BITUMINOUS COAL RESEARCH, INC.

OCR-SPONSORED
GAS GENERATOR RESEARCH AND DEVELOPMENT

Progress Report No. 15-A
(BCR Report L-497)

I. INTRODUCTION

This report summarizes progress during November, 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 NOVEMBER 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 received from Foster Wheeler on November 20, 1972. The complete package consists of the following:

I. Introduction

II. Basis of Design

1. Characteristics of Base Case Coal
2. Range of Operating Conditions

III. Description of Plant

1. Process Flow and Materials of Construction Diagram - Drawing No. OP-721-427C
2. Description of Flow
3. Material and Energy Balance - Drawing No. OP-724-63
4. Utilities Summary
5. Engineering Flow Diagrams - Drawings No. OP-721-432A and OP-721-434A

IV. Equipment Specifications for the following process items:

	Item No.	Service
Reactors	R-101	Stage One Reactor
	R-102	Stage Two Reactor
	R-103	Stage Three Reactor
Drums	D-101	Coal Feed Hopper
	D-102	Coal Lock Hopper
	D-103	Ash Lock Hopper
	D-104	Char Fines Hold Bin
Exchangers	E-101	Product Gas Cooler
Heaters	H-101	Stage Two Preheater
	H-102	Stage Three Preheater
	H-103	Gas Burner
Compressors	C-101	Natural Gas Compressor
Pumps	P-101	Scrubber Recycle Oil Pump
Filters	F-101	Bag Filter
	F-102	Coal Lock Hopper Filter
Feeders	FD-101	Coal Lock Hopper Feeder
	FD-102	Stage One Reactor Feeder
Separators	G-101	Stage Two Reactor Cyclone Separator
	G-102	Stage Three Reactor Cyclone Separator
Scrubbers	T-101	Quench Scrubber

In addition, the equipment specifications include the following vessel drawings:

Item No.	Service	Drawing Number
R-101	Stage One Reactor	OP-724-843A
R-102	Stage Two Reactor	OP-724-844A
R-103	Stage Three Reactor	OP-724-845A
D-101	Coal Feed Hopper	OP-724-839A
D-102	Coal Lock Hopper	OP-724-840A
D-103	Ash Lock Hopper	OP-724-841A
D-104	Char Fines Hold Bin	OP-724-842A

V. Experimental Program

VI. Plant Startup and Shutdown

VII. Plant Construction

1. Plot Plan and Elevation - Drawing No. OP-721-592
2. Engineering and Construction Schedule
3. Cost Estimate

The engineering design package was reviewed by BCR personnel, who met with Foster Wheeler representatives on November 29, 1972. Several corrections to the design package were indicated by BCR at that meeting. These corrections will be made and the revised and final copy of the engineering design will be submitted to BCR during the first week of December.

The FEDU engineering and construction schedule is given in Figure 31. The preliminary design is now essentially complete. Detail engineering, procurement, and construction have been estimated by Foster Wheeler as requiring 14 months. Thus, startup can be achieved in early 1974 only if authorization to proceed is received at the beginning of 1973.

The budget cost estimate included in the design package is being reviewed by Foster Wheeler. Specifically, the instrumentation cost is being rechecked in light of the experience gained by BCR in the purchase of instrumentation for the methanation PEDU currently under construction. In addition, the first estimate did not include the cost of totally enclosing the PEDU superstructure. This enclosure is required by local building codes and its cost will be included in the final estimate.

2. <u>Laboratory Investigations</u>: Cold model studies were initiated to determine the optimum size distribution for the coal fed to Stage 1 of the fluidized-bed PEDU. The data are too incomplete to allow quantitative conclusions, but it has been observed qualitatively that at low velocities of fluidizing gas, size distribution has no effect on bed behavior as long as the mean particle diameter of the coal is the same. At higher gas velocities, in a bed with a large length to diameter ratio, a coal bed having a narrow size distribution expands to a greater depth and slugging begins sooner than a bed consisting of a wide size distribution of coal particles. This observation will be explored in greater depth during the next report period.

