

COPY NO. 62

**SRC-II DEMONSTRATION PROJECT
PHASE ZERO
TASK NUMBER 1**

DELIVERABLE NUMBER 3

**DEMONSTRATION PLANT
SUPPLEMENTARY TECHNICAL STUDIES**

MASTER

JULY 31, 1979

**THE PITTSBURG & MIDWAY COAL MINING CO.
DENVER, COLORADO**

PREPARED FOR

**UNITED STATES DEPARTMENT OF ENERGY
UNDER CONTRACT
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SECTION 1 INTRODUCTION

The subjects discussed in this report supplement Deliverable No. 1, Demonstration Plant Description. The intent is to develop in depth some of the problems associated with raw material sources, critical design considerations, prototype equipment, environmental and safety regulations, safety, operability, data base, trade-offs, and confidence analyses. The report includes, where applicable, work that must be done in order to be able to produce the detailed final design for the Demonstration Plant. Areas where final decisions regarding trade-off studies and process configurations have not been made are also indicated.

In Phase I, detailed design work will produce additional revisions and trade-off studies that could affect both cost and schedule. This is to be expected in a large project on a process which has not been previously commercialized. Note that the possible revisions to be developed under Phase I must not be confused with the Design Revisions, Section 6 of Deliverable No. 1, Demonstration Plant Description which are part of the baseline Demonstration Plant design and cost.

The Statements of Work (S.O.W.) for certain of the subtasks resulted in some redundancy. To avoid repetition, these redundancies were handled by reference as follows:

<u>S. O. W.</u>	<u>TOPICS</u>	<u>REPORTED IN DELIVERABLE NO.</u>
1.3(d)	Environmental Regulations	18
1.3(d)	Safety Regulations	3, Section 6
1.3(i)	Confidence Level Operating and Capital Costs	2

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2. RAW MATERIAL SOURCES

2.1 COAL

2.1.1 Background

After several years of investigation of many potential sites in several states, a site north of Morgantown, West Virginia was chosen for the SRC-II Demonstration Plant in April, 1977. For that general area, the Pittsburgh seam is the most prevalent coal, has thick seams and is the most mined. Consequently, it was believed that it would be the most logical feedstock to consider for the Demonstration Plant. SRC-II experimental data available at the time indicated substantial variation in the properties of the Pittsburgh seam from one area to another. As a result, Gulf Mineral Resources Co. contracted with the John T. Boyd Company, Mining and Geological Engineers, to develop iso-interval maps for the Pittsburgh seam for the following properties:

- Run-of-Mine Ash (MF basis)
- Run-of-Mine Sulfur (MF basis)
- Volatile Matter - Fixed Carbon Ratio
- Carbon (MAF basis)
- Oxygen (MAF basis)
- BTU Content (MAF basis)
- Partially Washed Ash (MF basis)
- Partially Washed Sulfur (MF basis)

These maps are shown in Appendix 2A. The variability of the Pittsburgh seam also is shown by Figures 2-1* and 2-2. These figures show ranges in the percent of ash, pyritic sulfur in ash, pyritic sulfur in coal and organic sulfur in coal throughout the Pittsburgh seam. Table 2 -1* shows variability which can be expected from one shipment from one mine. It is obvious that any coal liquefaction plant must be designed to handle variability in feed coal.

* Figures and tables appear at the end of this section.

2.1.2 Experimental Test Program

The SRC-II test program on Pittsburgh seam coal was initiated in early 1977 utilizing coal from the general vicinity of the planned plant site -- Loveridge, Blacksville No. 1 and Blacksville No. 2 mines (see Figure 2-3). Tests at the 20 pounds per day Merriam bench scale unit, the one-half ton per day P-99 Pilot Plant and the 30 tons per day Ft. Lewis Pilot Plant showed that these coals were substantially less reactive than the Kentucky and Illinois coals previously tested.

A review of the analyses of these coals, along with coal from Kentucky, Illinois and other areas of the Pittsburgh seam, indicated that coal from the Pittsburgh seam in the northwest panhandle of West Virginia and adjacent counties in eastern Ohio, about 50 miles northwest of the plant site (subsequently referred to as the "Panhandle Area"), should be substantially more reactive than the coal in the immediate area of the plant. Subsequent testing of coal from the Ireland, Powhatan No. 5 and Valley Camp No. 3 mines confirmed this belief. This review also indicated that coals 20 or 30 miles south of the site probably would have a reactivity about midway between that of the "local" coal and the "Panhandle Area" coal. Subsequent testing of coal from the Robinson Run mine confirmed this.

Analyses of the coals which have been used in the SRC-II test program are shown by Tables 2-2 and 2-3. Referring to Table 2-2, it can be seen that the silica values and base: acid ratios are similar for most of the coals tested. These factors are measures of ash or slag acidity and will be a factor in the choice of refractory for the slagging gasifier used to process the high ash vacuum tower bottoms. Also, the T_{250} values (temperature at which the slag has a viscosity of 250 poises) also are similar for all of the coals tested. High ash vacuum bottoms produced at the Ft. Lewis Pilot Plant from both the Colonial mine (Kentucky) and the Powhatan No. 5 mine ("Panhandle Area") have been processed through the slagging gasifier at Texaco's Montebello Research Facility with no major slag problems. An extended test run of two to four weeks duration, at Demonstration Plant operating pressure and using vacuum bottoms produced at the Ft. Lewis Pilot Plant from Powhatan No. 5 coal, is scheduled at Montebello for late summer, 1979. This test should provide additional data on refractory life and will be of sufficient duration so that waste water should come to equilibrium and analyses of water and slag leachates should be typical.

Table 2-3 shows that from an organic composition standpoint, the "Panhandle Area" coal resembles Kentucky and Illinois coals more than it does northern West Virginia coal, especially with regard to volatiles and carbon content. Yields obtained for tests conducted near the Demonstration Plant design conditions at the three SRC-II experimental facilities are listed in Table 2-4. It can be seen that coal from the "Panhandle Area" is substantially more reactive than coal from northern West Virginia -- greater distillate yield and lower organic vacuum bottoms yields. The yields for the "Panhandle Area" coal are similar to those for Kentucky and Illinois coals.

Yields obtained for "Panhandle Area" coal only are shown by Figures 2-4 and 2-5. These figures point out that there is much less scatter in the data obtained from P-99 than from the other two units. Also, that P-99 has tested coals with a wider range of coal ash. The beneficial effect of high ash concentration on increased distillate and decreased organic vacuum bottoms yields is obvious.

Emphasis will be given in future testing to determine if coal from seams other than the Pittsburgh seam, in the general vicinity of the plant site, will be acceptable as feedstock for the Demonstration Plant -- either separately or as a blend with a more reactive coal.

2.1.3 Design Coal

Based on results of the SRC-II experimental program, coal from the "Panhandle Area" has been selected as the design coal for the SRC-II Demonstration Plant. Figure 2 - 6 shows the data from P-99 runs which were made near the Demonstration Plant design conditions with "Panhandle Area" coals with four levels of ash content. Design yield points are shown for the Phase Zero Conceptual Demonstration Plant and for the planned definitive design of Phase I. The planned design range of ash content is 9% to 14%.

Data also are plotted on Figure 2 - 6 which shows the substantially lower reactivity of coals which are located closer to the plant site -- Blackville No. 2 and Robinson Run mines.

2.1.4 Coal Supply

The shaded area on Figure 2 - 3 shows the counties from which the primary coal supply is currently expected to be obtained. Testing of other seams or blends of coal could alter this in time. As shown by Table 2-5, the Pittsburgh seam coal production in these counties was 17.8 million tons in 1976. The indicated excess capacity of 14.0 million tons per year should be more than adequate for providing the two million tons per year requirement for the SRC-II Demonstration Plant. Adequate rail facilities are available for its delivery.

For future commercialization of the SRC-II process utilizing Pittsburgh seam coal from the "Panhandle Area", approximately 4,800 million tons of reserves exist as shown by Table 2-6. These reserves would supply several 30,000 tons per day commercial SRC-II plants. Each such

plant would require 300 million tons over a 30-year plant life. Delivery of coal from this area to a commercial expansion of the SRC-II Demonstration Plant would be expected to be by unit train and barge.

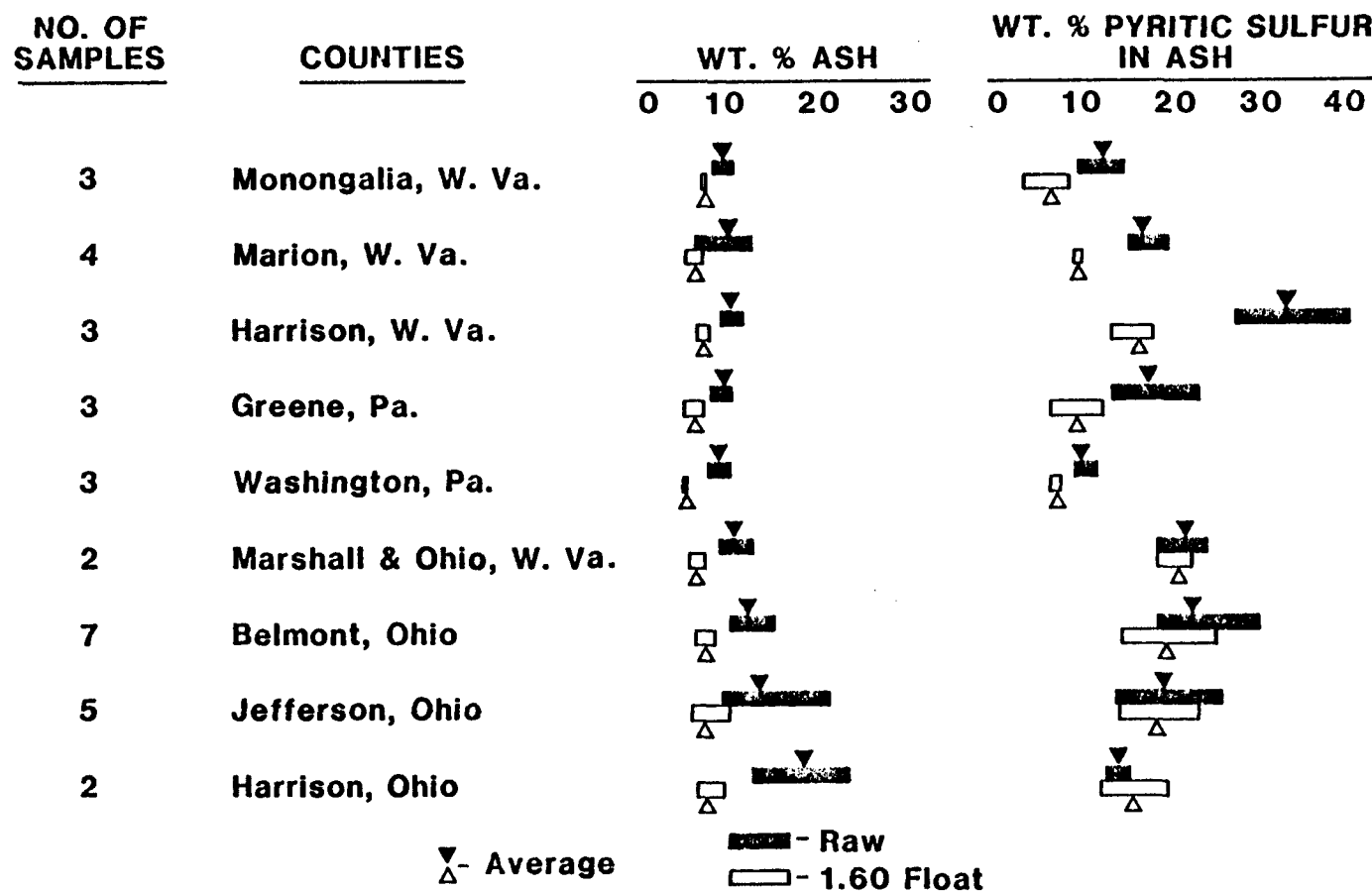
The ongoing SRC-II research may, in time, make more feasible the use of Pittsburgh seam coal from northern West Virginia and southwest Pennsylvania. In that event, an additional reserve of about 5,000 million tons would be available for SRC-II commercialization.

Both Kentucky 9 and Illinois 6 coals, with reserves of 4,600 and 29,000 million tons, respectively, have shown good reactivity in the SRC-II process and probably would be utilized if a large SRC-II industry develops. Although Illinois 5 coal, with reserves of 11,000 million tons, has not been tested in the SRC-II process, its properties are similar to Illinois 6 and, therefore, probably could be utilized for SRC-II commercialization.

2.2 OTHER RAW MATERIALS

Other than coal, the only other major raw materials which will be required in the SRC-II Demonstration Plant are air and water. The water will be obtained from the Monongahela River. The water supply for the plant is discussed in Phase Zero Deliverable No. 16, Site Suitability.

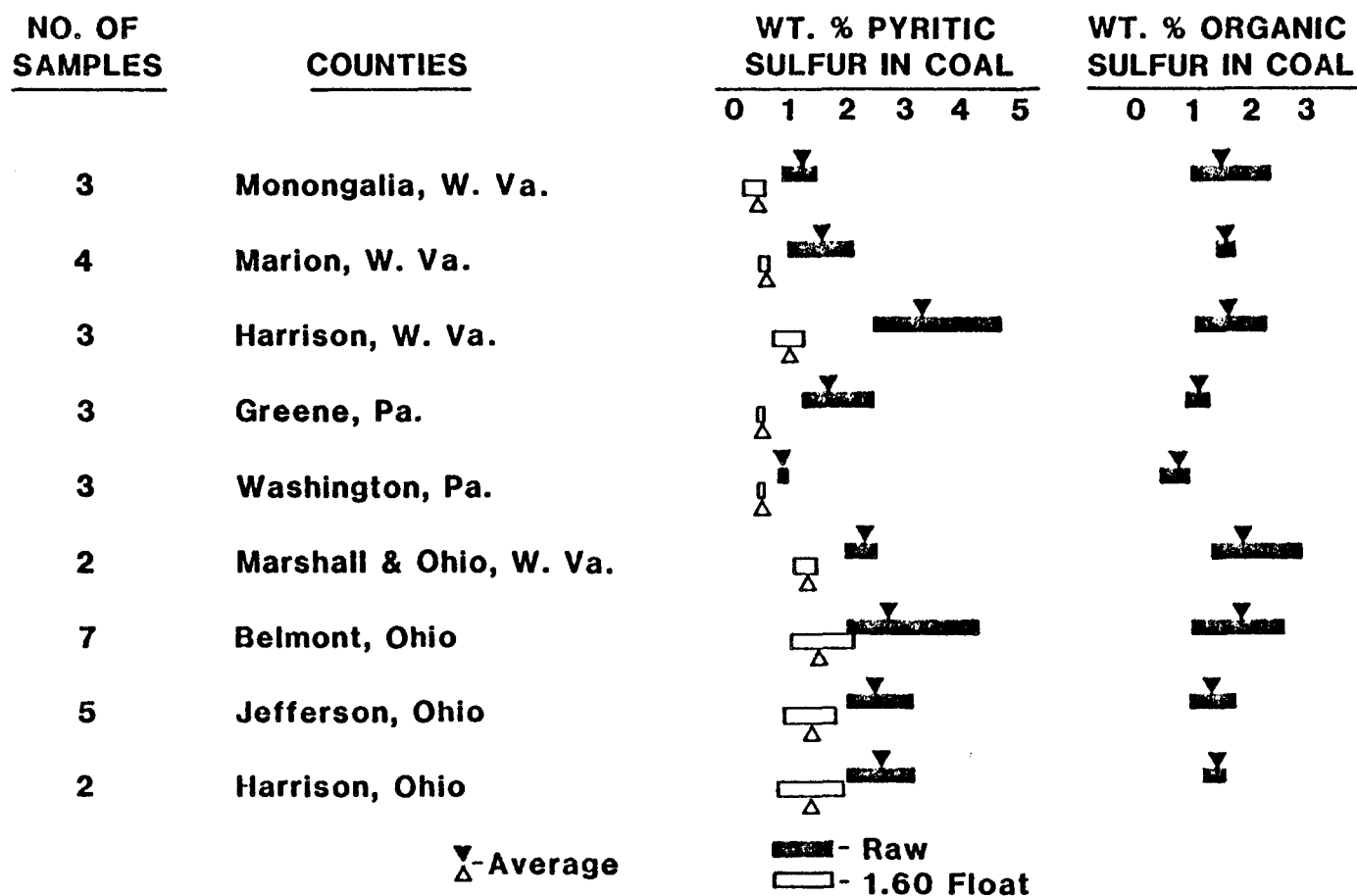
A substantial amount of catalysts and chemicals will be needed but they will be standard types which will be available from several sources on a competitive basis.



Data Source: U. S. Department of the Interior, Bureau of Mines Report of Investigations 8118, 1976.

600 pound samples from rectangular section of the coal seam, containing no roof or floor material.

Figure 2-1. Analyses of Pittsburgh seam channel samples for % ash and % pyritic sulfur in ash



Data Source: U. S. Department of the Interior, Bureau of Mines Report
of Investigations 8118, 1976.

600 pound samples from rectangular section of the coal seam,
containing no roof or floor material.

Figure 2-2. Analyses of Pittsburgh seam channel samples
for % pyritic and organic sulfur in coal

