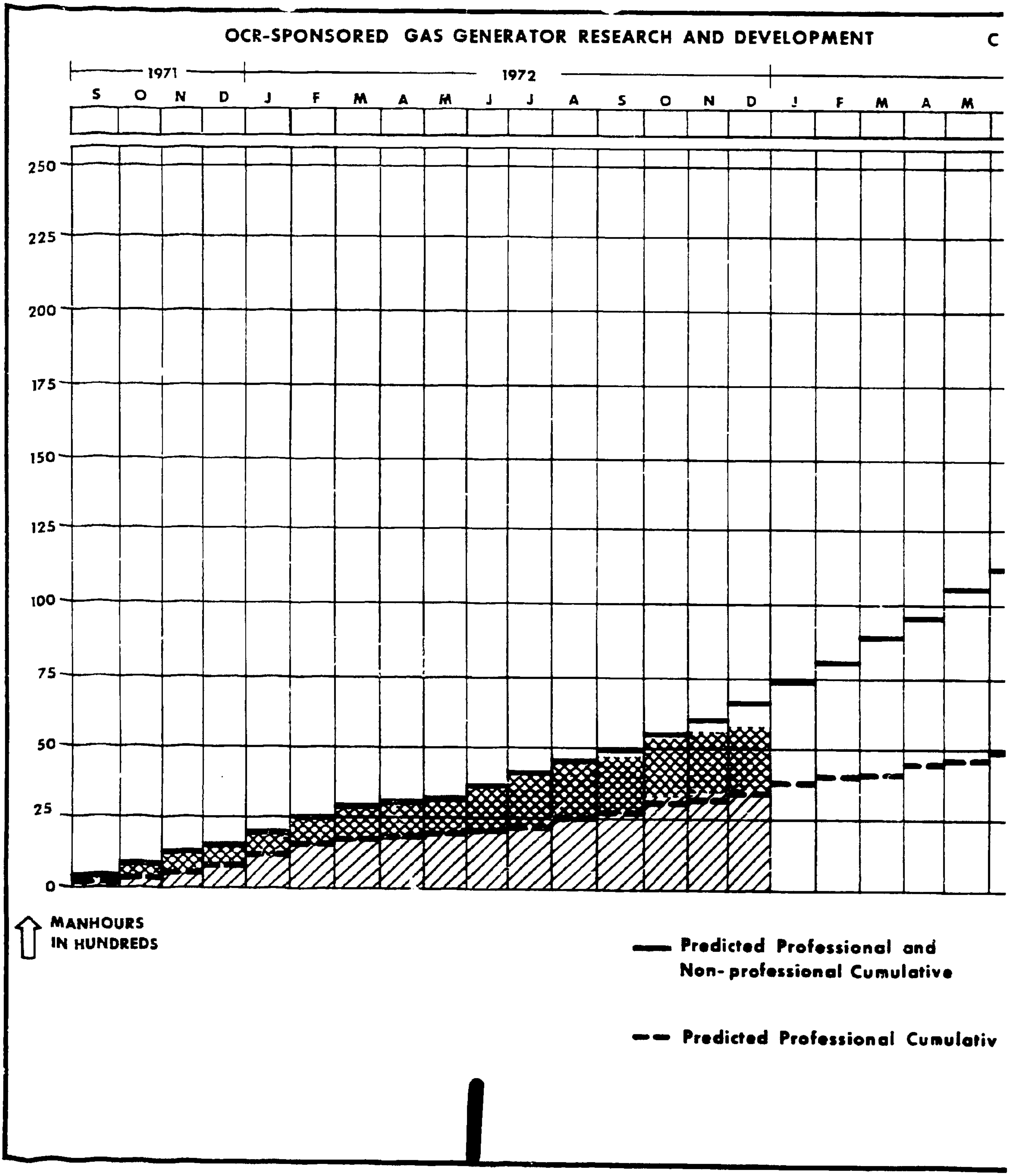
Quotations for the PEDU detail engineering and construction will be solicited as soon as authorization from OCR to proceed is obtained.

Brigham Young will continue design studies for apparatus to permit pre-heating the combustion gases that are fed to the reactor.