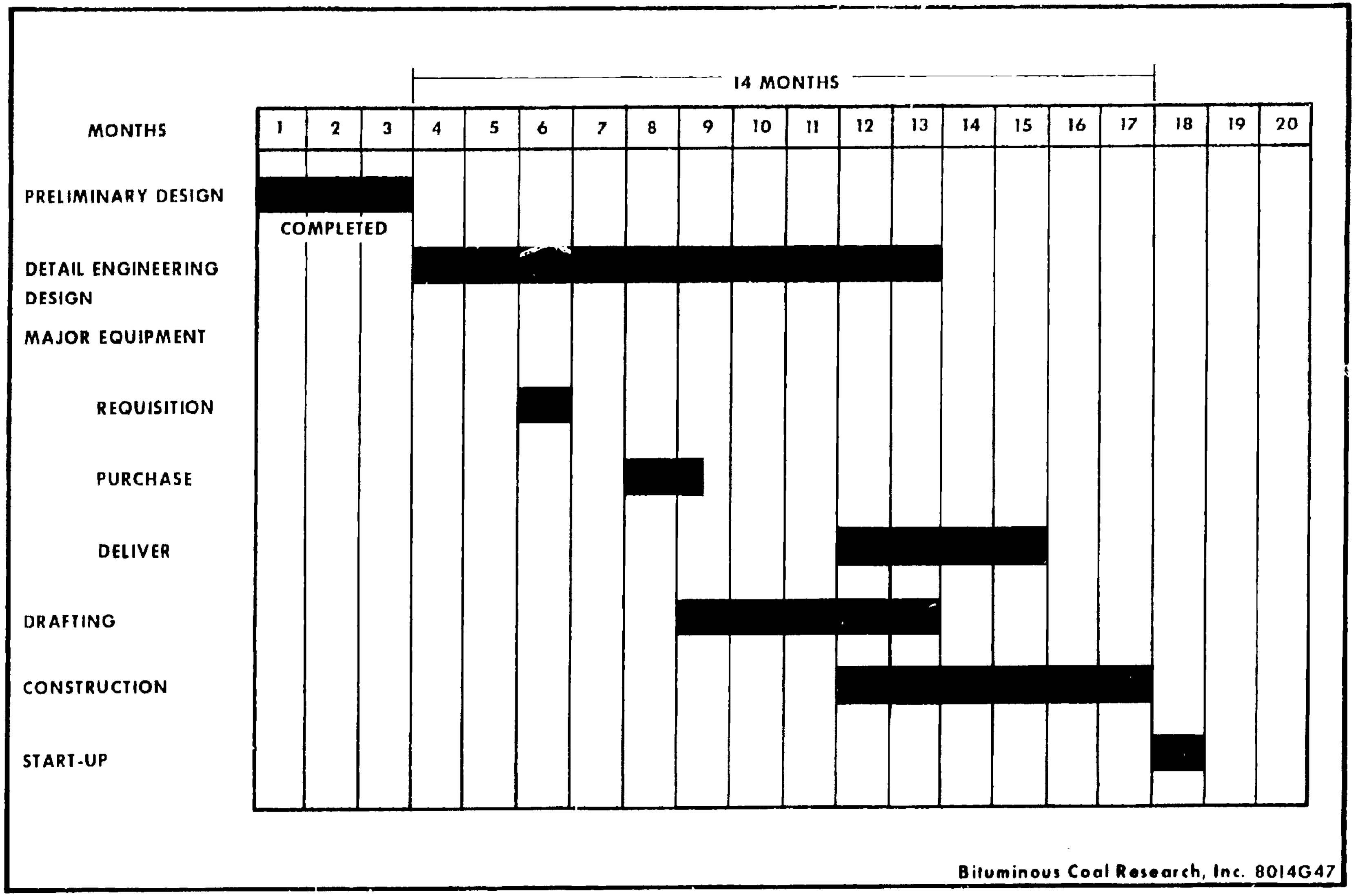


Figure 31. Fluidized-bed Coal Gasification PEDU - Engineering and Construction Schedule

a. Char Reactivity Studies: No TGA tests were made during the month.

b. Fluidized-bed Gasification Batch Reactor: No tests were made during the month.

3. Other: As approved by OCR, General Electric was contacted at their research center in Schenectady, New York, advising them of our interest to hold discussions on matters of mutual interest relating to coal gasification technology. Mr. Paul H. Kydd replied suggesting that the visit be postponed for a few months. My Kydd advised that at the present time they have a heavy schedule of visitors and that they are also anxious to accumulate additional data. Thus, a visit at a later date would be more productive.

4. Future Work: Laboratory studies will continue as needed to support the PEDU development program. The completed engineering design package, including BCR's best estimate of the cost of the fluidized-bed PEDU, will be readied for presentation to OCR.

B. 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 twentieth month. The Monthly Progress Chart, Expenditures, has not been received; it will be included in next month's report. The letter report of progress made during November is as follows:

As a result of the observation by BCR of an inconsistency in the ash balance resulting from the char collection rate data, the data summarized in the 3rd semi-annual Technical Progress Report have been reanalysed. Table 25 lists detailed ash balance data for ten selected runs. These data show that the total ash collected in the char is consistently less than the ash fed to the reactor; the recovery ranges from 42 to 91 percent. The apparent loss of ash could occur in three different ways. First, there is some settling of char in the piping connecting the reactor and the char collection container. Second, some of the char remains entrained in the gas downstream of the quench spray and is carried through the char collection container and into the filter which is located between this container and the gas meter. This material was not collected between runs since it was found to be very difficult to remove from the filter paper. Third, some of the ash may have dissolved into the quench water. Settling in the piping is considered to be the principal reason for the discrepancy, since the recovery is better for the longer duration runs. Because of this loss the "char collection rate" data are considered to be unreliable for use in material balance calculations.

Even though all of the char is not retained in the char container, the material that was collected should be representative of the char passing out of the reactor, and the ash content of this material should be useful in verifying the gasification yields. Figure 32 compares the percent carbon gasified based on the gas analysis versus the percent coal gasified (or dissolved in the quench water) based on the ash analysis of the char. There appears to be reasonably good correlation of the gas and char data. The fact that the percent of coal gasified based on the char analysis exceeded the percent carbon gasified when the carbon conversion is low suggests that there is a significant fraction of the coal converted to water soluble tars when the reactor temperature is relatively low. At high conversions of carbon to gas, the percent carbon converted exceeded the percent coal conversion. The high carbon conversions occurred at high reactor temperatures, and it would be expected that little tar would be formed under these conditions. The fact that the percent carbon gasified becomes higher than the percent coal gasified is consistent with the fact that although all of the carbon might possibly be gasified, provided sufficient oxidation occurred, the percent coal gasified cannot reach 100 percent due to the ash content.