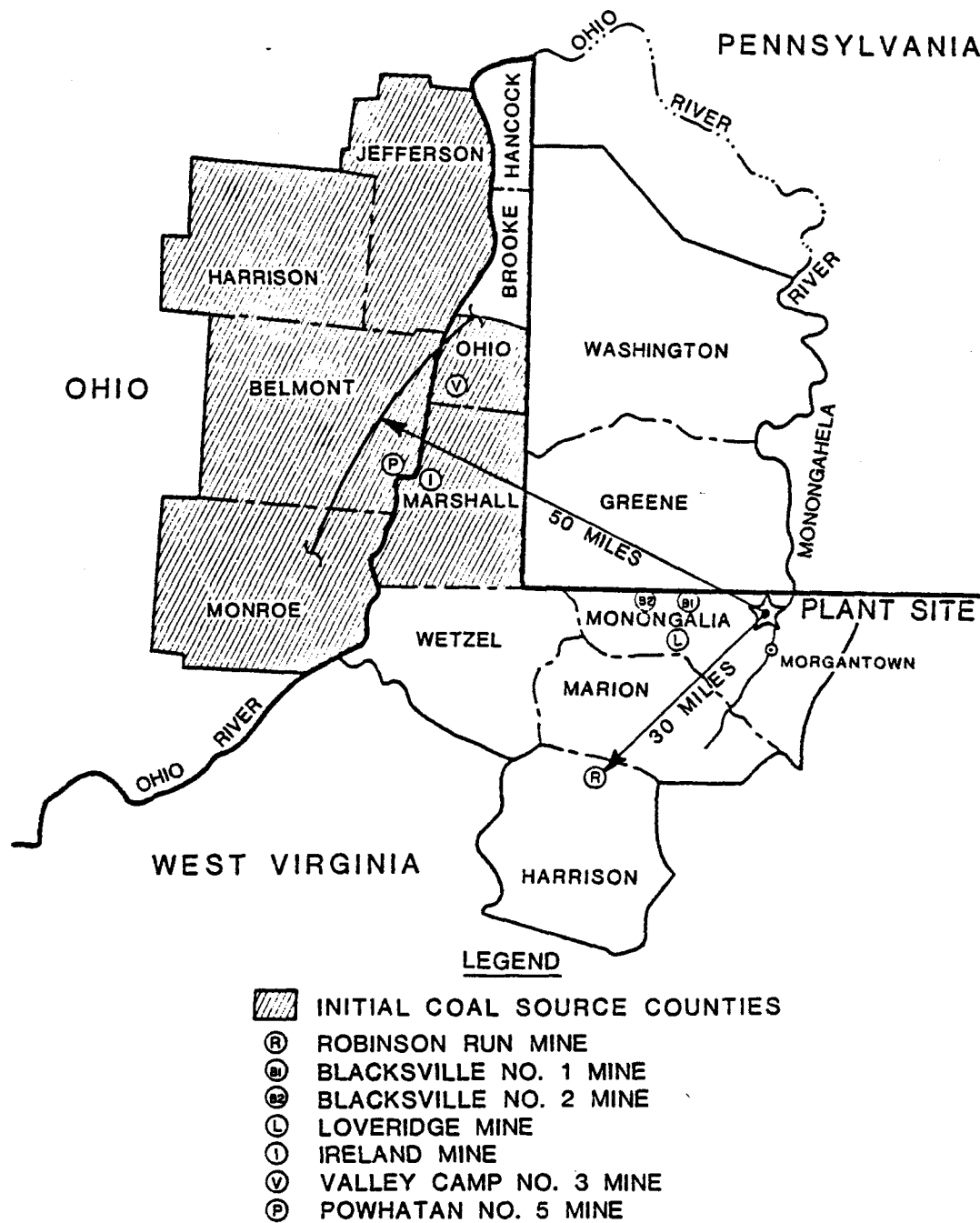
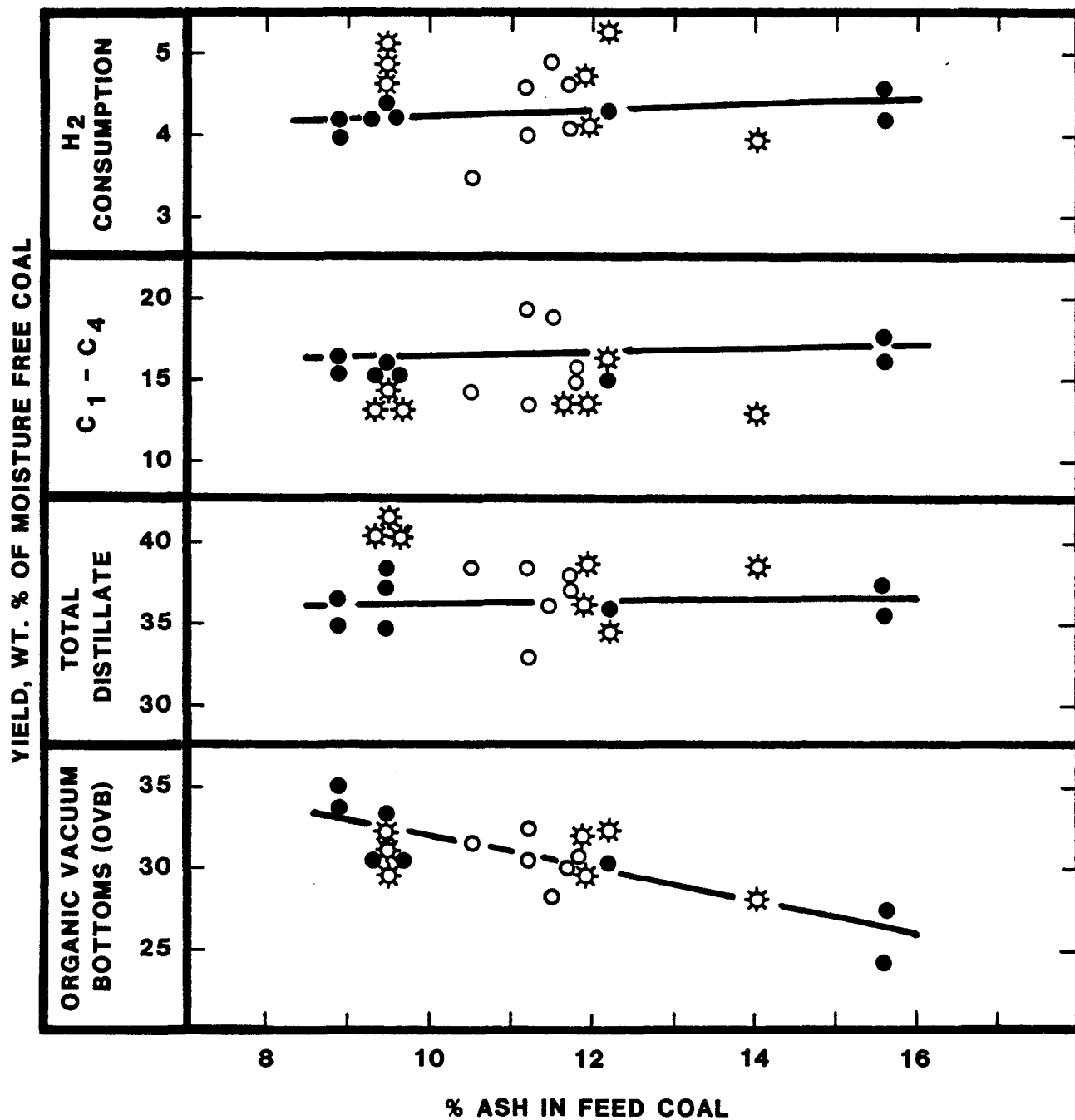


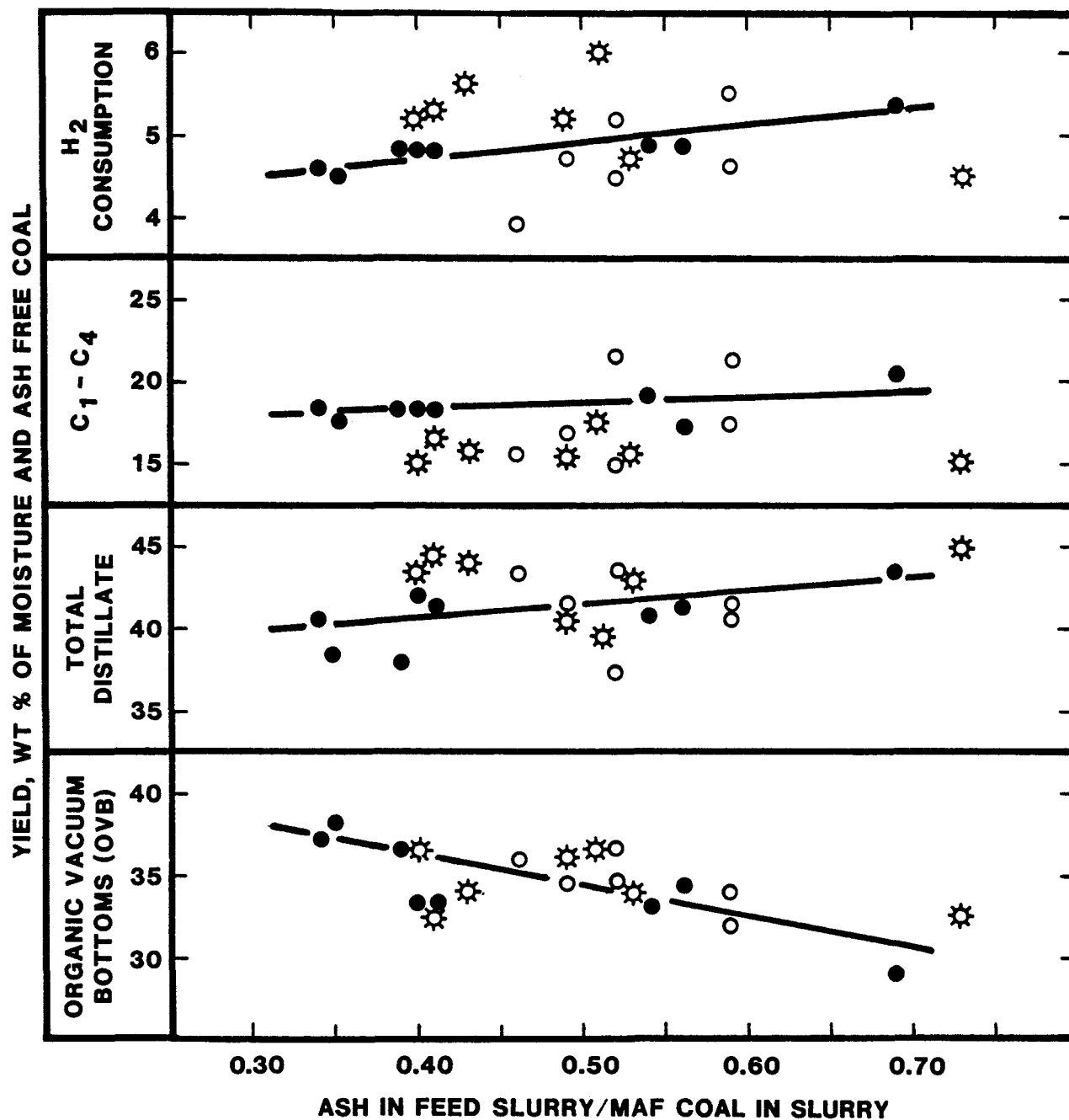
Figure 2 - 3. Mines from which coals have been tested for the SRC-II program and expected initial coal source counties for the Demonstration Plant



NOTE: CURVES DRAWN THRU P-99 DATA

- - P-99
- - FT. LEWIS
- ⊗ - MERRIAM

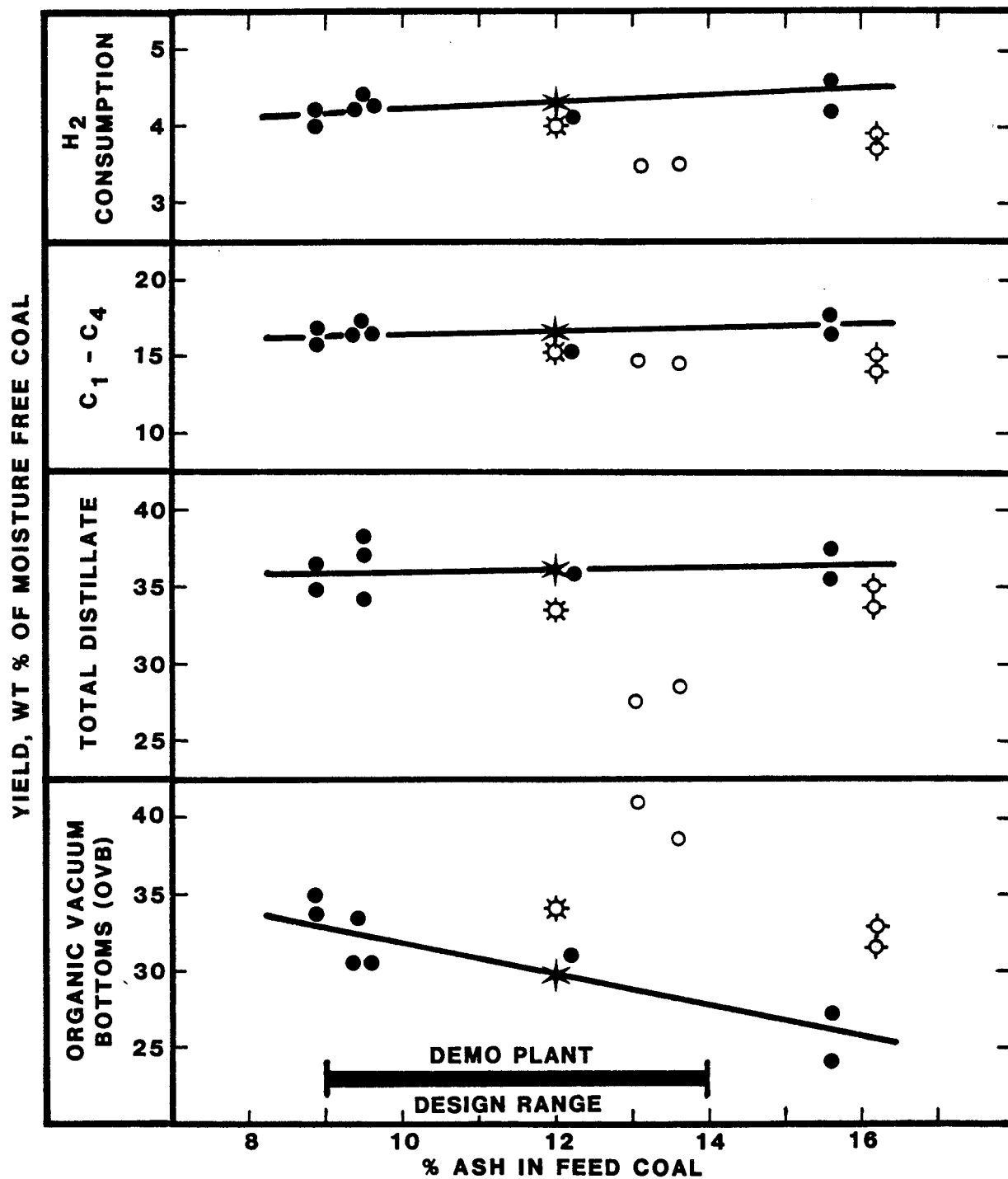
Fig. 2-4. SRC-II process yields near Demo Plant design conditions with "Panhandle Area" coal (Powhatan 5, Ireland, Valley Camp, 3 mines)



NOTE: CURVES DRAWN THRU P-99 DATA

- - P-99
- - FT. LEWIS
- ⊛ - MERRIAM

Figure 2-5. SRC-II process yields, near Demo Plant design conditions with "Panhandle Area" coal (Powhatan 5, Ireland, Valley Camp 3 mines).



- - PANHANDLE AREA COAL (POWHATAN 5, IRELAND, VALLEY CAMP 3 MILES)
- - NORTHERN W.VA. COAL (BLACKSVILLE 2 MINE)
- ◇ - NORTHERN W.VA. COAL (ROBINSON RUN MINE)
- ⊗ - CONCEPTUAL DEMO PLANT DESIGN POINT
- ★ - PLANNED DEMO PLANT DEFINITIVE DESIGN POINT (PHASE I)

Figure 2-6. P-99 SRC-II process yields, with Pitt Seam Coal near Demo Plant design conditions.

TABLE 2-1

COAL VARIABILITY
IN ONE RAIL SHIPMENT
RANGE OF ANALYSES, WT.% MOISTURE FREE COAL

Pitt Seam
Powhatan No. 5 Mine.
Samples From Each Car Of A
15-Car Shipment to Ft. Lewis

	<u>Low</u>	<u>High</u>	<u>Average</u>
Ash	10.0	12.6	11.3
Carbon	70.8	72.4	71.5
Hydrogen	4.8	5.4	5.2
Sulfur	3.5	4.0	3.7
Oxygen	6.1	8.3	7.1
Iron	1.6	2.5	1.9
Volatiles/Fixed Carbon Ratio	-	-	0.82
Reactivity Index	9.1	14.0	11.5

TABLE 2 - 2

TYPICAL ANALYSES, MOISTURE FREE BASIS, OF COAL FROM MINES PROVIDING COAL FOR THE SRC-II TEST PROGRAM

Coal Seam	KY 9/14	Illinois 6	Pittsburgh Seam						
Mine Location	Kentucky	Illinois	Northern W. Va.			Pandhandle Area, N.W. W. Va. - E. Ohio			
Mine Name	Colonial	Riverking	Loveridge	Blacksville No. 1	Blacksville No. 2	Robinson Run	Ireland	Powhatan No. 5	Valley Camp No. 3
<u>Proximate Analysis, Wt. %</u>									
Ash	10.3	12.8	7.5	6.4	11.8	15.8	15.6	11.6	9.0
Volatile	37.4	38.6	39.1	37.1	36.7	36.6	37.3	39.8	40.0
Fixed Carbon	52.3	48.6	53.4	56.5	51.5	47.6	47.1	48.6	51.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
BTU/lb.	13,070	12,220	13,960	14,280	12,880	12,610	12,630	13,050	13,360
<u>Ultimate Analysis, Wt. %</u>									
Carbon	71.9	67.9	77.3	78.4	73.1	69.1	68.4	72.2	75.8
Hydrogen	5.0	4.9	5.4	5.1	4.8	4.7	4.9	4.9	5.2
Nitrogen	0.6	1.1	1.1	1.2	1.1	1.4	0.8	0.8	0.8
Chlorine	0.06	0.04	0.10	0.13	0.08	0.02	0.04	0.07	0.02
Sulfur	3.4	3.7	2.7	2.4	2.7	3.6	4.6	3.7	3.4
Ash	10.3	12.8	7.4	6.4	11.8	15.8	15.6	11.6	9.0
Oxygen (diff.)	8.7	9.6	6.0	6.4	6.4	5.4	5.7	6.7	5.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
<u>Sulfur Forms, Wt. %</u>									
Pyritic	1.5	1.1	0.9	1.0	1.3	2.2	2.7	1.9	1.8
Sulfate	0.1	0.3	0.0	0.0	0.1	0.1	0.1	0.1	0.0
Organic	1.8	2.3	1.8	1.4	1.3	1.3	1.8	1.7	1.6
Total	3.4	3.7	2.7	2.4	2.7	3.7	4.6	3.7	3.4
Free Swelling Index	4.5	2.5	8.0	8.5	8.5	7.5	7.0	6.0	7.0
<u>Mineral Analysis of Ash, % Wt. Ignited Basis</u>									
SiO ₂	46.9	49.2	44.7	42.2	45.1	44.1	45.1	45.1	42.6
Al ₂ O ₃	18.9	19.6	22.0	23.7	21.1	20.4	20.7	22.5	22.3
TiO ₂	0.9	0.8	1.1	0.9	0.9	0.8	0.8	1.0	0.7
Fe ₂ O ₃	21.7	16.7	17.7	21.5	15.4	18.5	25.3	23.8	28.5
CaO	4.4	4.8	5.7	3.9	6.0	5.2	2.9	2.6	2.0
MgO	0.8	1.1	1.2	0.8	1.3	1.4	0.8	0.8	0.4
K ₂ O	2.1	1.7	1.6	1.2	1.7	2.4	1.6	1.6	1.3
Na ₂ O	0.3	0.5	1.0	0.9	1.0	0.7	0.5	0.6	0.5
SO ₃	3.2	4.6	4.0	3.9	6.8	5.6	1.2	1.7	1.3
P ₂ O ₅	0.1	0.2	0.2	0.2	0.5	0.6	0.2	0.2	0.2
Undetermined	0.7	0.8	0.8	0.8	0.2	0.3	0.9	0.1	0.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Silica Value ⁽¹⁾	64	69	63	62	65	64	61	61	58
Base: Acid Ratio ⁽²⁾	0.44	0.36	0.41	0.42	0.40	0.43	0.47	0.43	0.50
T ₂₅₀ Temperature, °F.	2,365	2,460	2,400	2,385	2,410	2,380	2,340	2,350	2,340

(1) $\text{SiO}_2/\text{SiO}_2+\text{Fe}_2\text{O}_3+\text{CaO}+\text{MgO}$ (2) $\text{SiO}_2+\text{Al}_2\text{O}_3+\text{TiO}_2/\text{Fe}_2\text{O}_3+\text{CaO}+\text{MgO}+\text{Na}_2\text{O}+\text{K}_2\text{O}$

TABLE 2 - 3

TYPICAL ANALYSES, MOISTURE FREE BASIS, OF COAL FROM MINES PROVIDING COAL FOR THE SRC-II TEST PROGRAM

Coal Seam	KY 9/14	Illinois 6	Pittsburgh Seam						
Mine Location	Kentucky	Illinois	Northern W. Va.				Pandhandle Area, N.W. W. Va. - E. Ohio		
Mine Name	Colonial	Riverking	Loveridge	Blacksville No. 1	Blacksville No. 2	Robinson Run	Ireland	Powhatan No. 5	Valley Camp No. 3
<u>Proximate Analysis, Wt. %</u>									
Volatile	41.7	44.3	42.3	39.6	41.6	43.5	44.2	45.0	44.0
Fixed Carbon	58.3	55.7	57.7	60.4	58.4	56.5	55.8	55.0	56.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
<u>Ultimate Analysis, Wt. %</u>									
Carbon	80.1	77.9	83.6	83.8	82.9	82.0	81.0	81.7	83.3
Hydrogen	5.6	5.6	5.8	5.4	5.4	5.6	5.8	5.5	5.7
Nitrogen	0.7	1.3	1.2	1.3	1.2	1.7	0.9	0.9	0.9
Chlorine	0.07	0.04	0.11	0.14	0.09	0.02	0.04	0.08	0.02
Sulfur	3.8	4.2	2.9	2.6	3.1	4.3	5.5	4.2	3.7
Oxygen (diff.)	9.7	11.0	6.4	6.8	7.3	6.4	6.8	7.6	6.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 2 - 4

AVERAGE YIELDS OBTAINED DURING SRC-II TEST PROGRAM AT CONDITIONS NEAR THOSE FOR THE DEMONSTRATION PLANT DESIGN

Coal Seam	KY 9/14			Illinois 6	Pittsburgh Seam											
Mine Location	Kentucky			Illinois	Northern W. Va.						Pandhandle Area, N.W. W. Va. - E. Ohio					
Mine Name	Colonial			Riverking	Loveridge	Blacksville No. 1	Blacksville No. 2		Robinson Run (4)	Ireland (4)	Powhatan No. 5			Valley Camp No. 3		
Experimental Unit ⁽¹⁾	<u>F</u>	<u>P</u>	<u>M</u>	<u>F</u>	<u>M</u>	<u>M</u>	<u>F</u>	<u>P</u>	<u>M</u>	<u>P</u>	<u>P</u>	<u>M</u>	<u>F</u>	<u>P</u>	<u>M</u>	<u>P</u>
No. of Runs	1	4	10	4	0 ⁽²⁾	1 ⁽³⁾	3	2	4	2	2	1	6	4	8	2
Average Yields, Wt. % Moisture Free (MF) Coal																
H ₂ Usage	4.3	4.4	4.5	3.6		5.2	3.1	3.5	4.1	3.7	4.3	3.8	4.2	4.3	4.9	4.2
C ₁ - C ₄	16.6	16.3	13.0	12.2		16.6	12.1	14.8	12.3	14.6	16.9	12.7	16.0	16.2	14.1	16.5
Total Distillate	38.2	37.2	38.1	38.0		37.5	29.8	28.0	32.9	34.2	35.9	38.0	36.6	36.6	38.4	35.7
Organic Vacuum Bottoms (OVB)	29.5	29.2	29.7	28.8		35.7	42.6	40.0	38.0	32.1	25.1	27.5	30.7	31.9	31.1	34.0
Ash	10.3	10.3	10.3	12.8		6.4	11.8	11.8	11.8	15.8	15.6	15.6	11.6	11.6	11.6	9.0
Average Yields, Wt. % of Moisture and Ash Free (MAF) Coal																
H ₂ Usage	4.8	4.9	5.0	4.1		5.5	3.5	4.0	4.7	4.4	5.1	4.5	4.8	4.9	5.6	4.6
C ₁ - C ₄	18.4	18.1	14.4	14.0		17.7	13.8	16.8	14.0	17.4	20.0	15.0	18.2	18.4	16.0	18.1
Total Distillate	42.4	41.3	42.3	43.7		39.9	33.9	31.8	37.4	40.7	42.4	45.0	41.6	41.6	43.6	39.2
OVB	32.8	36.4	33.0	33.1		38.0	48.4	45.5	43.2	38.2	29.7	32.6	35.9	37.1	35.3	37.4

- (1) F - Ft. Lewis
M - Merriam
P - P-99

(2) Unable to sustain pumping at total slurry recycle.