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

A. Papers to be Presented

April 1973	Meeting of American Chemical Society, Division of Fuel Chemistry Symposium on Coal Gasification Dallas, Texas	"Coal Gasification in Low Pressure, Low Residence Time Entrained Flow Reactor" R. L. Coates C. L. Chen B. J. Pope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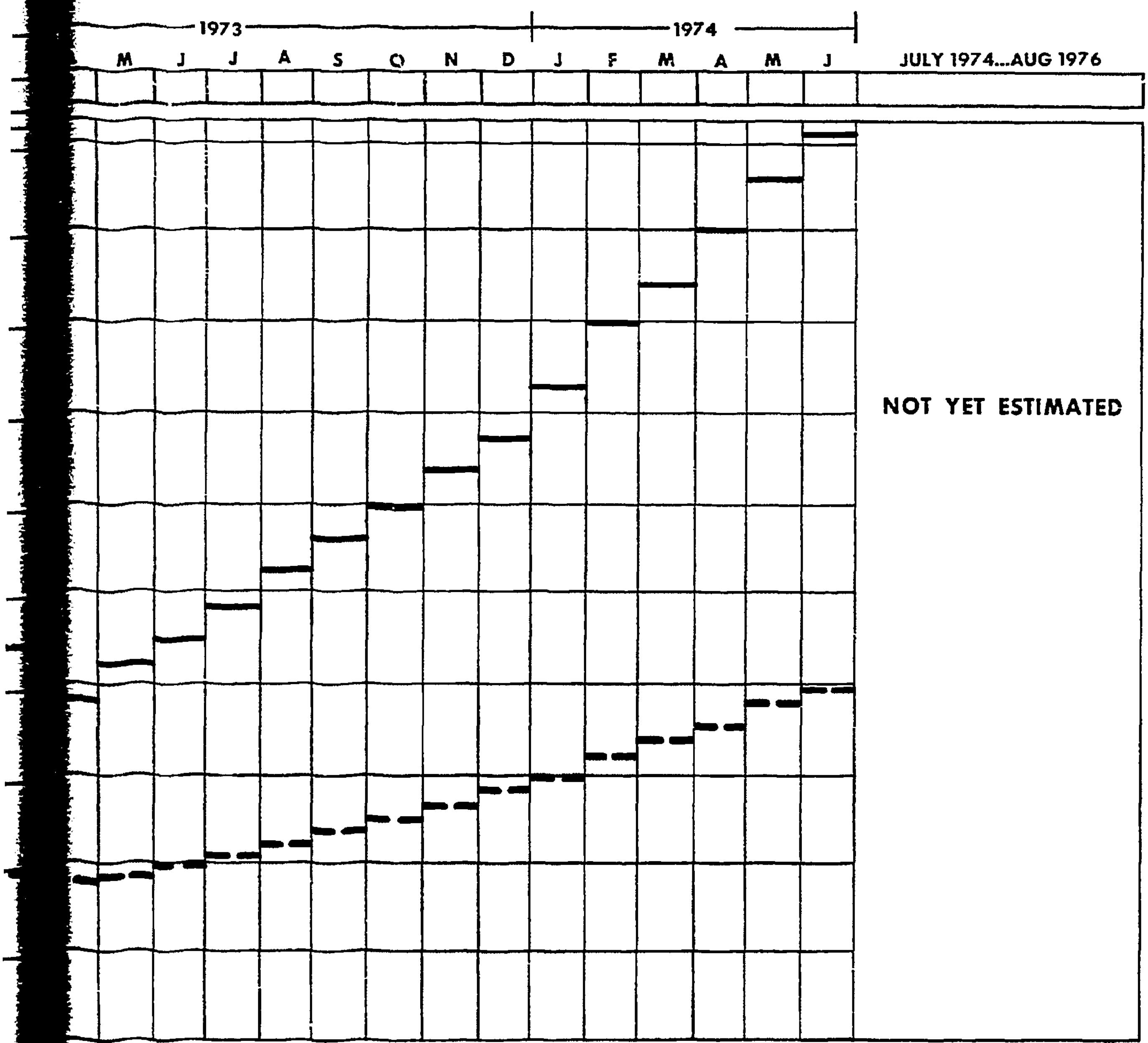