As a result of this reanalysis it was discovered that the tabulated data in the appendix of the 3rd Semi-Annual Technical Progress Report contain some mistakes due to an error in the data reduction program. This error occurred when the program was revised during the prior month to calculate partial pressures at the reactor outlet. When this change was made, the calculated yield of hydrogen in the product gases, and the heating value and volume of

TABLE 25. DETAILED MATERIAL BALANCE DATA FOR SELECTED GASIFICATION RUNS

Run No.	5-8-4	5-8-2	5-8-1	6-9-4	7-31-1	8-23-2	6-6-4	6-6-5	6-6-6	6-6-7
Feed Rate, lbs/hr										
Coal	1.590	1.590	1.590	2.043	1.670	1.180	1.350	1.350	1.350	1.350
Hydrogen Carrier	0.082	0.082	0.082(N_2)	1.020	0.082	0.082	0.082	0.082	0.082	0.082
Hydrogen Combustion	0.069	0.102	0.140	0.167	0.167	0.113	0.127	0.127	0.127	0.127
Oxygen	0.540	0.800	1.050	1.260	1.340	0.900	0.96	0.96	0.96	0.96
Run Time, Minutes	3.0	3.0	3.0	3.0	3.0	3.0	10.0	10.0	9.5	20.0
Total Coal Fed, gms	36.06	36.06	36.06	46.33	37.88	26.76	102.06	102.06	96.96	204.12
Total Gas Metered, SCF (carrier free)	0.812	1.145	1.563	2.171	2.282	1.249	4.666	3.769	4.378	9.972
Mass Carbon in gas, gms	6.531	9.084	11.261	14.274	15.459	9.296	33.343	28.138	29.515	67.931
Gms Carbon in gas/ gms C fed	0.247	0.340	0.422	0.416	0.551	0.469	0.441	0.373	0.411	0.450
Total Char collected, gms	11.56	11.56	12.47	14.96	12.25	7.38	37.64	35.22	38.28	86.62
Gms Char/ gms Coal	0.321	0.321	0.346	0.323	0.323	0.276	0.369	0.345	0.395	0.424
$\frac{\text{Ash collected in char}}{\text{Ash fed in coal}}$	0.423	0.678	0.776	0.755	0.720	0.546	0.691	0.696	0.841	0.910
$1 - \frac{\text{percent ash in coal}}{\text{percent ash in char}}$	0.2397	0.5255	0.5255	0.5702	0.5510	0.5337	0.4639	0.5017	0.5280	0.5317