(3) Run performed at 400 psi higher pressure than all other runs.

(4) Robinson Run and Ireland Mine runs would be inoperable in the Demonstration Plant due to excessive solids content of the vacuum bottoms.

TABLE 2 - 5
 DATA ON "PANHANDLE AREA" PITT SEAM MINES
 WITH PRODUCTION EXCEEDING 100,000 TONS PER YEAR EACH.
 THESE MINES POTENTIALLY COULD SUPPLY THE TWO MILLION TONS PER YEAR OF COAL
 REQUIRED FOR THE SRC-II DEMONSTRATION PLANT
 (From Keystone Coal Industry Manual, 1978 Edition)

State	County	Company	Mine	Underground (U) or Strip (S)	Millions of Tons		Yrs. of Reserves at 1976 Production Rate	Present Method of Shipment
					Annual Capacity Based on 240 Days/Yr.	1976 Production		
W. Va.	Ohio	Valley Camp Coal Co.	No. 1	U	1.4	1.0	10 Est.	Barge, Rail (PC)
W. Va.	Ohio	Valley Camp Coal Co.	No. 3	U	0.9	0.5	50	Rail (B & O)
W. Va.	Marshall	Valley Camp Coal Co.	Alexander	U	0.7	0.4	10 Est.	Barge, Truck
W. Va.	Marshall	Consolidation Coal Co.	Ireland	U	3.2 Est.	1.8	40	Captive to Utility
W. Va.	Marshall	Consolidation Coal Co.	McElroy	U	3.1	1.2	40	Captive to Utility
W. Va.	Marshall	Consolidation Coal Co.	Shoemaker	U	3.2 Est.	1.6	40	Barge
Ohio	Belmont	No. American Coal Co.	Powhatan 1	U	1.6	1.1	25	Barge, Truck
Ohio	Belmont	No. American Coal Co.	Powhatan 3	U	1.6	1.2	25	Barge, Truck
Ohio	Belmont	No. American Coal Co.	Powhatan 5	U	1.1	0.8	8	Barge, Rail (PC)
Ohio	Belmont	NACCO Mining Co.	Powhatan 6	U	2.4	1.4	35	Rail, (PC)
Ohio	Belmont	Oglebay Norton Co.	Saginaw	U	1.1	0.7	25	Rail (N & W)
Ohio	Belmont	Y & O Coal Co.	Allison	U	2.4	0.7	30	Rail (PC)
Ohio	Jefferson	Zimnox Coal Co.	Salt Run	S	0.1	0.1	7	Truck
Ohio	Jefferson	Anthony Mining Co.	No. 43	S	0.3	0.2	6	Truck
Ohio	Jefferson	Boich Mining Co.	Betsy	S	0.6	0.3	10	Rail (N & W)
Ohio	Jefferson	Ohio Coal & Const. Co.	Nos. 36/37	S	0.2	0.2	5	Barge
Ohio	Jefferson	R & F Coal Co.	Rice 6	S	0.3	0.3	10	Rail
Ohio	Monroe	Quarto Mining Co.	Powhatan 4	U	1.8	1.2	30	Barge
Ohio	Monroe	Quarto Mining Co.	Powhatan 7	U	2.0	0.3	30	Barge
Ohio	Harrison	Bedway Coal Co.	Amber	S	0.3	0.3	15	Barge, Rail (N&W)
Ohio	Harrison	Consolidation Coal Co.	Bradford 16	S	0.6	0.4	10 Est.	Rail (PC, N & W)
Ohio	Harrison	Consolidation Coal Co.	Georgetown 24	S	1.4	0.9	10 Est.	Rail (PC, N & W)
Ohio	Harrison	Consolidation Coal Co.	Franklin 125	U	1.2	0.9	10 Est.	Rail (PC, N & W)
Ohio	Harrison	Consolidation Coal Co.	Franklin 65	U	0.3	0.3	10 Est.	Rail (PC, N & W)
TOTAL					31.8	17.8		

TABLE 2-6

PITTSBURGH SEAM RESERVE SUMMARY FOR
 "PANHANDLE AREA" (USBM 1C 8655, 1974)

<u>State</u>	<u>County</u>	<u>Reserves in Seams 42 Inches or More Thick, Millions of Tons</u>
West Virginia	Ohio (1)	273
West Virginia	Marshall (1)	1,925
Ohio	Belmont	1,906
Ohio	Harrison	190
Ohio	Jefferson	187
Ohio	Monroe	<u>344</u>
	Total	4,825

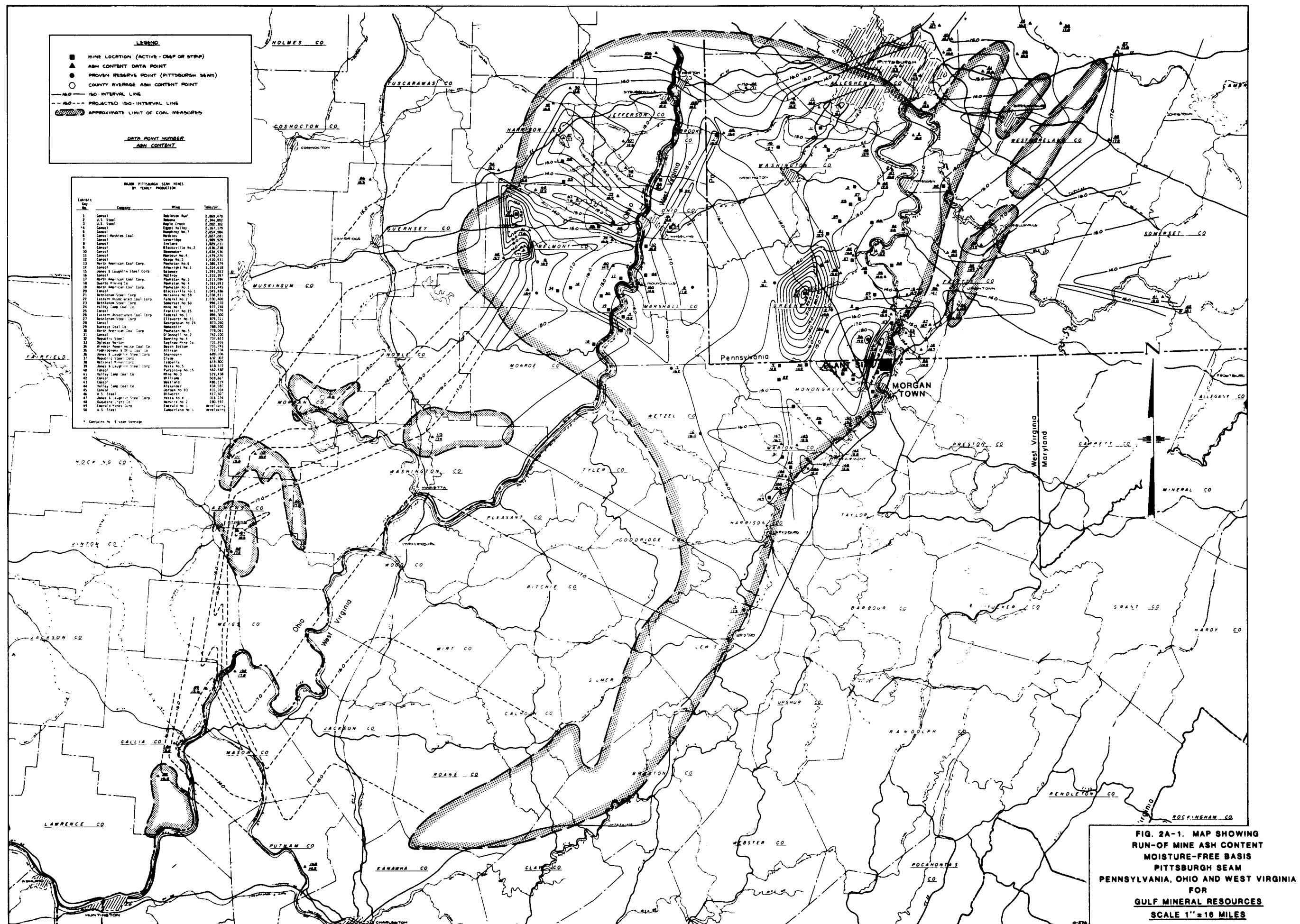
Note: Coal required for one 30,000 TPD Commercial SRC-II Plant,
 30 year life, equals 300 million tons.

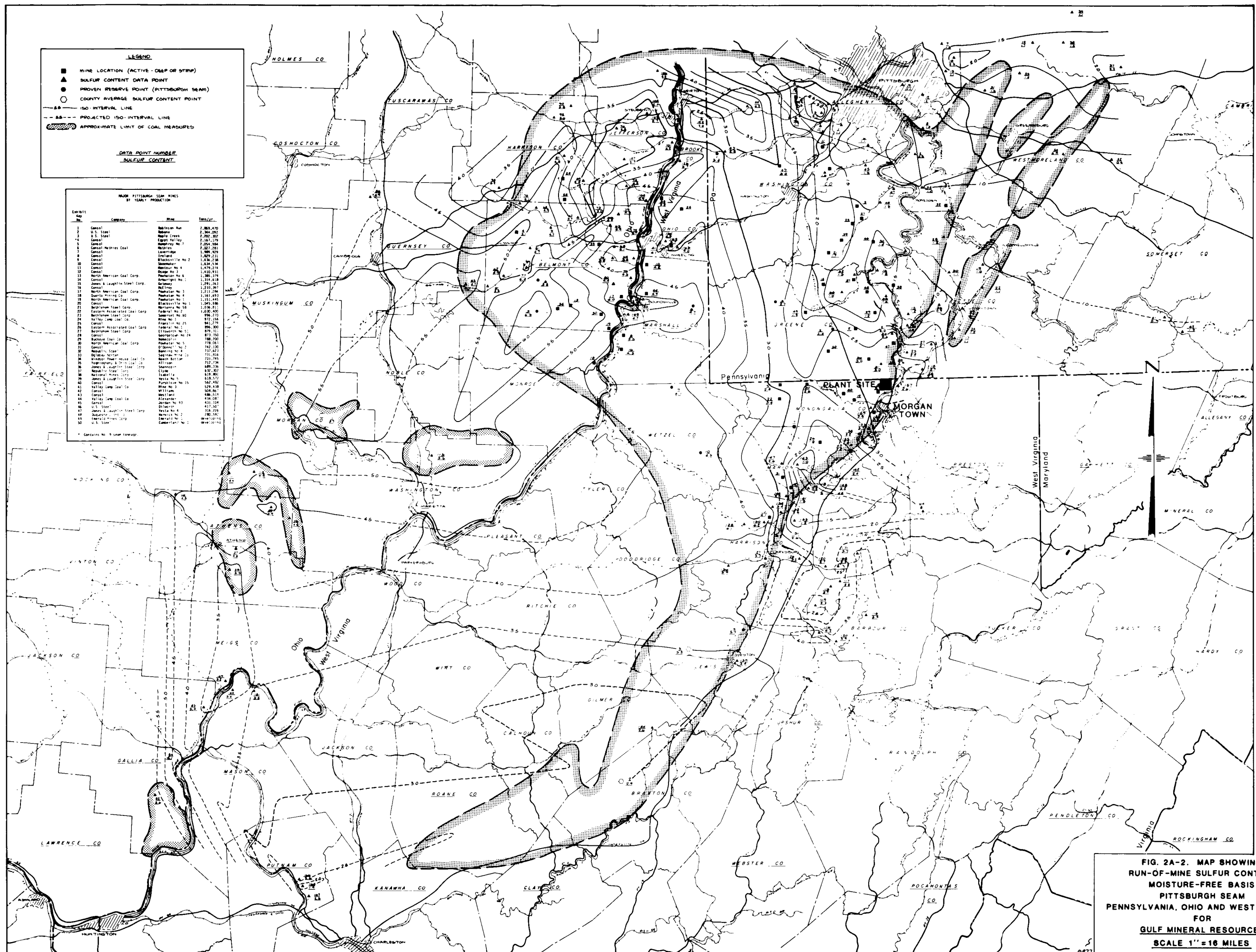
- (1) In general, the West Virginia coals tend to decrease in volatility, ash and total sulfur content south and south-east of the northwest panhandle area (Ohio and Marshall Counties.) This change in properties make these coals less desirable for feedstock to an SRC-II process. Based on information available at this time, it is estimated that another 4,000 million tons of reserves from various seams in Wetzel, Doddridge, Harrison, Gilmer, Braxton and Lewis Counties may be suitable for SRC-II processing. The total West Virginia reserves, all seams, is about 60,000 million tons.

APPENDIX 2A

ISO-INTERVAL MAPS FOR SEVERAL PROPERTIES OF THE PITTSBURGH SEAM OF COAL

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2A-1	Run-of-Mine Ash (MF basis).....	2A-2
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2A-7	Partially Washed Ash (MF basis).....	2A-8
2A-8	Partially Washed Sulfur (MF basis).....	2A-9





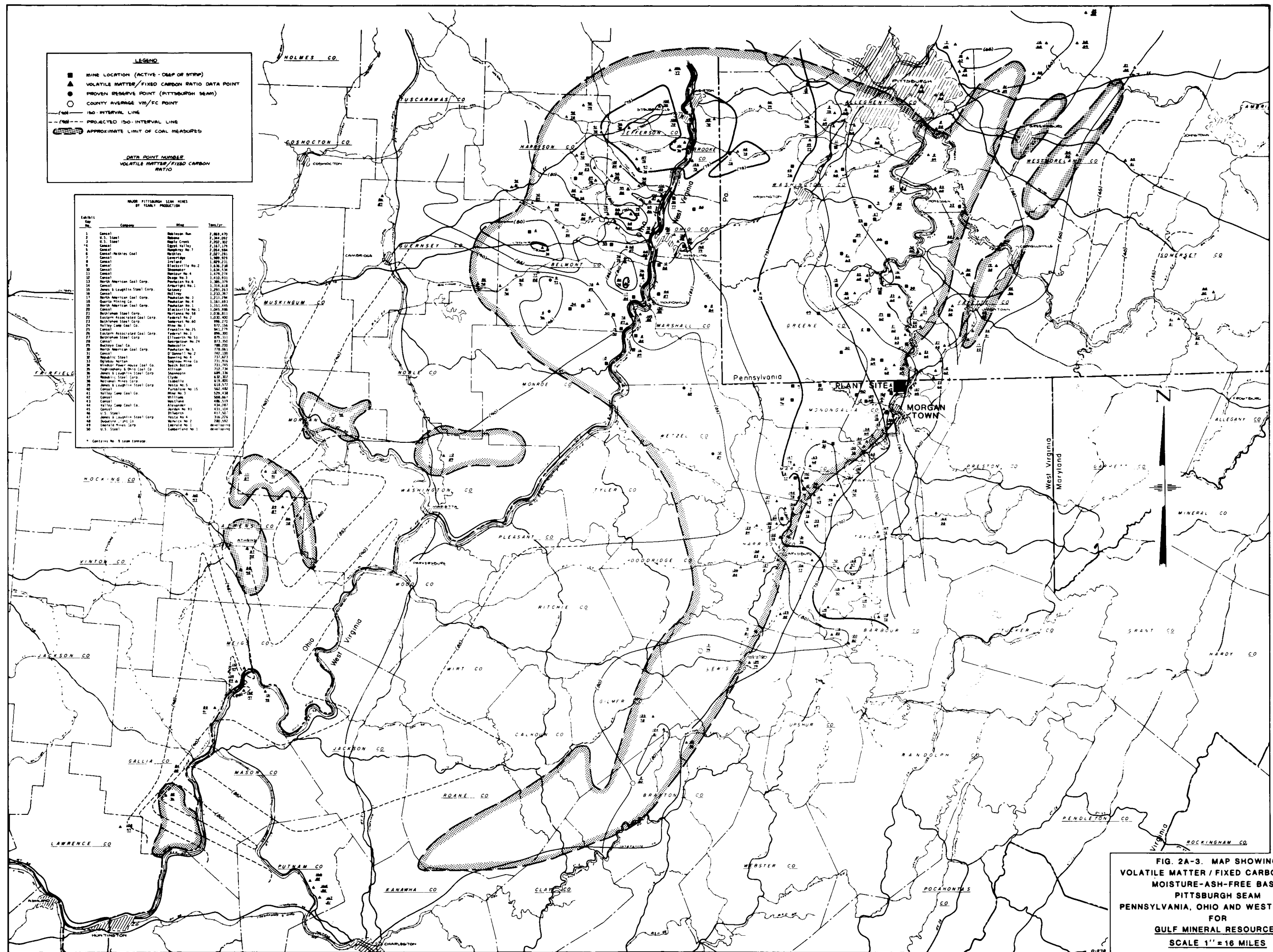


FIG. 2A-3. MAP SHOWING
VOLATILE MATTER / FIXED CARBON RATIO
MOISTURE-ASH-FREE BASIS
PITTSBURGH SEAM
PENNSYLVANIA, OHIO AND WEST VIRGINIA
FOR
GULF MINERAL RESOURCES
SCALE 1" = 16 MILES