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OCR-SPONSORED GAS GENERATOR RESEARCH AND DEVELOPMENT

Schedule of Predicted and Actual Manhours

	This Month				Cumulative			
	Professional		Non-Professional		Professional		Non-Professional	
Month	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	322.0	251.0	218.5	3,010.0	3,104.0	2,457.0	2,275.0
Nov. '72	240.0	261.0	251.0	42.0	3,250.0	3,365.0	2,708.0	2,317.0
Dec. '72	240.0	221.0*	250.0	45.0*	3,490.0	3,586.0*	2,958.0	2,362.0*
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	
[illegible] '74	[illegible]		939.0		9,875.0		15,476.0	
July '74 to Aug. '76	NOT YET [illegible]IMATED							

* Esti[illegible]ed

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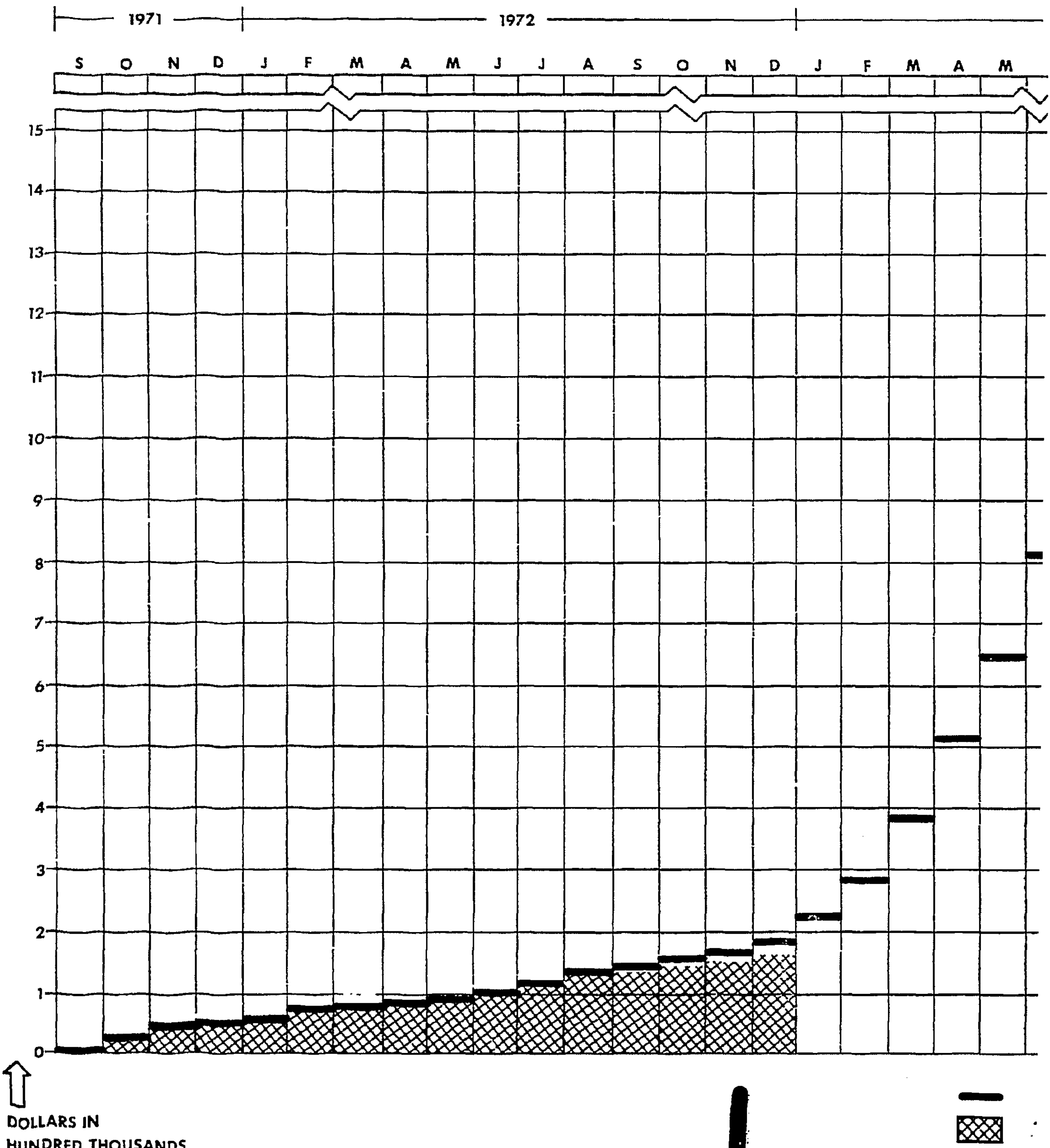