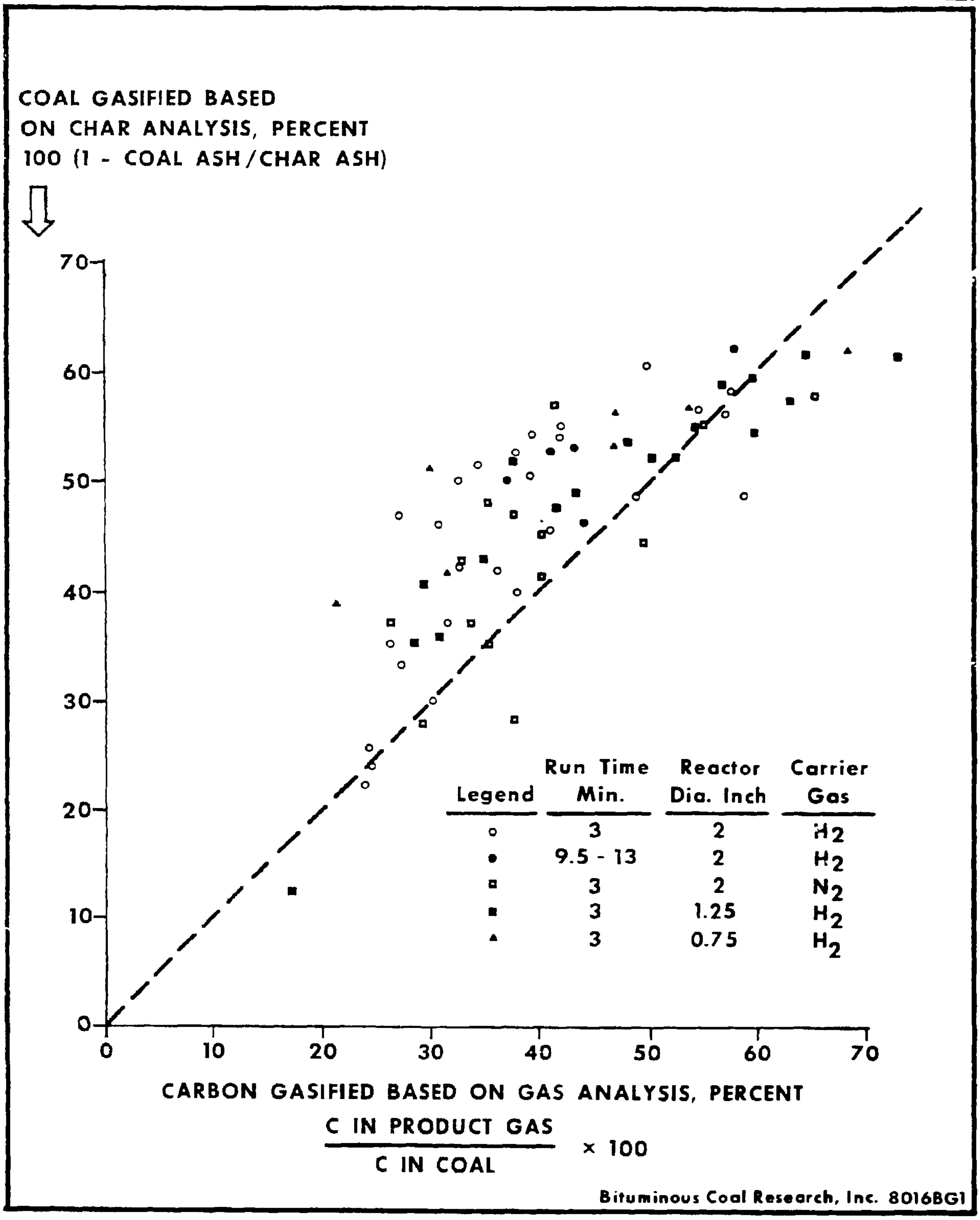


Figure 32. Comparison of Coal Gasified Versus Carbon in Gas

the carrier free gas was inadvertently not printed out correctly by the computer when the carrier gas was hydrogen. This error was corrected and a new set of tables has been prepared to replace those given in the appendix of the report. Five copies of the revised report will be sent shortly. The graphs presented in the report were not affected by this error; however, some data points were corrected for other reasons and additional points were added.

In addition to the work devoted to reanalysis of the data, work was accomplished toward designing a reactor to operate with recycled fuel gas and with the fuel gas, the coal, and the oxygen being preheated before being fed to the reactor. A computer program has been developed which will calculate the adiabatic reaction temperature and the composition of the product gas along with the gasification yields. A series of parametric calculations are being made with this program, and results from these calculations will be presented in reports for December.

C. Engineering Design and Evaluation

1. CCR/BCR Gasification--Power Generation: In mid-November, requests were received from Westinghouse and Combustion Engineering to have BCR make available the BI-GAS computer program; these requests have been approved by CCR. Both organizations are engaged in projects on low-Btu gas generation and believe that they could make good use of the mathematical model developed by BCR.

In order to conserve BCR manpower commitments, a meeting was arranged for December 5, 1972, at BCR. At that time, representatives of both Westinghouse and Combustion Engineering will be supplied with the necessary material and instructions for using the computer program.

D. Literature Search (V. E. Gleason)

Annotated literature references completed during the month are listed in Appendix B.

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. Trips and Meetings During November, 1972

November 29, 1972	Foster Wheeler Corporation Livingston, New Jersey	E. K. Diehl J. T. Stewart

III. WORK PLANNED FOR DECEMBER, 1972

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

The completed engineering design package of the fluidized-bed PEDU will be readied for presentation to OCR. Laboratory work will continue using the fluidized-bed batch reactor to study the PEDU Stage 1 reactor.

Brigham Young will conduct design studies for apparatus to permit preheating the combustion gases that are fed to the reactor. In addition, reanalysis of the data collected will be continued.