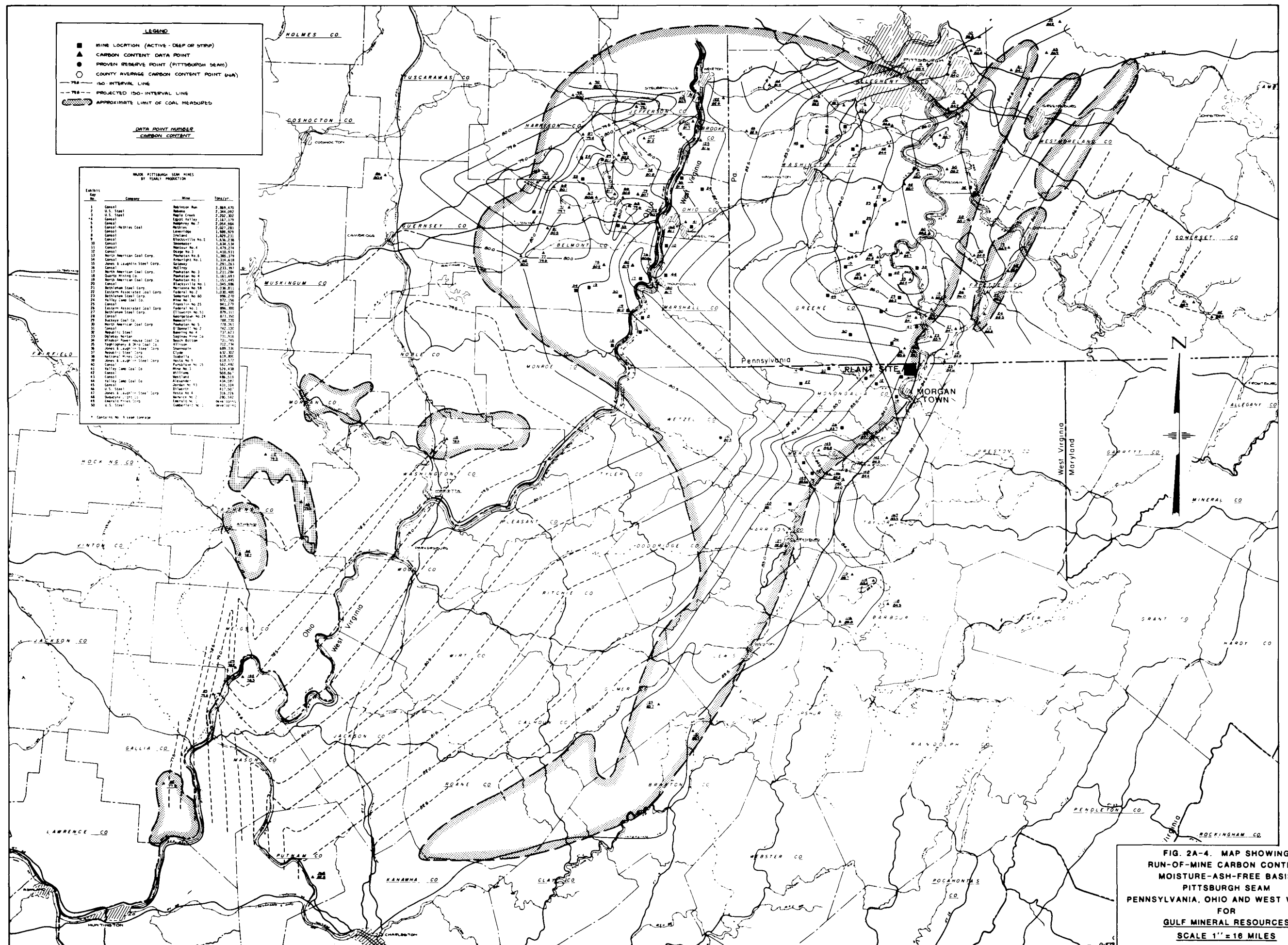
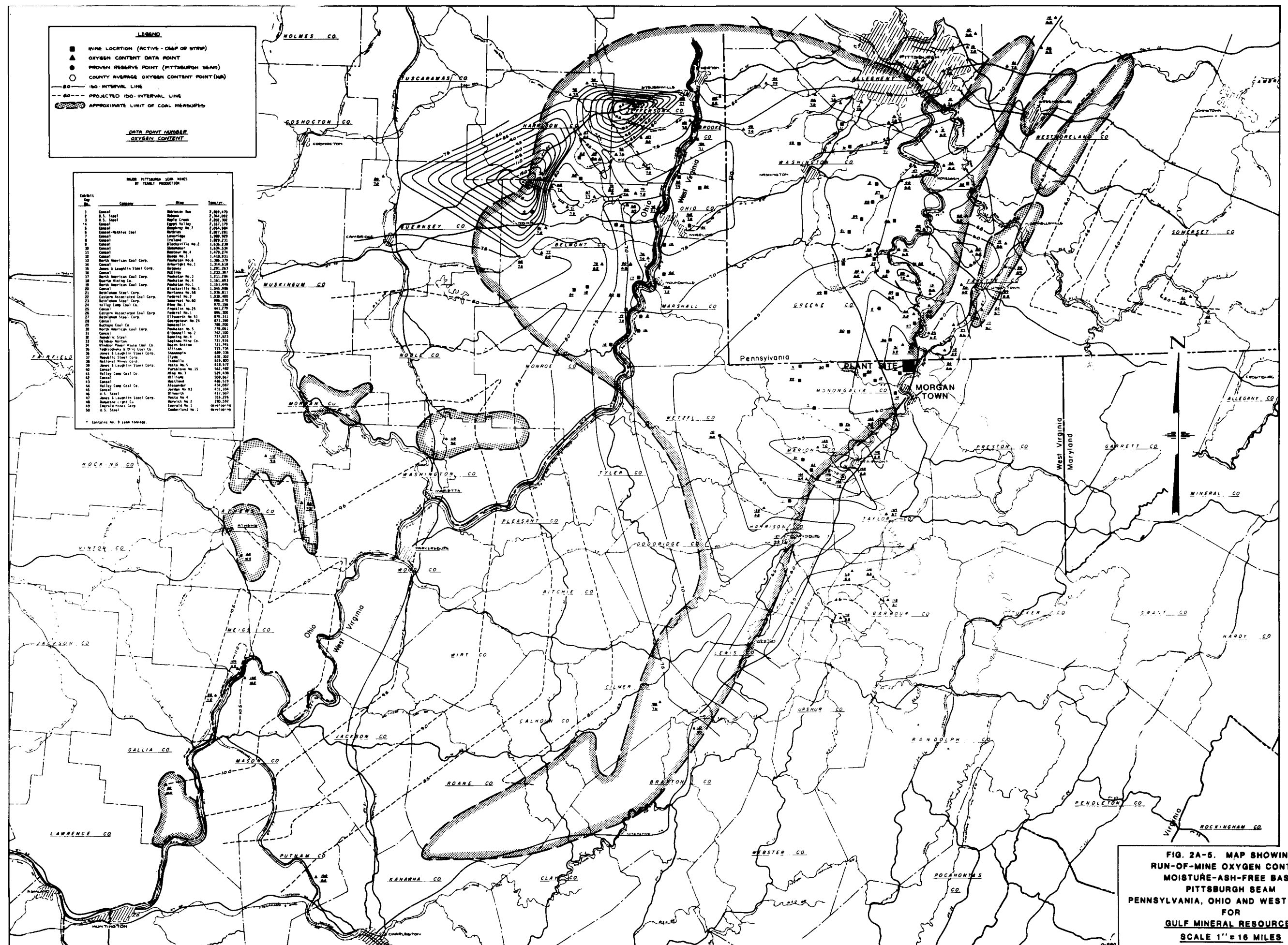


FIG. 2A-4. MAP SHOWING
RUN-OF-MINE CARBON CONTENT
MOISTURE-ASH-FREE BASIS
PITTSBURGH SEAM
PENNSYLVANIA, OHIO AND WEST VIRGINIA
FOR
GULF MINERAL RESOURCES
SCALE 1" = 16 MILES



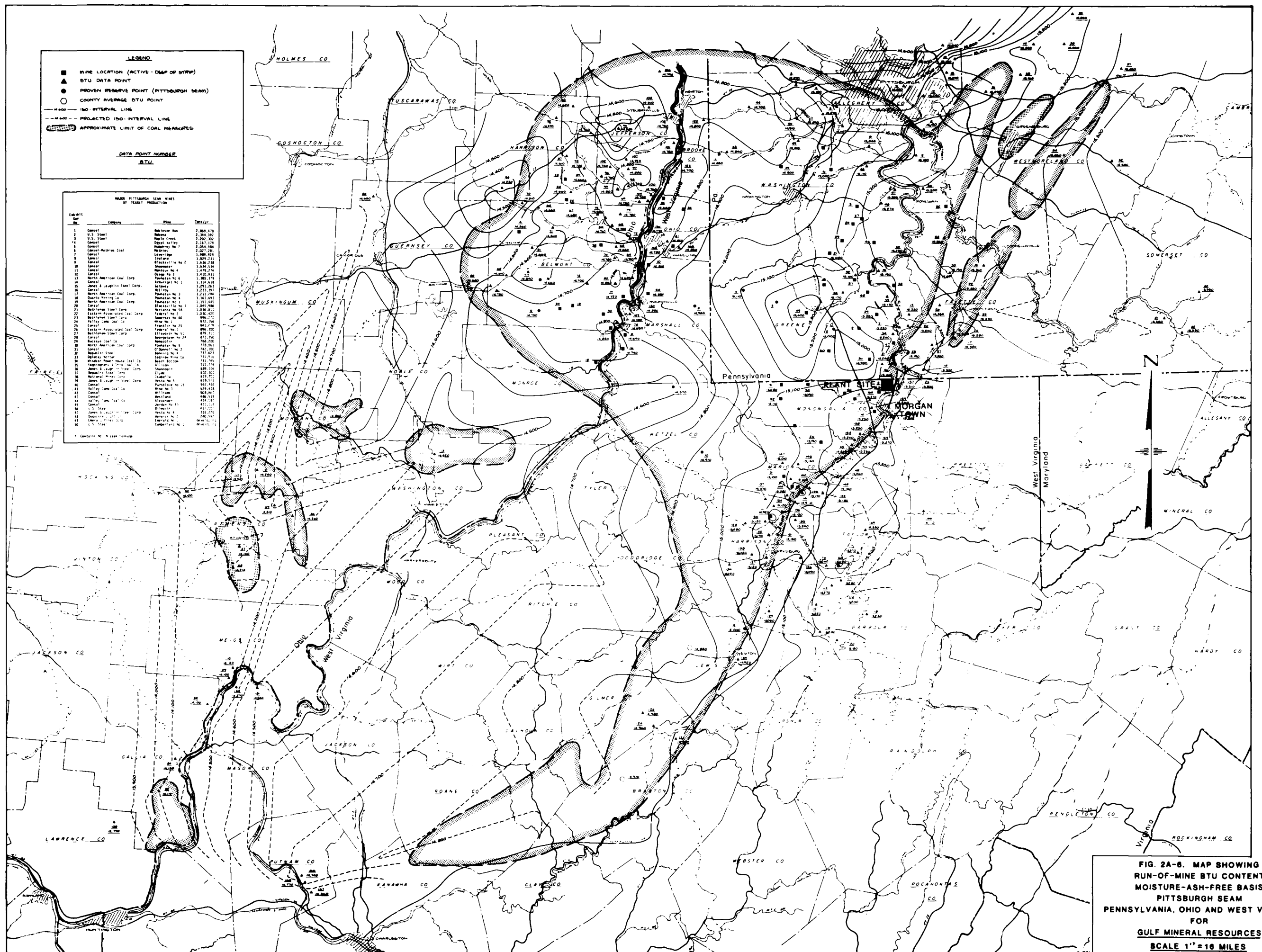


FIG. 2A-8. MAP SHOWING
RUN-OF-MINE BTU CONTENT
MOISTURE-ASH-FREE BASIS
PITTSBURGH SEAM
PENNSYLVANIA, OHIO AND WEST VIRGINIA
FOR
GULF MINERAL RESOURCES
SCALE 1"=16 MILES

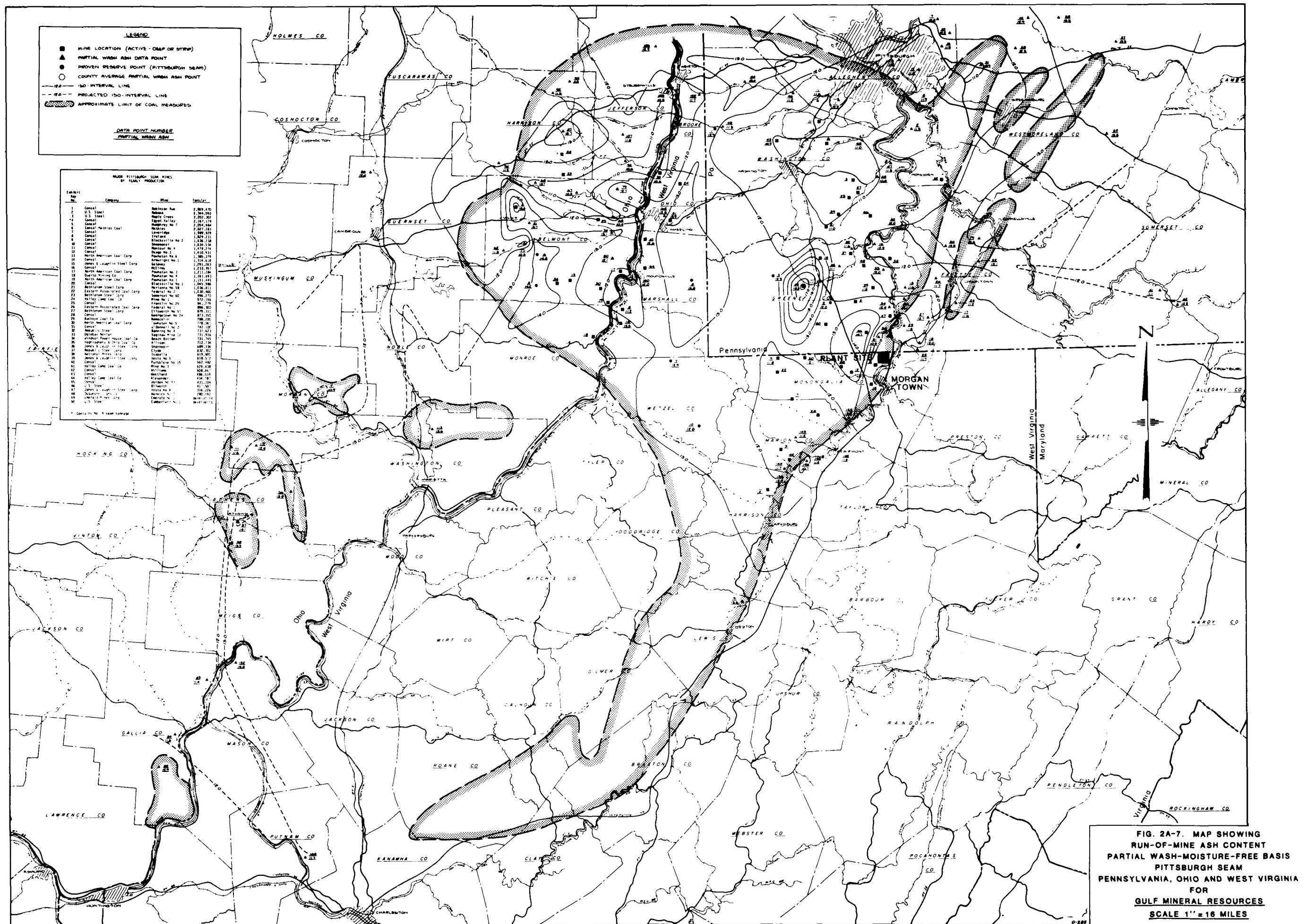


FIG. 2A-7. MAP SHOWING
RUN-OF-MINE ASH CONTENT
PARTIAL WASH-MOISTURE-FREE BASIS
PITTSBURGH SEAM
PENNSYLVANIA, OHIO AND WEST VIRGINIA
FOR
GULF MINERAL RESOURCES
SCALE 1" = 16 MILES

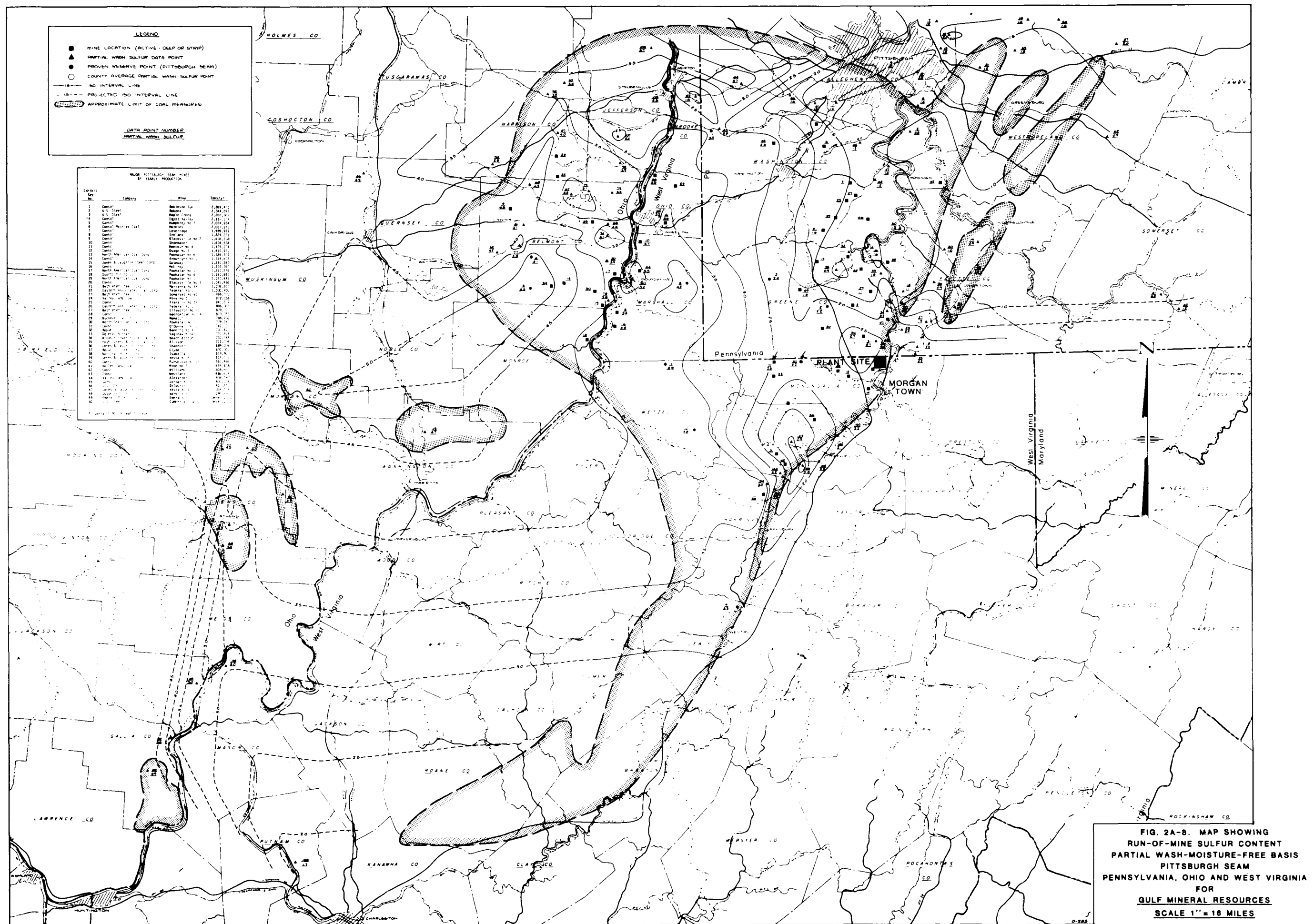


FIG. 2A-8. MAP SHOWING
RUN-OF-MINE SULFUR CONTENT
PARTIAL WASH-MOISTURE-FREE BASIS
PITTSBURGH SEAM
PENNSYLVANIA, OHIO AND WEST VIRGINIA
FOR
GULF MINERAL RESOURCES
SCALE 1"=16 MILES

SECTION 3

CRITICAL AREAS OF DESIGN

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SECTION 3

CRITICAL AREAS OF DESIGN

3.1 GENERAL - DEFINITION OF PROTOTYPE

Processes employed in the Demonstration Plant Design have been classified as prototype and thus by definition critical if they fall in one or more of the following definitions.

- (a) Never built before commercially,
- (b) Larger than built before commercially,
- (c) First time in this service commercially.

The areas have a wide range of degrees of criticality and are discussed as appropriate for each of the prototype processes and areas within the processes. These subjects include scaling factors, materials, planned redundancy, process control, maintenance consideration, reasonableness of extension of known art in design and selection of equipment, and future work required. Additionally, bridging task progress is discussed where applicable.

The above subjects normally are resolved during the definitive design stage of a project after the completion of the conceptual design. This project is no exception so these decisions will be made during Phase I.

3.2 SRC II PROCESS

3.2.1 Coal-Slurry Mixing

3.2.1.1 Phase Zero Design Basis

The original coal slurry mixing system design for the Demonstration Plant, as shown on drawing 11-06-101 in Deliverable No. 1 is based on a slurry eductor design. In this design, wet minus 1/8 inch coal is mixed with the recycle slurry in an eductor and the resulting slurry is discharged to a hold tank. This concept has been tested at the 30 tpd Fort Lewis SRC-II pilot plant; however, because of poor reliability, the system now serves only for backup.

3.2.1.2 Coal Slurry Mixing Problems

Pilot Plant process experience has demonstrated that coal slurry mixing is a difficult system to operate and control. Plugging has been the major cause of downtime with the slurry mixing system at the Fort Lewis Pilot Plant. The major causes of plugging may be categorized as follows:

- (a) Inadequate wetting of coal with slurry
- (b) Foaming and solids entrainment

(c) High slurry viscosity

(d) Feed control

Ground coal is not easily wetted by high boiling point slurries even if the slurry is forced to contact the coal particles. This phenomenon can lead to the formation of nonhomogeneous mixtures with partially wetted lumps of coal. When such conditions develop, plugging or loss of pump suction is likely to occur.