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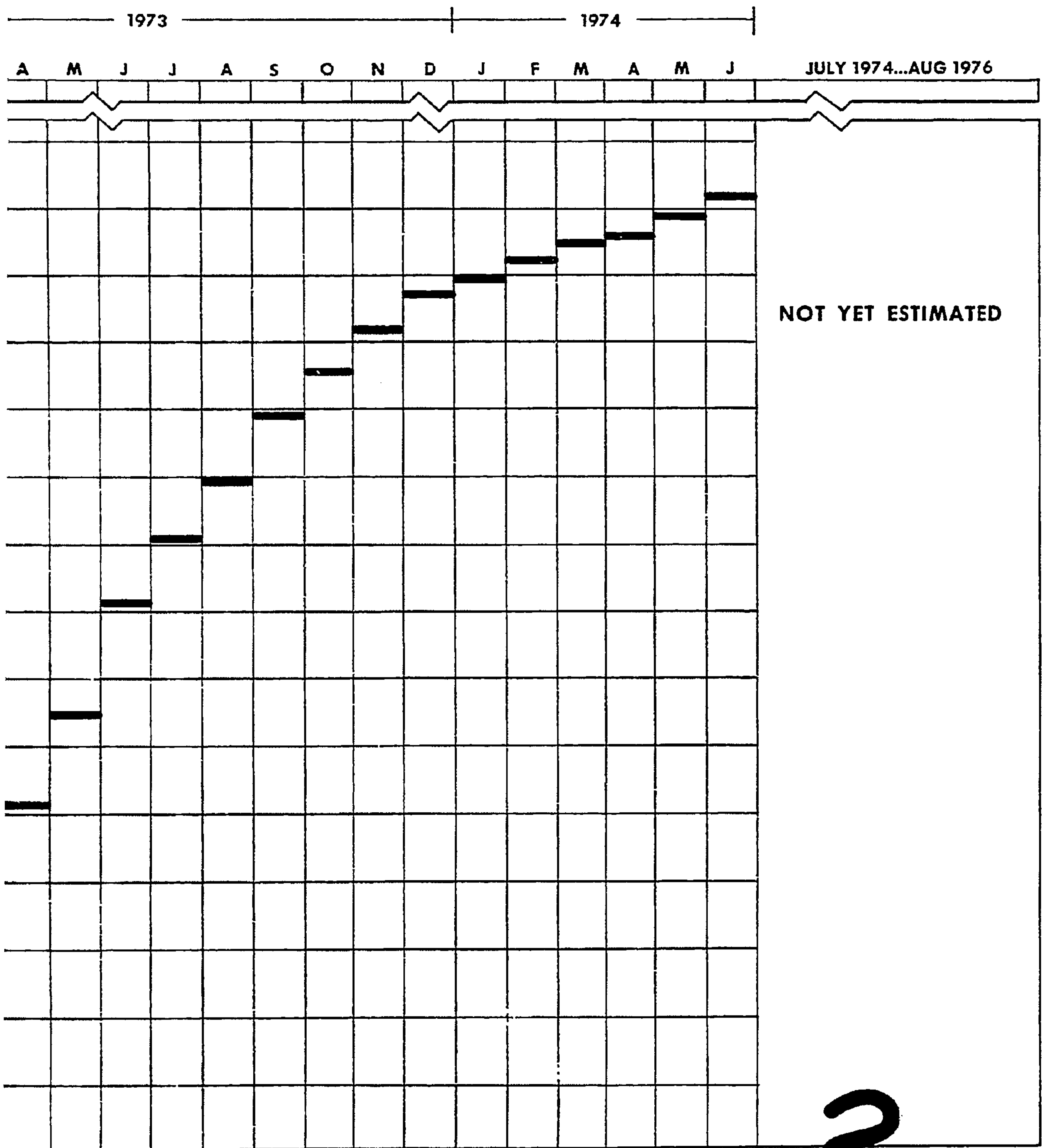
CUMULATIVE EXPENDITURES



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	11,344	160,373	146,268
Nov.	10,980	10,737	171,353	157,005
Dec.	10,980	7,042*	182,333	164,047*
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	

* Estimated

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