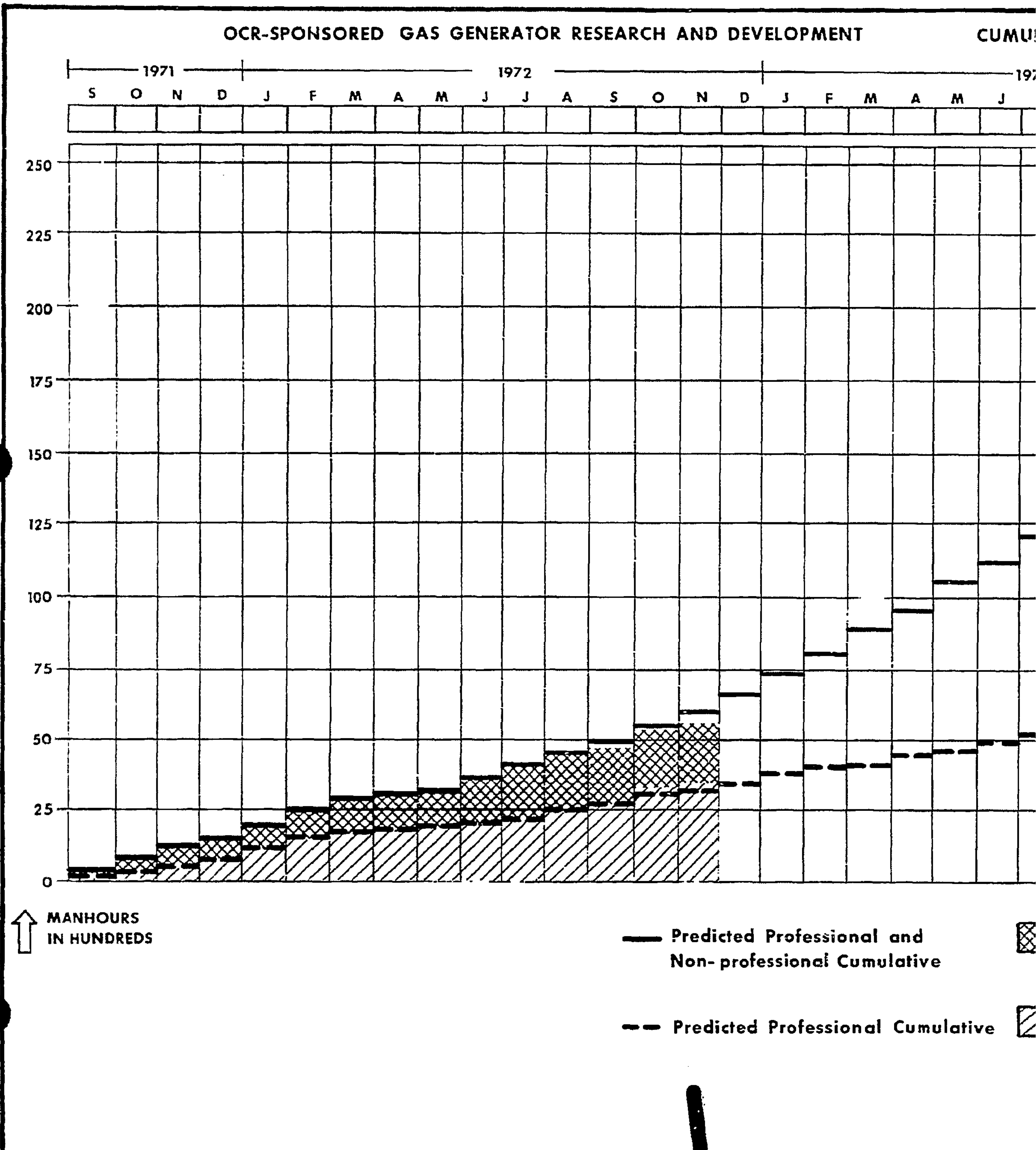
Discussions concerning power generation using the BCR/OCR gasifier will continue as requested and approved.

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

B. Meetings Planned

December 5, 1972	BCR Laboratory Monroeville, Pa.	Westinghouse Electric Corporation Combustion Engineering, Inc. BCR Staff


OCR-SPONSORED GAS GENERATOR RESEARCH AND DEVELOPMENT
CUMU
1971
1972
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250
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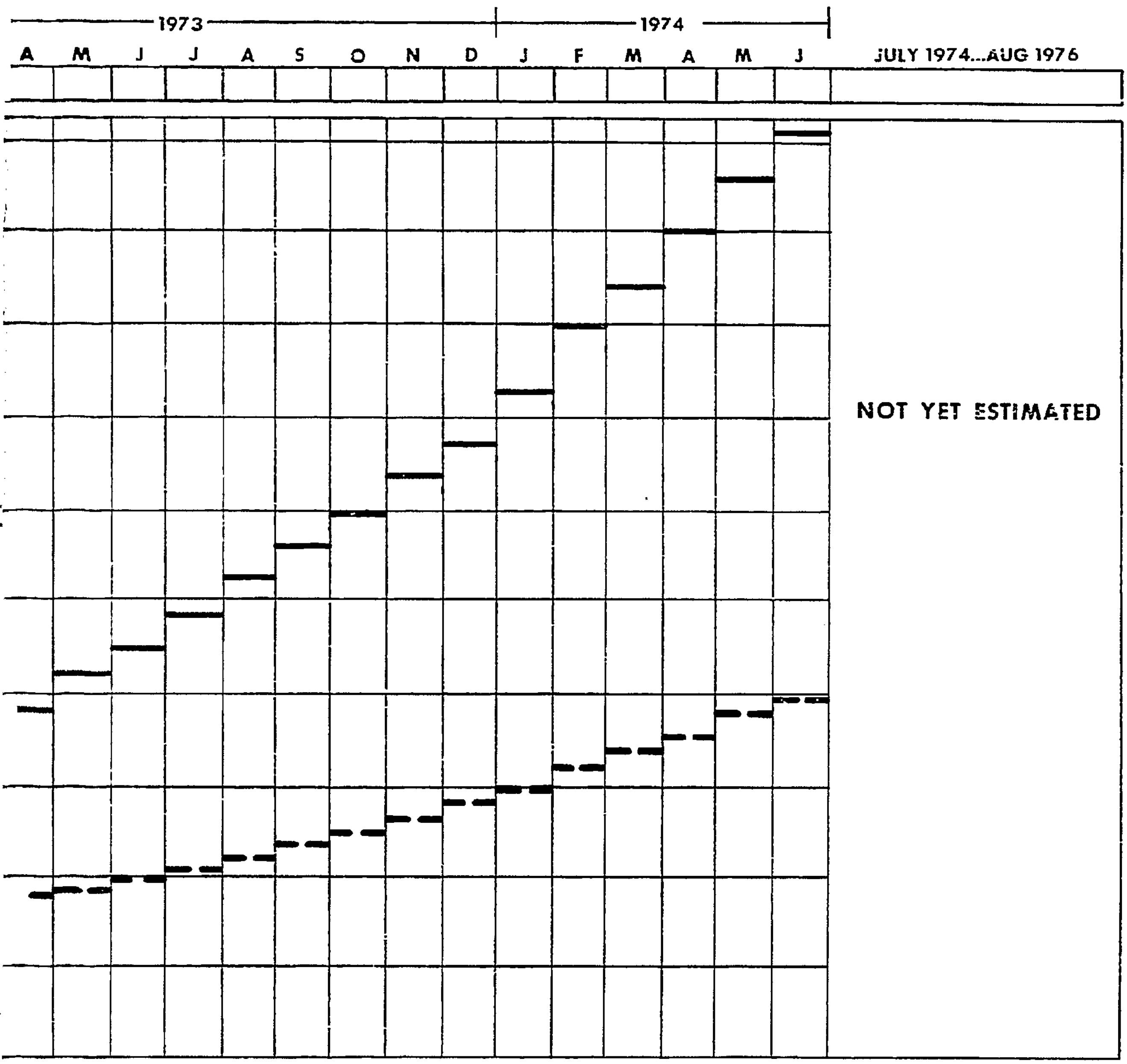