Foaming has been observed in pilot plant and laboratory tests when wet coal is mixed with the hot recycle slurry. When the moisture content is not excessive, the foam height becomes stable. Very high moisture content, however, can produce sufficient foam to overflow the charge tank. Solids carry-over is also expected to increase with high moisture content due to foaming and high vapor velocities. Testing is planned to quantify foaming conditions.

The viscosity behavior of coal slurries involves a complex mechanism which is dependent upon the coal slurry's characteristics, coal concentration, coal particle size, temperature, shear rate, and storage time. Measurements have shown that the coal slurry is a non-Newtonian, pseudo-plastic fluid. Because so many variables affect the coal slurry viscosity, correlations have been difficult to develop. No comprehensive viscosity model has yet been produced to describe the effect of all of the variables affecting the coal slurry viscosity.

3.2.1.3 Design Parameters

The design bases selected for the coal slurry mixing system largely determine the system design. A discussion of the primary design parameters follows.

Coal Size

Coal size preparation has a significant impact on the mix system design. Two cases are currently under consideration: pulverizing the coal to minus 200 mesh or grinding the coal to minus 20 mesh. From an equipment, cost, and horsepower requirement standpoint, the larger grind is preferable; however, there are other process considerations.

Pulverizing the coal to minus 200 mesh minimizes valve, pump and piping erosion and solids settling in slurry vessels, but it may limit the maximum mix tank temperature because of increased viscosity. The principal advantage of the larger coal feed is the probability of increasing the slurry mix tank

temperature, which improves the slurry mix system heat balance and decreases the required duty of the dissolver slurry preheater. Preliminary pilot plant work suggests that slurry erosion and solids settling may be increased when larger size coal is used.

Slurry Mix Tank Temperature

As described above, the slurry mix tank temperature impacts the design of the preheater, viscosity of slurry charge, slurry tank volume, and overall plant thermal efficiency. Tests at the pilot plants have been made at mix tank temperatures as high as 390 F, and tests at higher temperatures are planned. To control the mix tank temperature to an acceptable maximum, the recycle slurry temperature or the coal moisture content can be controlled.

Experimental measurements of the recycle slurry viscosity have shown that cooling below approximately 500 F requires an unreasonable recycle slurry heat exchanger design because of low heat transfer coefficients. Pilot plant experience also suggests that cooling the potentially viscous recycle slurry should be minimized to avoid plugging.

Design study calculations indicate that with coal moisture contents between 5-10% it may be possible to eliminate the requirement for cooling recycle slurry. Feeding moist coal complicates coal grinding and injection into the coal slurry mixing equipment. Higher moisture levels also increase plugging of conveying equipment, foaming, entrainment, and oil-water separation problems.

The Demonstration Plant design is based upon 5 weight percent moisture content in the coal feed to the plant. Up to 15 weight percent moisture can be present in the coal from the storage pile. Handling of the finely ground coal feed requires that the moisture content be controlled to less than 3-5 weight percent. Therefore, a drying system was added as part of Design Revision 2, described in Section 6 of Deliverable No. 1. The dried coal necessarily is heated requiring the slurry recycle temperature to be reduced for a given slurry mix tank temperature.

Because the slurry charge tank will be operated at relatively high temperatures, some vapor and light solvent will evolve. The amount of hydrocarbon vapor released will depend on the recycle slurry composition, coal moisture content, blending temperature, and operating pressure. Designing the system for pressures above atmospheric will limit the amount of vapor flashed and prevent the possibility of forming explosive mixtures of hydrocarbon vapor and air. An elevated pressure design could decrease vapor velocities and entrainment, reduce foam height, and eliminate the need for an overhead compressor to vent the mix system vapors. The principal disadvantage of an elevated pressure design is the need for injecting coal against a static pressure head.

Operating history at the Fort Lewis Pilot Plant has shown that preventing the mix tank vapors from contacting the incoming coal has significantly reduced frequency of plugging in this area. In order to minimize this contact, the system has been operated at subatmospheric pressures.

3.2.2 Slurry Flow Measurement

3.2.2.1 Importance

The control of the SRC-II Process is directly related to the ability to measure flows of coal feed and recycle slurry. Proven methods to measure the coal feed rate will be employed. The recycle slurry flow measurement must be reproducible for control even if flow accuracy cannot be attained. Design of a slurry charge preheater is very significantly affected if the liquid flow to each pass cannot be measured. This impact has reached the point where a one pump per heater pass is now the design basis in the Bridging Task Studies. The design expressed in the Demonstration Plant Description (Deliverable No. 1) presumes that slurry flows can be measured. However, until recently, slurry flow measurement devices at Ft. Lewis have not been satisfactory.

3.2.2.2 Improved Slurry Flow Measurement at Ft. Lewis

As a result of improvements made to the flush solvent system, a quadrant-edged orifice meter now has proven to be more reliable than the use of positive displacement charge pump capacity. Control of the pilot plant feed slurry composition now is based upon the slurry flowmeter reading rather than the pump indication of flow. In addition, a recent calibration of the flowmeter indicates a measured coefficient within two percent of the theoretical coefficient. No effect of erosion or corrosion has been noted on the Stellite orifice plate. However some erosion has occurred in the piping both upstream and downstream of the orifice plate.

3.2.2.3 Future Work

A meter test stand has been designed and will be ready for service at Ft. Lewis by the end of 1979. Several primary element flow sensing devices will be placed in series so that each will sense the same calibrated flow. Included initially will be the quadrant-edged orifice plate, elbow taps, thermal probe, Taylor Wedge and others.

Work has been proposed by Argonne National Laboratory utilizing advanced acoustical techniques.

3.2.3 Preheater Heat Transfer And Pressure Drop

3.2.3.1 Introduction

The slurry preheaters required in the operation of the SRC-II Demonstration Plant are extremely difficult to design. Heat transfer and pressure drop considerations must be based on very limited, indirectly obtained physical properties data. These process stream data are difficult to develop due to the nature of the gas-liquids-solids multiphase flow system.

The solvation of coal produces a highly viscous, non-Newtonian slurry which, under certain conditions, causes high pressure drops, low heat transfer rates, and possible coke formation and plugging. The viscosity of the system is greatly affected by fluid shear rate. In addition to the shear rate viscosity dependence, the slurry viscosity is also affected by the coal properties, coal-solvent-recycle slurry concentrations, slurry and gas velocities and temperature.

In time and at higher temperatures, the gel-structure of the coal slurry system breaks open. Following this solution process, the slurry viscosity rapidly decreases. Some reaction products are also released and a complex multiphase gas-liquids-solids system is evolved.

3.2.3.2 Pilot Plant Experience

Slurry preheater operations at the Ft. Lewis Pilot Plant have been very successful; however, the preheater operates at very conservative conditions. During SRC-II operation, pressure losses across the preheater coil typically average 75 to 125 psi; however, pressure drops as low as 25 psi and as high as 200 psi have been experienced. This variation in preheater pressure drop is a result of widely varying operating conditions. No significant coke has ever been found in the Ft. Lewis preheater, even during periods of unstable operation.

3.2.3.3 Design Considerations and Testing

The coal-oil slurry preheater at the Ft. Lewis Pilot Plant cannot be used directly to provide a basis for scale-up of the Demonstration Plant. It is so oversized in length and diameter that pertinent design data cannot be obtained. Process limitations keep both heat input rates and flow rates too low to meet Demonstration Plant preheater design conditions. Heat flux rates are less than 5000 Btu/hr-sq ft and flow velocities are less than 3 to 4 ft/sec. The design heat flux rates and flow velocities of the Demonstration Plant preheater will be 2 to 4 times as great as those in the pilot plant preheater.

These increased process conditions were necessary to limit the large physical size of the Demonstration Plant preheater and preheater tubes. Because the preheater has been designed for considerably different conditions, data from the existing pilot plant preheater concerning pressure drop, erosion, and coking is not directly applicable.

The Demonstration Plant preheater flow velocities were set to produce a bubble flow regime in order to provide excellent heat transfer, reduce pressure drops, minimize coking, and prevent unstable slugging flow patterns from developing.

3.2.3.4 Future Experimental Testing

Two new, smaller, coal-oil slurry preheater coils have been procured for installation in a separate new furnace at the Ft. Lewis SRC Pilot Plant. They have been dimensionally sized to give reasonably satisfactory heat flux, flow rate, and flow regime relationships to the Demonstration Plant coal-oil slurry preheater. Also, a greater number of temperature and differential pressure readings will be available with the new preheater to improve data evaluation.

Concurrently, Gulf Science and Technology is generating design methods and models for the slurry heater design. This work employs a fundamental approach augmented by available technical literature, information from DOE, and industry-sponsored study programs on multiphase flow. A systematic program of operation of the new slurry preheater coils at the Ft. Lewis SRC Pilot Plant will produce data at Demonstration Plant design conditions. The results obtained will be used to confirm or provide modifications to the Gulf Science and Technology models for predicting heat transfer and pressure drop information. Thus, it is anticipated that a reliable basis for scaling up the design for the Demonstration Plant slurry preheater will be available. The above testing and design model will provide a better basis for evaluation and selection of the most competent heater design vendor for the Demonstration Plant coal-oil slurry preheater.

3.2.4 Dissolver Reaction Kinetics

In an effort to better understand the SRC process, most of the available data on the processing of Kentucky coal from Ft. Lewis, P-99, Merriam, and the Hydrocarbon Research Institute were fed into a computer data bank (both SRC-I and SRC-II). The results and run conditions from these 72 runs were converted into a common form.

Multi-linear regression analysis was employed and each response was initially fitted to all six of the independent variables (temperature, pressure, slurry residence time, percent coal in feed, percent recycle SRC in feed, and percent recycle ash in the slurry feed).

Following the backward elimination method, coefficients were eliminated one at a time by means of a t-test at the 95% confidence level. The resulting product linear regression models were utilized to analyze the data. No apparent difference in scale showed over the data from three pilot plants (0.01, 1/2, and 30 tons/day). The differences between SRC-I and II yields appear to be that of operating level for the key independent variables.

A more comprehensive model was then developed and includes an extensive kinetics treatment consistent with the available data and is coupled with the hydrodynamic effects of a three-phase upflow fluidized bed reactor. As a result of computer simulations, the model has the capability of providing important impacts on the scale-up to commercial-sized reactors, the development of reactor performance information, the understanding of the coal liquefaction process, and the optimization of the operating conditions for the reactor system.

The comprehensive reactor model has been generated to consider the effects of variations in holdups of three phases as a function of reactor length, differences in backmixing of the three phases, and complex reaction mechanisms for the liquefaction process. This model provides a reasonable simulation method by which actual data can be extended to represent the behavior of larger reactors and predict the reactor performance both outside and within the data base. In addition to incorporating the primary reaction variables, the model also includes scale-up variables such as gas and slurry velocities and reactor dimensions.

Results from the simulation model do not indicate that any significant yield differences are expected with the demonstration plant dissolvers. Preliminary results show that the gas holdup volume may change by approximately 10%. Backmixing behavior of the gas and slurry phases is not predicted to change as a result of scale-up. As a means of testing the model predictions, pilot plant tests are planned to study the effects of different dissolver configurations.

Gulf has gained considerable experience with scaling various processes from the pilot plant scale to commercial size. Previous scale-ups have been successfully completed and are discussed in Section 8.9 of this report.

3.2.5 High Temperature Coking

3.2.5.1 Summary

High temperature coking of coal-oil slurry mixtures and internal process streams normally formed during the hydro-liquefaction of coal is a potential concern for all coal liquefaction processes. Experience from the Ft. Lewis SRC Pilot Plant, GS&TC's P-99 SRC-II Pilot Plant Unit and the Merriam Pilot Unit has illustrated that malfunctioning equipment or lack of good continuous flow control of process streams can lead to errant temperature control with resultant coking tendencies. Without proper design and control, stagnant zones can develop that in time can cause accumulation of solids with resultant aging-coking reactions taking place.

Coal slurry preheater and high temperature separator operations at each of the pilot units have, nevertheless, been very successful with essentially no coking or plugging being encountered during normal pilot plant process operations. At the Ft. Lewis Pilot Plant no significant coking or plugging of the dissolver preheater has ever been experienced even during major upset conditions. This is an excellent record, particularly considering the relatively large variations in slurry and gas flow rates, coal concentrations, and heater outlet temperatures which have been run.

3.2.5.2 Dissolver Preheater

The preheater coil installed at the Ft. Lewis Pilot Plant is upflow, helical, and radiantly fired. The over-sized tube, approximately 2.6 inches inside diameter, causes the superficial slurry velocities to be much lower than the Demonstration Plant design. The heater outlet temperature is normally controlled between 740 F and 790 F, with some operation as low as 725 F and as high as 800 F. The preheater appears to operate in the plug flow regime.

To facilitate stable operation and to avoid coking, relatively high volumes of gas to slurry are circulated through the Ft. Lewis preheater coil. Again, because of the tube size, the heat flux rates are low, approximately 5000 Btu/hr/ft² and the tube wall temperatures are low, approximately 800 to 850 F. Even at these low slurry velocities, and occasional high temperatures, no coking has been found.

In contrast, the Demonstration Plant slurry preheater will have much higher heat flux rates and tube wall temperatures. The process stream flow temperature, however, should be less than the normal operating temperature at the Ft. Lewis Pilot Plant. Additionally, greater turbulence and a more desirable bubble flow regime are expected despite bypassing most of the hydrogen around the heater. In this respect, provisions will be made for positive control of both coal-oil slurry and hydrogen gas flows to each pass in the heater. Thus, some compensating and favorable considerations can be included in the design of the Demonstration Plant slurry preheater.

The complex multiphase flow characteristics of the coal-oil slurry-gas mixture are further complicated by a transient Newtonian/non-Newtonian flow phenomenon caused by a coal solution-gelling action. Because of these factors, it is very difficult to reliably calculate process stream temperatures throughout the length of the heater tubes and the pressure drop required for slurry preheater design.

A considerable amount of effort has been spent in endeavors to determine the various factors influencing flow regime in order to correlate operations within slurry heaters. Currently, a new slurry preheater with extensive instrumentation has been designed for installation and testing at the Ft. Lewis SRC Pilot Plant. This new heater has been designed to simulate gas and slurry velocities, heat fluxes, and outlet temperatures predicted for the Demonstration Plant preheater.

Systematic studies will be made and evaluated against heat transfer and fundamental fluid flow models that were developed by GS&TC. The results of such work are expected to provide a means to properly design a coal-oil

slurry-gas heater with a reliable scale-up capacity. Additionally, GS&TC's participation in other DOE-sponsored coal liquefaction preheater studies is expected to further develop and define a better understanding of coking actions in slurry preheaters.

On-stream operation requirements are being studied intensively for the Demonstration Plant design and will be specially considered for normal, start-up, and shutdown conditions. Protection of the slurry preheater against sudden loss of the coal-oil slurry feed with accompanying potential overheating, tube failure, or coking in the heater tubes must be provided. In this respect, an emergency heavy oil high pressure flush pump system is to be provided to flood the heater tubes with oil. This will assure a means to reduce process tube wall temperatures along with the furnace's residual heat capacity to a proven noncoking temperature range of less than 650 F. Further experimental studies are planned by GS&TC to obtain reliable supporting coking temperature information in this respect as well as for other operating areas.

3.2.5.3 Dissolver

Dissolver operations at Ft. Lewis and Harmarville have been free of serious high temperature coking tendencies with the temperature ≤ 860 F and hydrogen partial pressure ranges ≤ 1250 psi that have been used in the majority of SRC-II studies. Experience has shown that the dissolver should have a conical design bottom; otherwise, a coke deposit develops, forming its own cone. Although an equilibrated coke deposit about 1/16 to 1/4 inch thick has accumulated on the wall of the dissolver, this has not caused further operating problems at Ft. Lewis.

The Demonstration Plant operating conditions will conform to proven criteria. Hydrogen quench will be provided to control reaction temperature and hydrogen purity will be controlled to maintain the required hydrogen partial pressure in the dissolver effluent. However, the fluid hydrodynamics of the contained gas-liquid-solids system in the Demonstration Plant may be different from those experienced at the pilot plants.

In order to predict the nature of the fluid hydrodynamics developed in the Demonstration Plant's very large-size dissolver compared to the small-size dissolvers used at Ft. Lewis and Harmarville pilot units, a fundamental approach is being used. Intensive efforts have been made to search and evaluate the technical literature in these areas of concern and to participate in cooperative industry-sponsored multiphase flow programs. Relationships of specific physical properties of the complex gas-liquids-solids system to vessel dimensional size, configuration, and quantitative flow volumes are used to generate gas, liquid, and solids volumetric holdups. This work indicates that a well-mixed system exists in the Demonstration Plant dissolver at the design operating conditions. As such, a stabilized operation should be expected without formation of stagnant zones subject to coking. However, scaleup is often most difficult when degree of mixing is critical.

3.2.6 Water Wash To Avoid Salt Deposits

The effluent vapors from the Dissolver Effluent Separator (V11.104, Drawing 11G06-101, Deliverable No. 1) are cooled both by steam generation and exchange with recycle hydrogen. The temperature level to which the vapors are cooled is limited by the deposition of salts on the heat exchanger surface from the vapors as they are cooled. Deposited salts reduce heat exchange, increase pressure drop, lead to plugging, and cause corrosion. This problem is critical because of the serious consequences of plugging and/or corrosion.

3.2.6.1 Similarity To Other Processes

Salt deposition similar to that described above is commonly known and resolved in several petroleum refining processes. In crude unit distillation column overhead condensers, salts will deposit at a higher temperature than the point

where the stripping steam will condense. The problem usually is solved by a water circulation system that washes salts continuously from the heat exchanger surface. A purge system prevents the buildup of salts in the circulating water.

Somewhat similar systems of water washing are utilized routinely in both Hydrocracking and Hydrodesulfurization processes. The temperature where salts deposit varies with physical and chemical conditions of the process.

3.2.6.2 Identification Of Problem

Salt deposition has been observed at the P-99 SRC-II pilot plant of Gulf Science and Technology Company located in Harmarville, PA. The temperature range where the salts have been observed to deposit is 550 to 600 F. Since heat recovery is limited by this temperature, process steps must be employed to remove the salts before additional heat can be recovered. Because this temperature has a substantial impact on the heat recovery system of the Demonstration Plant, proper specification of the maximum temperature of salt formation is essential.

Salt deposition has not occurred at the Ft. Lewis Pilot Plant because the dissolver effluent is directly quenched with water. The large quantities of quench water apparently solvate the salts and prevent salt deposition. The penalty for such a direct quench system is considerable loss in heat recovery and thermal efficiency; therefore it is not a part of the Demonstration Plant design.

3.2.6.3 Water Wash Facilities At P-99 Pilot Plant

A new separator and attendant water wash equipment have been installed at the P-99 pilot plant and have been in operation since February 1979. This equipment was installed specifically to obtain design information for the Demonstration Plant and is similar to the design shown in Deliverable No. 1, Demonstration Plant Description (Drawing 11G06-102, V11.106).

The process objective of the new separator at P-99 has been to quench the reactor effluent separator gas with a sufficient quantity of water to remove salts in the condensing water phase and saturate the gas with water vapor to prevent downstream salt deposition. Operation of the new separator and water wash system has been satisfactory to date.

3.2.6.4 Critical Concerns

Scale-up of the water wash system from the P-99 pilot unit is regarded as conventional since many similar scale-ups have been successfully accomplished in the petroleum industry. The P-99 pilot unit will be used to determine the salt deposition temperatures, water washing rates, sour water analyses and corrosion rate. These data will provide the basis for the design of the high pressure water wash system of the Demonstration Plant.

In addition to proving the process design for the water wash system, the P-99 pilot unit will be used to specify the materials of construction. Concerns regarding materials of construction prompted installation of corrosion coupons in the P-99 pilot unit. Data from these test coupons will be used to specify the vessel and piping metallurgy.

Oil-water emulsion formations resulting from pressure letdown of the liquid from this separator are being studied. Data from the P-99 pilot unit indicated that a stable emulsion does not form and that the oil-water separation can be accomplished with conventional equipment.

3.2.7 Ammonia Wash System

3.2.7.1 Introduction

The dissolver effluent is separated into a vapor stream and a slurry stream in the Dissolver Effluent Separator. The vapor stream is cooled and partially condensed by generating steam, preheating hydrogen-rich reaction gas, preheating boiler feed-water, aerial cooling, and finally cooling water. Included in this cooling scheme are two stages of direct contact water wash.

The purpose of the first water wash is to remove inorganic salts, primarily NH_4Cl . (This problem is discussed in detail in Section 3.2.6.) The primary purpose of the second wash is to reduce the ammonia content of the gas to less than 100 ppm. An additional purpose is to remove water soluble coal chemicals which are produced in the dissolver reactions. Both of these steps are part of the pretreatment process to protect the cold box (in the Cryogenic Unit) from freeze-up.

3.2.7.2 Scale-Up Factors

Scale-up of this system will not be a problem once an adequate prediction method is available for design. Sizing will require no new tools and in fact will be based upon standard vapor/liquid separation techniques.

3.2.7.3 Materials of Construction

Materials of construction should be primarily carbon steel. Experience at Ft. Lewis has shown that corrosion is less than 1 mil per year using carbon steel. However, the system at Ft. Lewis is not completely analogous to the Demonstration Plant in this area and selection of carbon steel requires further consideration.

3.2.7.4 Process Control

No major problems are anticipated for this area.

3.2.7.5 Maintenance Considerations

Due to the standard nature of this unit operation and relative isolation from potential upset causing systems, on-stream capability should be higher than much of the dissolver plant. However, the system will need to be designed with substantial priority placed on reliability due to the major potential impact any upset would ultimately have on the cold box.

3.2.7.6 Extention of Known Art

Ammonia is water scrubbed from the dissolver recycle gas at temperatures between 150 F and 400 F and a pressure of 2000 psia. This separation is a function of vapor/liquid equilibrium and of chemical reaction equilibrium. Thus to predict from theory the separation occurring in this step, data is required for both these phenomena. This prediction is significantly complicated by the presence of other water soluble compounds including hydrogen sulfide, carbon dioxide and water soluble coal chemicals such as phenol.

Currently available prediction tools for such sour gas and water systems are limited to less severe conditions than are present in the dissolver. These prediction tools have been developed for refinery sour water stripper applications, and are thus limited to lower pressures and temperatures and also to dilute solutions. No consideration has been made of rigorously accounting for materials such as phenol.

3.2.7.7 Bridging Study Progress

The general approach taken has been to develop the existing theoretically sound prediction tools for refinery sour water stripper conditions to dissolver plant conditions. A computer program available from the Chemical Engineering Department of the University of California, has been used as the basis for this work. This program has been developed from experimental data taken under the following maximum conditions.

Temperature	340 F
Pressure	200 psia
Liquid Ionic Molality	6

Close coordination is necessary with the Harmarville P-99 Plant to ensure data is available to input to and test the various phases of this work. Before the program can be accepted as a prediction tool, it will be necessary to run a series of tests on it to cross check it against data from the P-99 Plant. To minimize experimental error, great care will be needed to ensure that the analytical methods used on the P-99 Plant are representative and accurate.

3.2.8 Coal Chemicals Equilibrium

Coal chemicals equilibrium data are needed in both the primary high pressure process and the low pressure gas treating area where gas-liquid flash separation and distillation or absorption/stripping operations are being used. The present concern with coal chemicals is to understand enough about them to prevent problems that are caused by even trace quantities of certain coal chemicals in hydrogen purification and/or deethanizer operations. Their presence in sufficient quantity could cause bad foaming in DEA acid gas removal, serious fouling of molecular sieves, and possible freezing with subsequent plugging of cryogenic equipment during purification of recycle hydrogen. In another area, similar type problems could occur in amine treating, water removal, and low-temperature deethanizer operations. Such problems must be avoided in order to help achieve good operation of the Demonstration Plant.

While coal chemicals are not being considered for separate recovery as special products, their presence and distribution between naphtha (boiling range C_5 -350 F) and fuel oil (boiling range 350 to 900 F) should be established. The naphtha produced in SRC operations is very unstable and sour due to its unsaturated character and its sulfur, oxygen, and nitrogen-containing compounds. Provisions are made for hydrotreating the naphtha so as to reduce its sulfur content and to stabilize it moderately against oxidation and/or gum formation.

Such a treatment can be varied considerably. With minimal treatment, a naphtha product suitable only as a raw fuel can be produced. Using a severe treatment and consuming considerably more hydrogen, a preferred charge stock suitable for production of high octane gasoline can be obtained. As such, that gasoline would contain a considerable quantity of aromatics, principally benzene and toluene. Heavier aromatics and other coal chemicals are considered to be part of the fuel oil product. Thus, SRC products may be considered as a potential source of many coal chemicals in the future.

Experimental and analytical work is being conducted at GS&TC to develop some coal chemical equilibrium data. Selected process stream samples are being taken from the P-99 pilot unit. Although the sample areas do not correspond fully with Demonstration Plant conditions, the specially collected samples are considered similar to those desired. As such, intensive analytical work is underway to characterize olefinic, mercaptan, sulfide, phenolic, and nitrogen-containing compounds in a quantitative sense. Information thus obtained will be combined with the correspondingly appropriate P-99 pilot unit data to develop some limited coal chemicals equilibrium data. These data will then be compared against those projected by specialized computer programs for chemicals, such as CHEMSHARE. Assuming a good fit is obtained, this would substantiate further use of the CHEMSHARE program as a valid method in Demonstration Plant design calculations.

3.2.9.2 Scaling Factors

Problems exist in trying to scale up the Ft. Lewis Pilot Plant letdown equipment to Demonstration Plant size. Trim breakage on letdown control valves in the Pilot Plant is due to the small size (envision a pencil point in

a 1/4-inch diameter orifice). Larger valve and trim sizes required for the Demonstration Plant should minimize the particular trim breakage seen at Ft. Lewis. The letdown separator vessels at Ft. Lewis are very conservatively oversized for the amount of flashing present. The initial sizing of the letdown valves may not provide optimum valve life because of the large scaleup from Ft. Lewis. It may be necessary to change trim size after an initial operating period. The separator vessels can be sized less conservatively than those at Ft. Lewis and still provide acceptable gas-liquid separation. Operation on a larger scale than Ft. Lewis is the only way to prove the letdown system design.

3.2.9.3 Materials

Materials selection for the slurry pressure letdown system is designed for hydrogen partial pressure, corrosion, and erosion considerations. Type 321 SS has been selected for all parts of the system in contact with the process except for the high velocity erosive areas. This selection has been made to protect against sulfiding attack where erosion is not expected. The nozzles downstream of the letdown control valve will be tungsten carbide lined. Valve bodies will be stainless steel with trim and liners made of low binder content tungsten carbide. Letdown separator vessels will have plate and forgings of 2-1/4 Cr-1Mo to withstand hydrogen partial pressure. Vessels will be lined with 1/4 inch of 347 SS weld overlay due to corrosion considerations. Vessels internals will be 321 SS.

3.2.9.4 Planned Redundancy

Parallel letdown valve flowlines to each letdown stage are provided to ensure a one-year service life before letdown system maintenance is required. Two or three parallel flowlines are under consideration. The increased complexity for required piping, valves, and flush oil may make three flowlines impractical. Dual level control instrumentation will be provided on each separator vessel and provisions for switching from the operating to the standby level control instrumentation automatically and remotely is under

consideration. At present the use of null back pressure protection devices on each separator vessel which are sized for fire only are being considered. Each letdown separator in this case would be designed for shutoff pressures; i.e., high pressure separator pressure.

3.2.9.5 Process Control

Level control instrumentation will be redundant, i.e., a backup of either identical or different instrumentation for level control is provided. Level control instrumentation being considered is purged leg DP cells, nuclear, and capacitance probes.

3.2.9.6 Maintenance Considerations

Due to safety considerations for the high pressure hydrogen rich process fluids being handled in the letdown system, no on-line valve or system maintenance is being considered. Since total train flow is normally through only one parallel valve flowline, two block valves upstream of the control valve are provided in the design in order to isolate each parallel letdown valve service. The farthest upstream block valve is a sacrificial block and suffers wire drawing upon closure; whereas, the second block valve is used for tight closure. It is intended that all block valve closures will be implemented with the use of clean solvent purges for good valve seating.

In regard to line maintenance, design flow velocities are kept low to avoid erosion. Slurry lines are designed for 7 ft/sec and vapor lines are designed for 24 ft/sec. Also the lines will have extra heavy walls, possibly schedule 160 piping with a specified corrosion allowance.

3.2.9.7 Future Work

Testing will continue to confirm and describe coking considerations to be included in the letdown system design. Mechanical design work will continue to confirm the integrity of all separator vessel designs and materials.

Equipment and piping, general arrangement and layout work will continue to ensure that the most operable and economic layout is developed. Thermal stress analysis of piping will be performed. Work will continue to identify problems and recommend an overall solution to pressure relief protection for the letdown system. Work will continue to keep abreast of the technology of block valves, letdown control valves, pressure relief devices and materials for application to slurry systems. Information from DOE-sponsored programs, Oak Ridge National Lab, Battelle Columbus Lab and Morgantown Energy Research Center will be utilized.

Development of an on-stream calibration device to assure minimum wall thickness is essential if the integrity of lines and valve bodies is to be maintained.

3.2.10 Corrosion Erosion

Corrosion/erosion aspects encountered in the SRC-II process require very serious plant design considerations. Various highly corrosive inorganic and organic acidic components are generated during reaction along with ammonia and some water. A chloride stress corrosion environment is developed. High hydrogen partial pressures are experienced at elevated temperatures. And flowing slurries containing high concentrations of very abrasive solids must be handled appropriately. Thus metallurgy and equipment design are critical factors.

3.2.10.1 Demonstration Plant Design

These concerns have been considered in the design of the Demonstration Plant based on operations and maintenance experience at Gulf Research and Ft. Lewis pilot plants, some special laboratory and in-unit tests, and experience from other related processes similar to SRC.

Although a materials guide had been formulated for Gulf-responsible design areas, the results of recent work indicate that some changes will be made in

future work. Metallurgical and other information for non-P&M proprietary processes and areas will be specified by the related vendors. This would be mainly in the realm of existing conventional commercial operations, with perhaps some exception for the Texaco Gasifier.

3.2.10.2 Erosion

The problems of erosion are difficult to handle, principally because of the great differences in equipment size between pilot units and the Demonstration Plant. Therefore, velocities of slurry-containing streams are limited according to past experience and special laboratory tests. Also, slurry letdown through control valves is based only on experience with the best existing small-size equipment in operation at the pilot plants. However, letdown valve designs and materials selection are both being further developed as possible with commercial vendors for the Demonstration Plant.

3.2.10.3 Corrosion and Stress Corrosion

At present, it has been found that critical stress corrosion areas where hot vapors are cooled and partially quenched with water along with some downstream equipment require Hastelloy. This is very expensive, so alternate metallurgy - mainly duplex alloys - is being tested. Present indications are favorable, but more work is still required. In certain distillation areas where corrosion has been encountered at elevated temperatures stainless steels are required.

The dissolvers and some high pressure as well as some letdown separators are provided with a stainless steel overlay or clad metallurgy. Some of these systems will require further changes and specific shutdown procedures because of stress corrosion problems. Again, further work is being done to determine what is causing corrosion and just how it can be controlled practically and economically.

3.2.10.4 Future Work

Erosion studies are continuing in order to expand information on 3-phase (gas-liquids-solids) systems. At present, experience using 1/4-inch ID tubing and 2-inch IPS schedule XXH piping indicates that velocities on the order of 25 ft/sec are feasible in stainless steel tubing while carbon steel has shown excessive wear. In the future, the effects of increasing velocity from 50 to 150 ft/sec will be examined, particularly for use in designing pumping equipment.

In the low pressure high volume pump area, existing metallurgy and centrifugal pump design and tip speeds are being used as guidelines for commercial size pumps. Where possible work is also being done with cooperating pump vendors to further improve pump-wear characteristics. Positive displacement pumps are being used for high pressure service.

3.3 HYDROGEN PURIFICATION

3.3.1 Design Basis and Scaleup

The basis for scaling factors in the gas pretreatment and cold box recovery systems will involve total gas stream compositions and flow rates. The pretreatment systems (lean oil wash, acid gas scrubbing, carbon beds, and molecular sieves) are sized based upon volume flow and impurity removal capabilities which is a function of inlet and outlet concentrations. The levels of impurities such as coal chemicals, CO_2 , H_2S , HCN , COS , C_5^+ hydrocarbons and NH_3 will dictate equipment size.

The cold box hydrogen recovery unit will be scaled dependent on overall gas flow rates, bypassing capabilities and turndown requirements. At present Air Liquide (the DOE acknowledged sole source subcontractor for the cold box), has expressed that turndown requirementw in excess of approximately 50 percent will require multiple cold box units due to exchanger flow problems.

In the Demonstration Plant design including Design Revisions (Section 6, Deliverable No. 1) all recycle hydrogen gas flow will be upgraded by cryogenic purification. For the autorefrigerated case, this corresponds to a maximum of 225 MM scfd. This rate is about 4 to 5 times the flow processed in the largest similar cryogenic separator constructed by Air Liquide for Monsanto. This Monsanto cold box operates at 37.7 MM scfd of 60 to 65 percent H_2 feed and produces high purity H_2 product at 350 psig. Air Liquide also has experience with a cryogenic heat exchanger handling natural gas at 276 MMscfd and 600 psig. Gas product pressures of 1000 psig or greater have been handled in ammonia synthesis gas production units by Liquide Air for BASF, Germany.

3.3.2 Materials

Materials of construction in the pretreatment system will be dictated by the presence of possibly corrosive acid gases and the nominal 2000 psig operating pressure. Extreme operating temperatures will not be a problem in

the pretreating system except for the molecular sieves where thermal cycling is required for regeneration. In this case, refractory lining may be specified.

The cold box heat exchanger construction will be dependent on pressure and temperature operating limits. However, Air Liquide has expressed that material economics is the primary basis for material selection capable of handling the auto-refrigerated limits for temperature and pressure (-320 F, 2000 psig). The materials of construction generally specified for the above conditions are aluminum tubes and stainless steel shells.

3.3.3 Planned Redundancy

There is a high degree of redundancy in the gas pretreatment system prior to the cold box. A water wash system, incorporated in the third high pressure flash drum will remove water soluble coal chemicals and ammonia salts. The lean oil wash, located directly after the water wash, will absorb C_{5+} hydrocarbons that escape the cooling and separation system to levels less than 2000 ppm wt. Oil soluble coal chemicals will also be absorbed at this point. Acid gases such as H_2S and CO_2 will be removed to concentrations between 10 ppmv and 50 ppmv by a DEA Scrubbing System.

Trace components escaping the lean oil or acid gas wash will be removed in one of three final backup systems. The first system is comprised of carbon beds for trace heavy hydrocarbon and coal chemical removal. The second system is the molecular sieves which will remove remaining trace components in the recycle gas to prevent freeze-up in the cold box. Such components as H_2S and CO_2 will be reduced to levels of 1 ppm and 10 ppm, respectively. The final backup system will be an oil-chemical condensing step (C_3-C_4+ range) at the cold box front-end consisting of a Freon refrigerated system. A solvent wash such as tetralin may be considered, if additional treatment is required. If, for some reason, all of the above backup systems fail to remove impurities to critical levels during upset or normal operation, the gas flow will be bypassed around the cold box.

3.3.4 Process Control

The primary role of the hydrogen treating and recovery system is to supply a reasonably pure hydrogen source to maintain dissolver hydrogen partial pressure at a predetermined level. To achieve this, light hydrocarbons, nitrogen and carbon monoxide are rejected. These materials are products of the dissolver reaction or are introduced with the makeup hydrogen stream.

The required dissolver hydrogen partial pressure will determine the necessary hydrogen purity at a given recycle gas rate. This will in turn set the parameters for cold box equipment design. Recent specifications, as outlined in the dissolver hydrogen partial pressure Design Revision, Section 6, Deliverable No. 1, have required a higher dissolver partial pressure and higher purity hydrogen product. A high purity hydrogen product requires an external refrigeration system which offers a wider range of process control. However, the most recent specification used for the current bridging task work has reduced the required dissolver partial pressure allowing a Joule-Thompson (J-T) Autorefrigerated Cold Box.

The two major trade-offs between the externally refrigerated and J-T systems are reliability versus operability. Process control limitations will be more restrictive in an autorefrigerated cold box although reliability will be increased due to the elimination of rotating equipment items such as compressors, drivers, etc. Additionally, there will be more restrictive limitations on inlet feed gas composition (methane gas concentration) and byproduct gas stream purities. However, the autorefrigerated cold box will offer slightly less capital investment and significantly less power consumption.

3.3.5 Maintenance Considerations

The hydrogen pretreatment systems will be markedly affected by upset or inconsistent dissolver operating conditions. However, they must be designed to minimize impact on the cold box operation since any resultant cold box

failure will result in dissolver downtime. It will probably be necessary to continuously purge the oil and acid gas wash streams to prevent contaminant build-up. It will also be necessary to change out carbon and molecular sieve beds periodically if upsets are common.

Maintenance required for the cold box itself will be dependent on the need for rotating equipment items to supplement the Joule-Thompson refrigeration, the front end oil-chemical condensing load, and the service life of the J-T throttling valves. Air Liquide has stated that expanders and compressors in the nitrogen liquifier units typically have given fewer problems than instrumentation or other miscellaneous equipment. However, increased equipment complexity will always tend to sacrifice system reliability. If the cold box front-end oil-chemical wash successfully removes final impurity traces, maintenance associated with exchanger freeze-up will be eliminated or greatly reduced.

3.3.6 Extension of Known Art

It is a recognized fact that the cryogenic hydrogen purification unit will be a prototype that has unique combined operating requirements compared to any previously constructed. Air Liquide has duplicated or surpassed some of the individual conditions such as gas flow rate or product purities in other applications including LNG production or hydrogen purification.

For illustration, the Area 12 Autorefrigerated Unit will purify a maximum of 225 MMScfd of low purity H_2 feed to a high purity product at 2000 psig. In applications with similar feed compositions, they have surpassed the product purity but at total gas flow rates of only 47.7 MMScfd. In separate nonsimilar feed-product applications they have surpassed 225 MMScfd gas flow rates (276 MMScfd per exchanger for LNG production).

Air Liquide has had some experience with coal derived impurities and necessary pretreatment in coke oven gas facilities. One of these facilities was built for Ketona Chemical Corporation producing ammonia and synthesis gas at 14 MMScfd.

3.3.7 Bridging Study Progress

The initial design basis for the cold box hydrogen recovery system had assumed a point operating condition for a low purity hydrogen J-T refrigerated cold box. Subsequently, a process range design was specified for the higher partial pressure, high purity, externally refrigerated case resulting in a design shown in the dissolver hydrogen partial pressure Design Revision. The equipment complexity and operating cost represented by this high partial pressure system has renewed efforts to attain a J-T operated cold box.

The most recent design parameters transmitted to Air Liquide for the current bridging study work consists of an autorefrigerated cold box producing a somewhat lower hydrogen purity product over a wide range of recycle gas feed compositions. These ranges in recycle gas compositions are a result of processing various reactivity coals altering hydrogen consumptions in the dissolver. The limiting cases setting cold box design have been determined to be high reactivity coal (4.7% H_2 consumption) at low recirculation rate and low reactivity coal (4.0% H_2 consumption) at high recirculation rate. The former representing the easiest case (least flow, greatest impurities); the latter representing the most difficult case (greatest flow, least impurities).

Efforts are also focused on the H_2 pretreatment system to define those contaminants most likely present in the recycle gas stream. Feasibility studies for alternate methods of heavy hydrocarbon and acid gas impurity removal, which might tend to decrease the molecular sieve sizes are underway.

3.3.8 Future Work Required

The Recycle H_2 Pretreatment System is the least defined part of the Hydrogen Purification system requiring the greatest future work effort. To properly define the pretreatment system, the type and quantity of currently unspecified impurities such as HCN, COS, Olefins, and coal chemicals must be known. Also required are the maximum acceptable tolerances of CO_2 , H_2S , NH_3 and C_5+ into the cold box to set operation and upset condition limits for the

oil wash, acid gas scrubber, carbon beds, and molecular sieves. The type of regeneration gas for the molecular sieves and the disposition of the gas after regeneration are yet to be resolved.

Documentation of experience with similar H_2 treating and recovery processes will aid in defining the adverse effects of trace impurities on cold box operability. Similar processes in operation are coke oven offgas, ethylene offgas, and refinery offgas operations.

Studies are in progress to examine alternate and/or improved methods for recycle gas pretreatment. Definition of optimum lean oil cuts, flow rates, and absorption characteristics will increase the lean oil wash efficiency. Utilizing an acid gas absorption system which can economically remove CO_2 and H_2S to levels less than the 50 ppmv and 10 ppmv currently specified will decrease the loading, and hopefully, the size, of the molecular sieves. If acid gas concentrations are sufficiently reduced, the molecular sieves could be replaced with a potassium hydroxide or desiccant bed.