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OCR-SPONSORED GAS GENERATOR RESEARCH AND DEVELOPMENT
Schedule of Predicted and Actual Manhours

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	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		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							

* Estim

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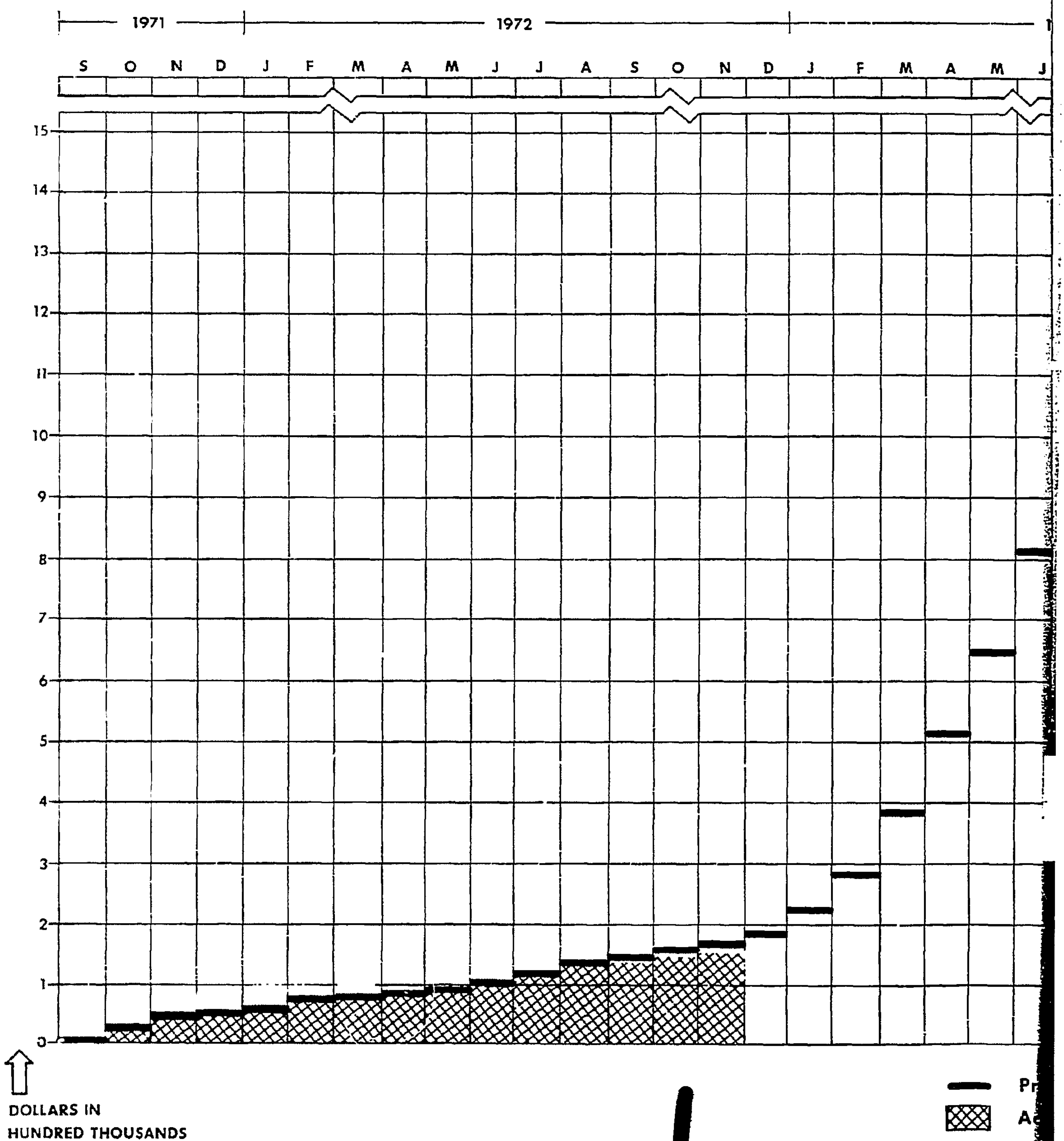

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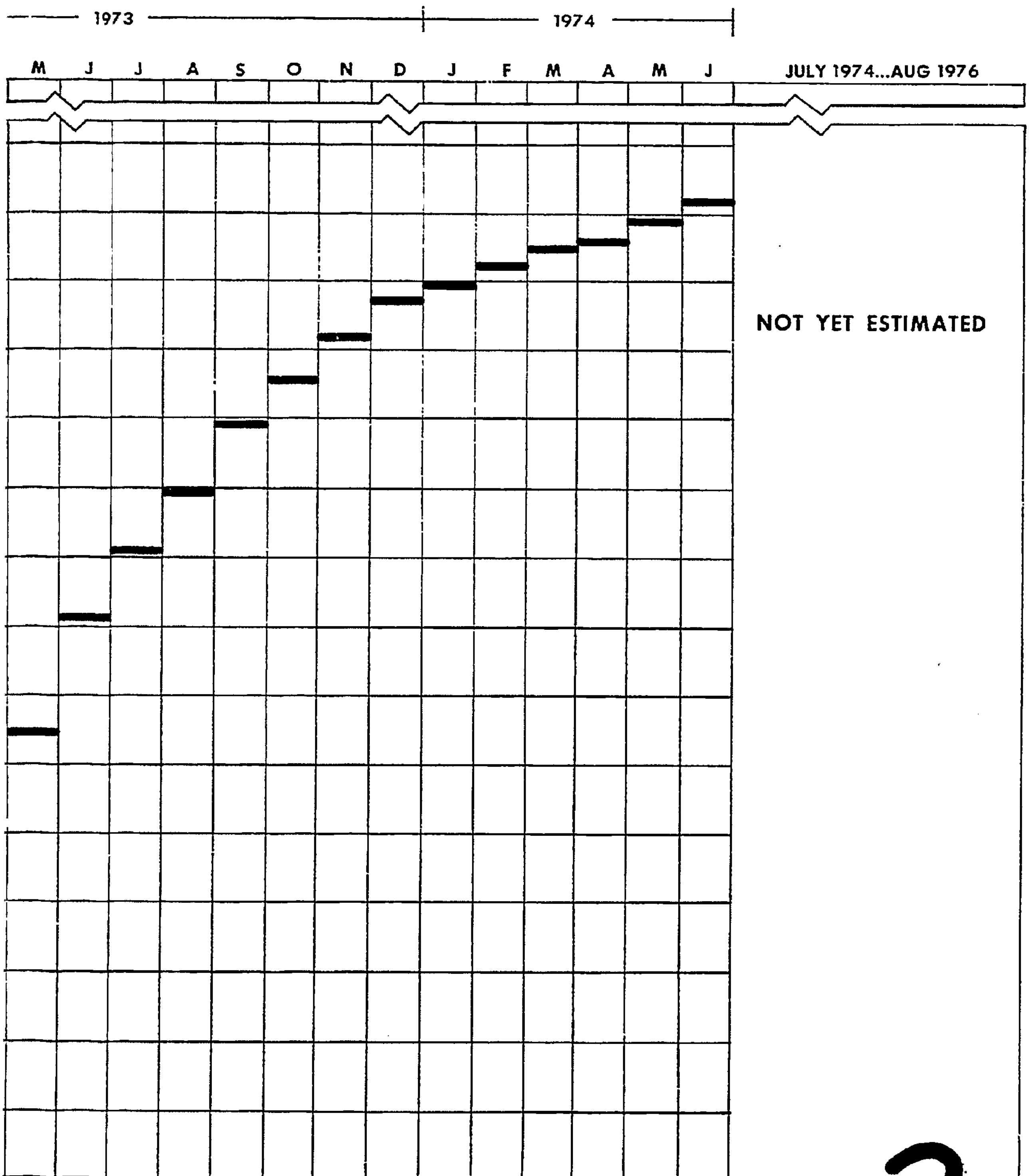
CUMULATIVE EXPENDITURES



▬ Predicted Expenditures, Cumulative

▨ Actual Expenditures, Cumulative

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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		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	NOT YET ESTIMATED			

* Estimated

APPENDIX B

ADDITIONS TO ABSTRACT FILE - NOVEMBER, 1972

Archer, D. H., Vidt, E. J., Morris, J. P., and Chen, J. L., "Coal gasification for clean power production," Third International Conf. Fluidized Bed Combustion, Session III, by U.S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 43 pp. 660. F 646 1972

A fluidized bed coal gasification process adapted to power generation has been devised. It uses air and steam for gasification and limestone or dolomite sorbent for desulfurization. A development effort is underway which includes the construction of a 1200 lb/hr coal gasifier and the performance of a supporting laboratory program. (From authors' abstract)

Coles, E. T., "The Union Carbide-Chemco coal gasification process: a strategy for commercialization," Fourth Synthetic Pipeline Gas Symp., Chicago, Ill., by Am. Gas Assoc. and U.S. Office Coal Res., 1972. 9 pp.+ 540.000 72-13

Chemco's evaluation of the Carbide coal gasification system and its potential for production of various fuel gases is discussed.