Work must also continue with Air Liquide on the cold box design and operating range conditions. The cold box must be expected to operate over a range of feed purities resulting from varying coal reactivities and dissolver effluent cooling-separation conditions. Verification of operating limits for J-T refrigeration also is required.

3.4 TEXACO GASIFICATION

This section has not yet been released for publication. The text was submitted to Texaco on July 17 to verify that it contains no proprietary information.

3.5 SULFUR RESISTANT SYNGAS SHIFT CONVERTER

The process under consideration for this area uses technology licensed by Haldor Topsoe and has been jointly developed by Exxon Research and Engineering Company (ERE) and Haldor Topsoe A/S (HTAS). The sulfur resistant shift conversion process is prototype both because it is larger than previously used commercially and has a different feed source. Existing commercial applications derive syngas from fuel oil gasification compared to the high solids content vacuum bottoms gasified in the Demonstration Plant. Scrubbing for solids removal must be very efficient to avoid plugging the shift conversion catalyst.

The sulfur-tolerant shift technology, comprising process design and catalysts, was developed in the early 1970's. The various types of catalysts developed are generally designated as SSK Catalyst. One advantage the SSK Catalyst has over conventional shift catalysts is that in addition to being sulfur tolerant it is capable of operating in the broad temperature range of 200 to 400°C.

The ERE-HTAS Shift Process and the SSK Catalyst are extremely suitable for plants utilizing partial oxidation of coal or oil where the gasification products have a sulfur concentration which would be detrimental to conventional shift catalysts. There is no upper limit to the H₂S content of the gas.

The ERE-HTAS Shift Technology has been demonstrated commercially since 1974 on syngas produced from partial oxidation of oil. The demonstration plant syngas flow rate is about 8 times the flow of the largest commercially proven unit.

The ERE-HTAS Shift Technology is being used on the TVA project at Muscle Shoals, Alabama, to produce ammonia from coal.

The design of the syngas shift unit will utilize conventional materials of construction, process control and instrumentation technology.

The overall confidence level for the SSK Catalyst and Process in this application is very high. The catalyst has been proven to be mechanically rugged and to perform as predicted from a process standpoint.

A competitive catalyst developed and manufactured by BASF has been in commercial service for 9 years in Ludwigshafen, Germany. This technology will be specified for two plants in India and four in Red China, all used to react syngas made from the Texaco partial oxidation process. An inquiry has been sent to BASF to evaluate their technology as applied to the Demonstration Plant Design.

3.6 METHANATION UNIT

The process under consideration for this area uses technology licensed by Haldor Topsoe A/S, (HTAS), Copenhagen, Denmark. The technology, consisting of process design, reactor design and catalysts designated as MCR Catalysts, was developed in the 1970's. This process is prototype because it has not been commercially proven.

3.6.1 Extension of Known Art

Methanation processes have been used for many years for final purification of ammonia synthesis gas. In this application, the concentration of carbon oxides is very low. Methanation of process gases containing high concentrations of carbon oxides creates special problems because of the large amount of heat released by the methanation reactions. The development of new technology to solve the problems with respect to process and reactor design and catalyst properties was based on extensive experience with conventional methanation technology.

3.6.2 Development

The HTAS Methanation Process has been designed for operation in a fixed bed reactor at conditions of low inlet temperature and high outlet temperature. At these conditions catalyst properties are rather critical. The catalyst must be heat resistant but still have good activity at low temperatures and should have a low tendency to carbon formation. Such catalyst properties have been achieved in the development of the MCR Catalysts. In addition to the methanation of carbon oxides, the catalyst will reform ethane to methane.

The process and catalyst have been demonstrated in a one-stage pilot plant reactor (about 2-inch diameter) for over 3 years. One run included a period of over 7000 hours of successful operation.

A three-stage process similar to the one to be used in the Demonstration Plant is installed in a West German project to develop a long distance energy transportation system. The reactors are somewhat larger in diameter than the HTAS pilot plant reactor. A successful test run of this plant was completed in early 1979. Information from this unit will be available through Haldor Topsoe and will be used for scale-up to the size required for the Demonstration plant.

3.6.3 Materials and Maintenance

The unit as conceived will utilize conventional, proven equipment. No unusual problems with respect to materials or maintenance are anticipated.

3.6.4 Process Control

There is a difficult feed control problem due to the different compositions of the streams being methanated and the possible variation in their flow rates. The feed gas must be controlled to a proper stoichiometric composition to produce a product gas, within acceptable limits of hydrogen, carbon monoxide, carbon dioxide and heating value.

As a result of bridging work, it is planned to send the excess synthesis gas stream to the fuel system rather than to the methanator to simplify the control problem. This will eliminate one of the three major feed streams and, since this stream was the major contributor of carbon oxides to the methanator feed, concern for highly exothermic temperature excursions is much less.

Other important parameters to be controlled are the overall H/C and O/C ratios at the first reactor inlet.

3.7 SUPERSCOT TAILGAS UNIT

3.7.1 Introduction

A SCOT Unit takes tail gas from a Claus sulfur recovery unit, converts elemental sulfur and sulfur compounds to H_2S , strips the H_2S out of the tailgas, and recycles the H_2S back to a Claus Unit. The word SCOT is an acronym for Shell Claus Offgas Treating.

A SUPERSCOT Unit is a modified SCOT Unit. In addition to the tail gas from a Claus sulfur recovery unit, a SUPERSCOT unit receives one or more extraneous gas streams, usually for H_2S enrichment.

3.7.2 Scaling Factors

The Absorption/stripping portion of the SUPERSCOT Unit is large but larger SCOT Units have been built.

3.7.3 Materials and Maintenance

Materials of construction for a SUPERSCOT Unit are the same as for a SCOT Unit. Materials of construction for a SCOT Unit are well known. No unusual maintenance conditions exist.

3.7.4 Planned Redundancy

All process pumps are spared.

3.7.5 Process Control

The process control of a SUPERSCOT Unit is the same as for a SCOT Unit. No unusual process control problems exist.

3.7.6 Extension of Known Art

All the components of the Superscot Process have been operated commercially, but they have not been combined in a single plant. However, quality engineering will allow the process to be used with the only extension of known art to be combining tested components.

3.7.8 Bridging Study Progress

Bridging studies in Unit 20, Hydrogen Production Plants, indicate that Selexol Units may be a preferred alternate to Benfield Units for H_2S removal. Since Selexol is a selective absorption process, the Unit 20 streams feeding Area 33, Sulfur Recovery Plant, would be rich in H_2S and enrichment would not be required in the SUPERSCOT Unit. This means a conventional SCOT Unit could be used resulting in a smaller sized unit with less energy consumption since less solvent flow is required in the SCOT Unit and refrigerated solvent is not required in the SCOT Unit.

The overall availability and demand for utility steam must be evaluated in further detail to support the selection of the Selexol Process over the Benfield Process. In addition further comparison of complexity, operability and reliability of these processes is required.

3.8 REFINING PLANT

3.8.1 General

This process is prototype because coal liquids have not been refined commercially using this combination of unit operations.

3.8.1.1 Scaling Factors

All process vessels and pumps in the Demonstration Refining Plant are within commercially-proven sizes. All process vessels are less than 20 feet in diameter and the largest pump is approximately 500 gpm. The only piece of equipment that could be considered prototype is the agitator in the large (80-foot diameter) Mineral Residue Hold Tank. The mineral residue slurry in this tank could approach 30 percent solids in an upset condition.

3.8.1.2 Materials of Construction

The majority of the process equipment in the Refining Plant is constructed of carbon steel. The only exceptions are the slurry-handling equipment and equipment exposed to hydrocarbon vapors above 300°F. The atmospheric fractionator and solids-wash tower are stainless steel clad with Hastelloy internals. The overhead condensers of both columns and the vacuum flash vessel are also stainless steel.

3.8.1.3 Planned Redundancy

The operational reliability of the process vessels in the Refining Plant is high and therefore requires no redundant capabilities. All pumps are spared for increased operational reliability.

3.8.1.4 Process Control

Process control requirements in the Refining Plant are for the most part conventional and no problems are expected. Control problems are anticipated in the process areas where slurries are handled. These areas are the atmospheric and vacuum flash bottoms and the vacuum overhead accumulator. Control functions involved are level control and slurry flow measurement.

3.8.1.5 Maintenance Considerations

High maintenance requirements are anticipated in the vacuum flash bottoms/Texaco feed area due to the high temperature and high solids content. Line pluggage and high erosion rates are anticipated.

3.8.1.6 Extension of Known Art

There is minimal extension of known art in the process design area of the Refining Plant. One area of concern is the vapor-liquid equilibrium "K's" used at the low pressure conditions of the vacuum flash vessel. To date, these "K's" have not been verified.

The Jet Mix Pump used to provide mixing and agitation for the MRS Hold Tank is considered to be prototype. The metallurgy required for this 50,000 gpm propeller-type slurry pump must be determined. However, recent information indicates that a single top mounted turbine agitator can meet the agitation requirements, deleting the above pump.

3.8.1.7 Bridging Study Progress

Two improvements have been made in the Refining Plant design; the addition of the Solids Wash Tower and a two-stage vacuum flash. The Solids Wash Column increases the reliability of producing a solids-free fuel oil product and flushing oil. This is a further improvement over that described in Design Revision No. 5 (Section 6, Deliverable No. 1).

The two-stage flash results in more realistic equipment sizes and significantly reduced utility requirements. The combination of the two concepts also allows less severe conditions of service and increased process flexibility.

3.8.1.8 Future Work Required

Process simulation work is required to establish the ability of the Solids-Wash Tower/Vacuum Flash system to handle rerun Mineral Residue Slurry both during normal operation and alone. The system startup sequence also must be developed.

Vapor-lined equilibrium "K's" must be verified. Plans are underway to do this at both Fort Lewis and Gulf Science and Technology Corporation in Harmarville, PA. Also there are plans to install equipment at Ft. Lewis to test requirements for pumping vacuum bottoms slurry.

3.8.2 Solids Entrainment in Vacuum Tower

3.8.2.1 Product Specification

The fuel oil product from the Demonstration Plant was designed to contain a very low weight percent ash. This limit was set based upon some shipments of fuel oil produced by the Fort Lewis Pilot Plant. The limit on ash content of the fuel oil product necessary for customer usage is to be determined by market studies during Phase I.

3.8.2.2 Demonstration Plant Design

Wherever the slurry product from the dissolver area is flashed to recover high boiling-point oils, some entrainment of droplets and particulates will occur. The initial design utilized a very large vacuum flash tower at a very low absolute pressure to maximize the recovery of fuel oil. A wash section to reduce solids entrainment was not utilized to avoid both the pressure drop and possible plugging of the wash section with solids.

It appeared unlikely that the solids content could be controlled at the design vacuum flash tower velocity. Therefore, the fractionation system was revised as shown in Section 6, Design Revisions of the Demonstration Plant Description, Deliverable No. 1. This consists primarily of a two stage vacuum flash and a re-run column to redistill the solids-containing vacuum distillate.

3.8.2.3 Bridging Task Progress

Many processing schemes were studied with a resulting improvement over the Design Revision that combines the first stage vacuum flash with a re-run tower. Work is continuing to optimize this design.

3.8.2.4 Test Data and Future Work

Within the past 6 months an operational problem of the vacuum flash tower at Fort Lewis was resolved. Prior to then, solids content of the vacuum distillate was variable. One series of tests gave acceptable entrainment at about 5 ft/sec. vapor velocity. Confirmation at higher velocities is required for assurance that a reasonably sized vacuum flash tower will produce an acceptable product.

3.8.3 Coal Chemicals Water-Oil Equilibria

The presence of oxygen, nitrogen and sulfur coal chemicals, particularly in the fractionation portion of the refining plant can provide some design problems. These chemicals are soluble both in oils and water. Prediction of distribution coefficients where oil and water phases are coexistent is very difficult with available data. In addition it is believed these chemicals play a role in combination with water, H_2S , CO_2 and NH_3 in the corrosion problems experienced in the fractionation column at Ft. Lewis.

The best information available to use for designing the refining area will result from test work at the P-99 pilot plant in Harmarville, PA.

3.8.4 Mineral Residue Slurry (MRS) Handling

3.8.4.1 Introduction

Mineral Residue Slurry, produced in the Refining Plant as vacuum tower bottoms, is feed for the Texaco Gasifier. Between the Vacuum Tower and the Texaco Gasifier, however, surge capacity of two different types is provided. In the first case a "wide place in the line" is provided to take any short term discrepancies in flows between the Vacuum Tower and the Gasifier. This tank can take 30 minutes of full flow from the Vacuum Tower. In the second case, a rundown storage tank and a dilute hold tank are provided in the event that an emergency shutdown of the Gasifier's necessitates storage of larger quantities of vacuum tower bottoms. In the second case Mineral Residue Slurry would be diluted and cooled to about 300°F prior to storage in the Dilute MRS Hold Tank.

The following sections assume that the jet mix pumps, previously specified for the Dilute MRS Hold Tank, will be replaced with a turbine agitator.

3.8.4.2 Scaling Factors

All vessels and pumps are within commercially proven capacities. The agitator on the Dilute MRS Hold Tank will be one of the larger agitators built, but not the largest.

3.8.4.3 Materials

Rotating and reciprocating equipment will employ erosion-resistant materials due to the highly erosive characteristics of the slurries being handled. Vessels and lines will be carbon steel.

3.8.4.4 Planned Redundancy

All pumps will be spared.

3.8.4.5 Process Control

Process control requirements should pose no unsurmountable problems.

3.8.4.6 Maintenance Consideration

Pump and line maintenance will be higher than conventional applications due to the erosive and potential plugging nature of the slurries being handled.

3.8.4.7 Extension of Known Art

The equipment in the Mineral Residue Slurry System must be designed to maintain the solids in suspension. Further studies and experimental data are required before a final design can be made.

The agitator design in the Dilute MRS Hold Tank will require careful consideration due to varying slurry properties that could exist, especially during upset or emergency situations.

3.8.4.8 Future Work Required

A program has been approved by DOE to modify certain existing equipment and add other needed equipment, at the Ft. Lewis Pilot Plant that will permit simulation of the Texaco Gasifier feed system. This information includes maximum practical temperature level at which the slurry can be pumped, viscosity at pumping conditions (1500 PSI), seal flush requirements, and level of maintenance required on centrifugal and reciprocating pumps.

3.9 NAPHTHA HYDRODESULFURIZATION (HDS)

3.9.1 Summary

The Hydrodesulfurization Unit for treating raw naphtha uses a proprietary Gulf Process now conventionally employed to desulfurize and up-grade various sour petroleum stocks in typical refinery operations. Its use to treat an SRC-II produced naphtha is considered a prototype process.

The distinctive character of SRC-II naphtha, with its very high oxygen and nitrogen contents, is evident in assays which have been made and compared to typical petroleum naphthas. Also, preliminary tests made at Gulf's Science and Technology Laboratory revealed fouling in charge preheater and product cooling exchangers. A wide range of product quality is obtained dependent on the severity of processing. Thus additional experimental work must still be done to define process design conditions, hydrogen consumption, and catalytic requirements for hydrotreating SRC-II naphtha in order to convert it into an acceptable quality plant fuel.

3.9.2 Discussion

Scaling factors, materials, process control and maintenance considerations can all be resolved because the HDS process is commercially proven. Additives may possibly be used to control heater and exchanger fouling as is practiced commercially. Likewise, prevention of oxygen contact with the raw naphtha would be employed to reduce possible polymerization reactions that could foul exchangers. A commercially proven water wash system very likely will be used to prevent salts depositing on the effluent side of feed/effluent exchangers.

Although currently this SRC-II process design uses naphtha as a plant fuel, recent considerations may change that basis. Other available plant products may displace naphtha as a plant fuel. Also, the need to use naphtha as a source of gasoline and/or petrochemicals is developing. The high aromatic

content of SRC-II naphtha makes it potentially an excellent feedstock for catalytic reforming to high octane gasoline. Under these circumstances, additional experimental work and more complete catalyst life evaluations are required.

3.9.3 Conclusion

For a definitive engineering phase, Gulf will obtain and supply the necessary detailed naphtha processing information. This would include either moderately treating naphtha for use as a plant fuel or more severely treating it for use as a source of gasoline or petrochemicals, depending on which choice is made.

3.10 AMMONIA RECOVERY

The Ammonia Recovery unit under consideration will utilize the Phosam-W process licensed by USS Engineers and Consultants, Inc. (UEC). The Phosam Process is in successful operation in several coke plants around the world. The Phosam-W process differs from the Phosam process only in the addition of a sour water stripper (superstill). The Phosam-W superstill has been demonstrated by continuous use in U.S. Steel's largest coke plant. The Phosam-W process has not been used in treating coal liquefaction type ammoniacal water streams and therefore should be demonstrated.

3.10.1 Scaling Factors

The superstill in operation at U.S. Steel's coke plant is capable of processing up to 2000 gpm of water. The SRC-II Demonstration Plant treats about 300 gpm, so the superstill will be scaled down in size. Other equipment in this unit is similar in size to those treating coke oven gases and size is not a problem.

3.10.2 Materials of Construction

Equipment materials of construction were provided by UEC and are similar to those commercially proven in coke oven plants.

3.10.3 Process Control

Process control of this unit is proprietary UEC technology. The same proven control system will be utilized in the SRC-II Demonstration Plant.

3.10.4 Planned Redundancy

All of the normally operating pumps in this unit are spared to allow for normal pump maintenance. Feed storage is provided to allow shutdown and maintenance of this unit without affecting overall plant operation. Major maintenance would, however, be done during plant turn-around.

3.10.5 Future Work

The preliminary design of this unit is based on the best available sample and analysis of the dissolver wash water. The Harmarville pilot unit has now been modified to be more representative of the ammonia wash system to be used in the Demonstration Plant. Therefore, representative samples will be obtained and thoroughly analyzed. These analyses will be reviewed with UEC for their assessment. If required by UEC, a sample will be sent to them for pilot test runs to determine final process design parameters.

3.11 TAR ACID RECOVERY

Tar Acid Recovery is based on a licensed process from Chem Pro Equipment Corporation. This process has been successfully used in the steel industry and Phenol Resin Plants, but has not been utilized in coal liquefaction processes. The largest unit built processes 200 gpm of water containing phenolic compounds (Tar Acid). The SRC-II Demonstration Plant will process approximately 300 gpm. This results in a scale-up factor of 1.5, if the Chem Pro Equipment process is chosen. However, the equipment in this unit is small by the present commercial standard and the scale-up to 300 gpm is not expected to be a problem.

3.11.2 Materials of Construction

Equipment materials of construction will be recommended by Chem Pro and are similar to those commercially proven in operation.

3.11.3 Process Control

Process control of this unit is similar to that successfully utilized in existing plants.

3.11.4 Planned Redundancy

All of the normally operating pumps and parallel heat exchangers in this unit are spared to allow for normal maintenance. When an operating heat exchanger fouls, the other exchanger is brought on line and the fouled exchanger is steamed out. The feed storage system in Area 41 can also be used in the event that this unit is down for maintenance.

Recently obtained samples from Harmarville were sent to Chem Pro for preliminary screening tests. Chem Pro has run these screening tests and has confirmed the feasibility of this process in handling SRC-II process water.

3.11.5 Future Work

A larger sample of process water from Harmarville will be sent to Chem Pro to run a pilot test. This pilot test will provide the process licensor with design data to effectively design the unit. A firm design basis can then be established based on results of this pilot test plus range design evaluation for the different types of coal that will be run in the Demonstration Plant.

3.12 WASTE WATER TREATING

The design of the Waste Water Reclamation Area (Area 43) for the Desmonstration Plant is based on maximum flexibility and minimum capital cost considerations and energy consumption considerations. This is necessary due to the current lack of knowledge on the chemical makeup and flow rates of the various waste streams and the assumption that hazardous characteristics are associated with these streams.

Oil-water separation and water concentration by evaporation are the primary unit operations employed. The resulting evaporator condensate is recycled. Brine streams and waste oil are incinerated.

3.12.1 Scale-up

There are no design scale-up problems for the present plant design.

3.12.2 Materials

The choice of materials for the various unit operations primarily are based upon corrosion and pressure considerations. The Brine Concentrators utilize titanium heat exchange surfaces and considerable stainless steel in those areas not subject to high salt concentrations. Construction materials for the other equipment cannot be discussed at this time due to insufficient analytical information on the various waste streams.

3.12.3 Maintenance and Process Control

Equipment maintenance and unit operation process control also cannot be discussed until the design basis is complete.