Craig, J.W.T., Moss, G., Taylor, J. H., and Tisdall, D. E., "Sulphur retention in fluidised beds of lime under reducing conditions," Third International Conf. Fluidized Bed Combustion, Session III, by U. S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 24 pp. 660. F 646 1972

The results of an extensive test program, carried out on a batch basis since the Second Conference, are presented. Also, the results of three successful runs in the continuously operating gasifier are reported.

Curran, G. P. and Gorin, E., "The CO_2 Acceptor gasification process - a status report - application to bituminous coal," Third International Conf. Fluidized Bed Combustion, Session III, by U.S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 28 pp. 660. F 646 1972

Included in the discussion are the experience gained and problems encountered during startup operations of the Rapid City pilot plant and the process revisions that must be made in application of the CO_2 Acceptor system to high-sulfur bituminous coals. Experimental work on the pretreatment of bituminous coals to render them suitable for pressurized gasification is described. A revised flow sheet and heat and material balance is given for application of the CO_2 Acceptor Process to the processing of bituminous coals. (From authors' abstract)

Curran, G. P., Pasek, B., Pell, M., and Gorin, E., "Low-sulfur producer gas via an improved fluid bed gasification process," Third International Conf. Fluidized Bed Combustion, Session III, by U.S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 26 pp. 660. F 646 1972

The evolution of the process concepts for generation of clean low Btu gas from bituminous coals via fluid bed gasification is described. Hot sulfur recovery from the gas is achieved by the use of dolomites. Experimental background data around other key process steps are briefly presented. (From authors' abstract)

Goldberger, W. M., "The Union Carbide coal gasification process - status of the development program," Fourth Synthetic Pipeline Gas Symp., Chicago, Ill., by Am. Gas Assoc. and U.S. Office Coal Res., 1972. 8 pp. 540.000 72-14

This process involves application of the self-agglomerating fluidized-bed coal burner to provide the heat for steam gasification of coal. The program will involve the design, installation, and operation of a 25-ton-per-day coal gasification pilot plant at Battelle's Engineering Pilot Plant Station at West Jefferson, Ohio. (From the text)

Gregory, S. A., "Problems of plant design for fluidized processes," J. Appl. Chem., 2, Supplementary Issue No. 1, S1-S7 (1952). 530.000 52-6

An attempt is made to indicate the main elements involved in a satisfactory functional design in descriptive terms, and as far as possible, these elements are listed in order of use, starting from the feed and finishing with the discharge. Heat-exchange methods are then considered. Pilot plant, instrumentation, and maintenance problems are excluded. (From author's abstract)

Matthews, C. W., "A design basis for utility gas from coal," Third International Conf. Fluidized Bed Combustion, Session IV, by U.S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 17 pp. 660. F 646 1972

This paper discusses the selection of design criteria for the gasification of coal and cleaning of the generated gas before combustion in an electric utility boiler. The preliminary plant design description is for a large pilot plant installation that will demonstrate the feasibility of this concept. (From author's introduction)

Moss, G. and Tisdall, D. E., "The design, construction and operation of the Abingdon fluidised bed gasifier," Third International Conf. Fluidized Bed Combustion, Session V, by U.S. EPA, Office of Res. and Monitoring, Hueston Woods, Ohio, 1972. 27 pp. 660. F 646 1972

A detailed description is given of the design and construction of the desulfurising fluidized bed gasifier which was built and operated at the Esso Research Centre, Abingdon, England. The unit was operated under gasifying conditions for a total of 450 hours during the commissioning period. Information is presented concerning the operational problems which were encountered and the remedial steps which were taken. (Authors' Summary adapted)

Robson, F. L., "Fuel gasification and advanced power cycles - a route to clean power," Third International Conf. Fluidized Bed Combustion, Session IV, by U.S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 21 pp.

660. F 646 1972

A review of the Combined Gas And Steam (COGAS) System is presented and the technical and economic advantages are enumerated. Several problem areas, particularly in the interface between the power system and the fuel system are presented to stimulate discussion. (From author's abstract)

Shultz, F. G. and Lewis, P. S., "Hot sulfur removal from producer gas," Third International Conf. Fluidized Bed Combustion, Session III, by U.S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 17 pp. 660. F 646 1972

A stirred-bed pressurized producer is described, and results are discussed for gasifying caking coals. Progress is reported in developing a process using a regenerable solid sorbent for removing hydrogen sulfide from hot producer gas with recovery of elemental sulfur formed during regeneration. (From authors' abstract)

Stewart, J. T. and Diehl, E. K., "Fluidized bed coal gasification - process and equipment development," Third International Conf. Fluidized Bed Combustion, Session III, by U.S. EPA, Office Res. and Monitoring, Hueston Woods, Ohio, 1972. 19 pp. 660. F 646 1972

This paper describes the BCR fluidized bed gasifier concept. It also summarizes the development program which began with laboratory-scale kinetic experiments and has progressed through the semi-continuous operation of a small fluidized bed batch reactor and the design of a process and equipment development unit planned to gasify 100 pounds of coal per hour at 250 psia and temperatures to 2100 F. (Adapted from authors' introduction)