3.12.4 Planned Redundancy

Redundancy considerations include excess capacity for the brine concentrator and oil removal equipment, 100 percent excess capacity for the evaporator system, holding tanks providing up to 24 hours holding time and spare pumps for all systems.

3.12.5 Bridging Study Progress

After completion of the Demonstration Plant written description, a variety of waste water reclamation problem areas were studied. Resources Conservation Company has completed their pilot plant brine concentrator test work on a Texaco Gasifier blowdown sample. They were able to successfully concentrate this stream to the level used in the design. Their test work also brought out some interesting reactions that occur when the pH of this waste stream is increased.

A complete analysis of the blowdown water from a pilot plant gasification run has been completed but has not been released by Texaco for engineering purposes.

A search type study has begun and is ongoing for new and innovative methods of treating wastes similar to these.

3.12.6 Future Work

Future work will include scheduling of more analytical work on all of the incoming waste streams with particular attention to those from the dissolver area, coal pile area and the slag pond area.

A series of lab tests will be scheduled to evaluate the effect of the addition of various chemicals (lime, caustic, hydrogen peroxide, ferrous sulfate, etc.) to each of the waste streams. Of particular interest will be the degree of dissolution or chemical oxidation/reduction that occurs and the resulting precipitation, flocculation and sedimentation characteristics.

A series of trade-off studies as a continuation of the Bridging search type study are planned to evaluate alternate methods of treating these waste streams. The goal of these trade-off studies will be to reduce energy consumption and to provide more comprehensive treatment of each stream. Segregation of certain waste streams will be studied.

3.13 COAL GRINDING AND DRYING

Coal grinding and drying is a critical area due to the design problems that impact the SRC-II Process. The effect of moisture and particle size upon coal-recycle slurry mixing and slurry viscosity has been discussed in Section 3.2.1. Particle size may be a factor in erosion of pumps, piping and valves.

Flash drying of minus 1/8 inch coal slurry was preferred in the work that began the Demonstration Plant Design. However, indications from the Fort Lewis Pilot Plant showed that erosion could be a problem with this size coal. To make a finer grind of coal, drying is required to prevent the plugging of coal handling equipment. Therefore, the Design Revision shown in Section 6, Deliverable No. 1, was added to provide minus 20 mesh coal containing 3-5 percent moisture.

3.13.1 Extension of Known Art, Scale-up

Equipment to grind and dry coal to the feed conditions for the Demonstration Plant is available without any problems of scale-up. The equipment has been proven both in preparing coal for coke ovens and the feed streams to steel making blast furnaces. Likewise, materials can be specified reliably and maintenance of equipment is a known factor.

3.13.2 Planned Redundancy

Planned redundancy includes a spare conveyor from the coal storage pile to the grinding area, 4 grinder-dryer trains each with 1/3 of design capacity and provision for spare conveyors to the fine coal hoppers.

3.13.3 Process Control

Control of the coal moisture and particle size must be achieved. While it would be convenient to have an on-stream moisture analysis, it has been found by experience that spot samples can be used with a run-around chart to control

the dryer operating conditions. The capability of the Foxboro Control System also will bring improved control due to ability to monitor, store, process and compare information.

3.13.4 Bridging Study Progress

A test program began in June 1979 to determine design conditions and equipment required to produce minus 20 mesh coal containing 3-5 percent moisture. Tests are scheduled with Koppers, C. E. Raymond, and Fuller. The Koppers tests also will include a determination of the environmental effects from drying coal. The two coals submitted for the above tests are from Powhatan and Robinson Run mines.

3.13.5 Future Work

The Bridging Study tests described above will be completed. Additional testing may be required to resolve design data requirements during Phase I.

3.14 SLAG HANDLING

3.14.1 Demonstration Plant Design Basis

Test data for the slag produced by the Texaco Gasifier have not yet been released by Texaco for design. Therefore, the slag handling design is based upon another type of slagging gasifier that has been proven in operation.

Similarly, data on properties of the slag design were not released for disposal sites for the recovered slag. Therefore, it is intended to manage the slag as if it were a hazardous waste in conformance with Federal Resource Conservation and Recovery Act (RCRA) proposed regulations, U. S. Environmental Protection Agency proposed guidelines, and State of West Virginia Solid Waste Regulations and Groundwater Protection Policies. The Demonstration Plant design includes a slag disposal system to conform with worst-case conditions under RCRA until test data are available to indicate this is not required.

The slag disposal impoundment design consists of an earthen retention dam, clay liner, drainage diversion system and seepage collection system. The leachability characteristics of the slag are not yet available, therefore the clay liner is included to limit seepage from the bottom and sides of the impoundment to minimize the potential for ground-water contamination. Any seepage from the earthen dam will be collected in a catch basin at the toe of the dam and diverted to the waste-water reclamation system. Direct rainfall and snowmelt waters collected in the impoundment area also will be diverted to the waste-water reclamation system.

Concerns such as scaling factors, materials, planned redundancy, process control and maintenance cannot be reasonably discussed until slag tests are made available to provide a design basis.

3.14.2 Future Work

Slag samples were taken from two short runs on the Texaco Gasifier Pilot Plant in Montebello, California. The pilot runs utilized vacuum flash bottoms samples from Fort Lewis. Slag samples taken at Montebello in August 1978 and

January 1979 were derived from Kentucky and Powhatan coals, respectively. To date, no results from testing the slag samples have been released by Texaco for design work.

A longer gasification pilot run is scheduled for late summer or fall in Montebello and it will utilize vacuum flash bottoms from Fort Lewis made from Powhatan coal. Significant sampling and testing of the slag made during this run is required for design to proceed.

SECTION 4
PROTOTYPE EQUIPMENT

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SECTION 4 PROTOTYPE EQUIPMENT

Prototype equipment is defined as follows:

- (1) Unique equipment that has not been built before.
- (2) Equipment which is larger than previously built.
- (3) Equipment which has never been used previously in the required service.

Equipment which meets one or more of these criteria is listed in the Table of Contents and has been reported in the following format:

Equipment Name and Number
Equipment Service
Purpose of Study
Results of Work
Continuation of Study

Any discrepancies in capacities and/or vessel sizes between equipment in Deliverable Number 1 and this Section are the result of on-going bridging task work and/or work described in Section 6 of Deliverable Number 1.

4.1 SLURRY CIRCULATION PUMP (P11.106 A/B)

4.1.1 Equipment Service

The Slurry Circulation Pump will be used to circulate feed slurry in the Slurry Charge Tank (V11.102). The purpose of circulating the slurry is to keep the coal mixed with the solvent and to prevent solids from settling out. The Slurry Circulation Pump will have a flow rate of 7700 gpm, a high pumping temperature and a differential head of 52.5 ft. The slurry will be coal and recycle slurry and is expected to have a viscosity of 350 Cp at pumping temperature.

4.1.2 Purpose of Study

This pump will be handling the same slurry as the Slurry Feed Pump (Reference Section 4.2). It too, will be a high flow, low head pump. Finding a slurry pump which is capable of handling the high abrasivity of the slurry and able to withstand and pumping temperature is the main problem.

4.1.3 Results of Work

Because the conditions of service for both the Slurry Feed Pump and the Slurry Circulation Pump are similar, the study of possible pumping problems was conducted simultaneously.

4.1.4 Material Selection

For a description of the investigation done in the area of material selection, see "Results of Work," Section 4.2.3.

4.1.5 Pump Seals

One area of pump design which becomes critical when dealing with high temperature slurries is proper stuffing box sealing. Several seal manufacturers were contacted and their proposed systems were evaluated. Sealing systems studied included: tandem seals, double seals with a disaster bushing, a double seal followed by an outside tandem seal and a tandem seal with packing as a secondary seal.

Because this slurry will congeal at lower temperatures, a hot clean solvent flush must be used. The type of seal selected must therefore be able to handle a flush oil of high temperature. Due to maximum possible pumping temperatures, the seal manufacturers contacted felt that a metal bellows type seal would offer the least problems in this service. The pumps operating in the hot slurry services at the Fort Lewis Pilot Plant are all using a John Crane 15W metal bellow seal.

Detection that a seal failure is imminent is of prime importance in determining the proper sealing approach. The tandem seal configuration showed the most promise of providing a reliable means of detecting that primary seal failure is imminent. A tandem seal configuration consists of two mechanical seals both facing the same direction, as shown in Figure 4-1.* The seal closest to the impeller, the primary, will be flushed with hot clean solvent. The primary seal flush will be at about 50 psi above suction pressure. This higher pressure will force 3 to 6 gpm of flush to leak into the pump casing. The outboard secondary seal will have a closed flush loop. The secondary seal flush will enter the seal cavity at about 5 to 10 psi and will circulate around the seal. It will then flow from the seal cavity and will return to a small reservoir. Figure 4-3 shows a schematic of the recommended piping for a Dura-metallic tandem seal arrangement. The secondary seal flush buffer fluid would preferably have a high flame point. There are several ways of circulating the flush fluid through this loop. John Crane has a device called an axial flow pumping ring which is in the seal cavity and rotates with the shaft, causing a positive flush flow. Durametallic has a small flush pump which is part of the seal flush circulating system called a Dura Circulator. If the primary seal should fail, the hot solvent flush will leak into the secondary seal cavity raising the pressure. A pressure sensing switch in the secondary seal loop will detect the pressure increase and sound an alarm. The secondary seal will then keep the shaft and pump sealed until the pump can be shut down and the primary seal replaced. A throttle bushing can be added to the outboard side of the secondary seal to keep flush from readily flowing to atmosphere should there be a secondary seal failure.

* Figures are at end of section.

A double mechanical seal arrangement was also studied for these services. Figure 4-2 shows this double mechanical seal arrangement. The major problem with this type of seal is keeping the product from reaching the primary seal faces. In the double seal arrangement, the main flush is a closed loop flush. Since very little of this flush flows into the pump casing, the pumpage can advance as far as the primary seal faces. This problem can be remedied by introducing a separate secondary flush between the primary seal and the pump casing. This flush can then flow directly into the casing and isolate the pumpage from the seal. A second problem with the double seal is detecting that a seal failure is imminent. By using a pressure switch in the main flushing line, a decrease in flush pressure could be used to detect a seal failure. The Fort Lewis Pilot Plant personnel used several double seals in the early stages of plant operation. These were later removed due to failure and operating problems and were replaced with single metal bellows seals followed by throttle bushings. This approach resulted in improved performance, but the need for further improvement remains. Because of its relatively simple design and the ability to detect primary seal failure while still maintaining a shaft seal, the tandem seal arrangement is the recommended approach to these severe slurry applications.

4.1.6 Pump Performance

As is pointed out in "Results of Work" (Section 4.2.3) correcting pump efficiency, head and flow for viscous, non-Newtonian fluids still requires further investigation. At present, the only means of correcting for viscous flow is by using the graphs in the Hydraulic Institute Standards. This topic is discussed further in "Study Continuation," Section 4.1.8.

4.1.7 Pump Manufacturers

Four pump manufacturers have submitted information on pumps to meet this application. Lawrence Pump Company is proposing a 20 inch DD slurry pump. This pump was specially designed by Lawrence to be used in coal conversion applications and is presently being commercially manufactured. The pump has a claimed operating horsepower of 212 with a viscous efficiency of 53%. A 250-hp motor operating at 1800 rpm was recommended as a driver. The pump

would have a carbon steel casing with the impeller and liners made of HC-250, which is a type of 25% chrome iron. The pump would be sealed with a tandem seal arrangement, using two metal bellows seals. A commercial version of this pump has not been tested yet, but an early version of the "AL" slurry pump is currently in service at the Fort Lewis Pilot Plant.

Barrett-Haentjens and Company proposed a 16 inch Type "CIP" process slurry pump. This pump has a carbon steel casing, hard surfaced volute, and 28% chrome iron impeller, wear plates, and suction head liner. With a claimed pump viscous efficiency of 55%, the operating horsepower would be 206. The pump would be driven by a 250-hp motor. Barrett-Haentjens is not currently designing or manufacturing any pumps for a coal-solvent slurry application, but they have devoted a significant portion of their business to custom and specialized centrifugal pump design.

Ingersoll-Rand is currently developing a new type "AM" coal slurry pump. Although this pump has not been tested and is not being commercially manufactured at this time, I-R has submitted preliminary information on an 8 x 15 "AM" pump for slurry circulation service. The "AM" pump has a carbon steel casing and 26% chrome iron liners. Details of this pump are not available at this time.

The Durco Mark II pump and the Durco Mark II recessed impeller pump are two types of pumps currently in use at the Fort Lewis Pilot Plant. These are ANSI-type pumps with casing made of CD4MCu which were flame sprayed with tungsten carbide by a Subcontractor for Ft. Lewis. Because these pumps are not lined, a large number of spare pumps are needed to keep the pilot plant in service.

Even with the tungsten carbide coating, these pumps have experienced heavy erosion and consequently maintenance is extensive. Durco has proposed using three 10 x 8-17 standard Mark II pumps for the slurry circulation application. Each of the three pumps would have a flow rate of 2565 gpm. This would provide a combined flow rate of 7700 gpm. The casing and impeller

would be 316 S.S. and Durco has recommended that these parts be flame sprayed with tungsten carbide. The operating horsepower is claimed to be 68 for each pump which would be V-belt driven by a 75-hp motor operating at 1180 rpm. The pump speed would be 901 rpm.

All of the lined pumps show good potential, but none have been commercially tested in the size required for the demonstration plant. Lawrence however has received several orders for their "AL" slurry pump. Barrett-Haentjens has good experience in design and manufacturing of large custom centrifugal pumps. Further study of the I-R "AM" coal slurry pump will be needed to properly evaluate this pump and to determine if the proper size for the conditions of service can be commercially manufactured. Due to the problems inherent in a casing coated with tungsten carbide and because the coating and maintenance costs are high, a coated pump should only be used if no other erosion protection is practical.

4.1.8 Study Continuation

Continued research to find a means of accurately correcting for non-Newtonian viscous flow, head, horsepower, and net positive suction head (NPSH) will receive high priority.

Further information concerning the different types of variable speed drives is needed. Continued discussions with the pump manufacturers and direct contact with variable speed drive manufacturers will help supply this information.

Erosion control methods and materials properties will be studied further.

4.2 SLURRY FEED PUMP (P11.101 A/B)

4.2.1 Equipment Service

The Slurry Feed Pump will be used to feed slurry from the Slurry Charge Tank (V11.102) to the Dissolver Charge Pumps (P11.102 A thru H). This pump will have a flow rate of 3550 gpm, with a high pumping temperature and a differential head of 97 ft. A nominal viscosity of 350 Cp is expected (see discussion on non-Newtonian fluids to follow). The slurry will be a mixture of coal and recycle slurry. This will be a high flow and low head centrifugal pump, and must be able to handle a viscous, high-temperature, non-Newtonian slurry.

4.2.2 Purpose of Study

There are many pumps on the market which can handle a highly abrasive slurry. The problems arise in trying to find a pump that has excellent abrasion resistance and can also handle the specified temperatures. At the present time there are no slurry pumps in commercial applications handling abrasive slurries at these temperatures. However, the Fort Lewis Pilot Plant does have pumps in this service but they require relatively high maintenance effort.

4.2.3 Results of Work

It was necessary to study several areas of pump design to determine if the conditions of service for the Slurry Feed Pump make it a prototype.

4.2.4 Material Selection

The first area investigated was material selection. With a standard slurry pump at ambient temperature, this area presents little problem. For highly abrasive slurries, such materials as hard rubber, Ni-hard, tungsten carbide, and ceramics can be used as liners to protect the pump casing. Because the Slurry Feed Pump has a high pumping temperature, rubber liners cannot be used. Ceramic liners must also be eliminated because the epoxy which is used to attach the liner to the casing will not hold at the necessary temperature.

At the Fort Lewis Pilot Plant several metals have been tried for pump casings. Among these are carbon steel, 410 stainless steel and CD4MCu. All of these metals have relatively low hardness and have been severely eroded by the slurry.

Several of the softer metal pump casings were flame sprayed with tungsten carbide. This is a process in which a thin layer of tungsten carbide, about 3 to 5 mils thick, is sprayed on the pump casing forming a hard coating. However, these hard metal coatings have a thermal coefficient of expansion which is lower than that for the softer casing that causes the coating to crack or chip, promoting rapid erosion in the chipped area.

To combat the high erosion, metals with Brinnell hardness of 500 or better must be used. Tungsten carbide, 28% chrome iron, and Ni-hard all have a hardness above 500 Brinnell. They are also very brittle and difficult to machine. Tungsten carbide must be ground, but the 28% chrome iron can be rough machined prior to heat treatment. Therefore an alternative suggested by several vendors is to make a lined pump with liners of 28% chrome iron and a casing of a softer metal such as carbon steel. The liners will be used to combat erosion while the casing materials will handle the pressure requirement. In addition, the liners can be designed such that the temperature gradient problems are less severe.

4.2.5 Pump Seals

Proper pump sealing requires special consideration when dealing with these slurry pumps. For a discussion of sealing techniques currently being studied see "Results of Work," Section 4.1.3.

4.2.6 Pump Performance

Because the feed is a viscous slurry, viscosity corrections must be made for head, flow and efficiency. The normal procedure for correcting for viscous flow is to use the viscosity correction chart found in the Hydraulic Institute Standards to obtain head, flow, and efficiency correction factors. However,

these correction charts are limited to Newtonian liquids. The feed slurry has been defined as a non-Newtonian pseudoplastic, which means that the slurry viscosity varies with temperature, time and shear rate. Because the feed slurry is non-Newtonian, problems arise in finding an accurate means of sizing the pumps. The pump manufacturers contacted to date have little knowledge in the area of pumping non-Newtonian liquids. When asked how they would correct pump efficiency for viscous flow, most manufacturers felt that they would use the Hydraulic Institute charts and add a safety factor. A continuing effort is being made to find a more accurate method of correcting for viscous flow. See "Results of Work," Section 4.2.3 for a discussion of these efforts.

4.2.7 Pump Manufacturers

Presently four pump manufacturers have offered pumps for this slurry and the required conditions of service. Lawrence Pump Company has begun to commercially manufacture a slurry pump which is specially designed to handle coal liquefaction applications. The pump Lawrence offered is a model DD slurry pump. It has a claimed operating horsepower of 222 with a viscous efficiency of 43%. A 300-hp motor operating at 1800 rpm has been suggested as a driver. The pump would have a steel casing with impellers and liners made of HC-250, which is a 25% chrome iron. A tandem seal configuration would be used in the stuffing box. Both seals would be metal bellows type. Lawrence is currently manufacturing several of these slurry pumps for coal conversion plants. In addition, an earlier version of the "AL" slurry pump is presently in service at the Fort Lewis Pilot Plant.

Barrett, Haentjens and Company have offered a 10-inch Type "CTP" process slurry pump (see Figure 4-4). This pump has a carbon steel casing, hard-surfaced volute, and an impeller, wearing plates and suction head liner all made of 28% chrome iron. With a corrected efficiency of 55%, the operating horsepower was claimed to be 174. The recommended driver was a 200-hp. motor operating at 870 rpm. Double mechanical seals with an oil circulator was offered with this pump.

Ingersoll-Rand (I-R) is currently developing a new type "AM" coal slurry pump. Although this pump has not been tested and is not being commercially

manufactured, I-R has submitted preliminary information in which they are proposing a 10 x 20 AM slurry pump for the slurry feed service. The "AM" slurry pump has a carbon steel casing with a 26% chrome iron liner. Estimated (nonviscous) pump efficiency is 80%. Pump speed will be approximately 950 rpm. More complete data is not available at this time.

The Duriron Company currently has several of their Durco Mark II and Durco Mark II recessed impeller pumps in service at the Fort Lewis Pilot Plant. These are ANSI-type pumps with casings made of CD4MCu, which were flame sprayed with tungsten carbide by other subcontractors for the pilot plant. Because there are no liners in these pumps, a large number of spare pumps are needed to keep the pilot plant in service. The tungsten carbide coated pumps have experienced heavy erosion and maintenance on these pumps is extensive. For the slurry feed application, Durco has recommended using two Mark II standard 8 x 6-16 pumps each handling 1775 gpm. These pumps, running in parallel, would provide a total flow of 3550 gpm. The pump casing and impeller would be 316 S.S. and Durco recommended having both these parts flame sprayed with tungsten carbide (which has proven marginal). The operating horsepower for each pump was claimed to be 91. A 100-hp. motor operating at 1180 rpm was recommended by Duriron to drive each pump.

All three of the lined pumps show good potential. Lawrence is commercially manufacturing their "AL" slurry pump and has received several orders for this pump. Although Barrett-Haentjens has not manufactured a pump to meet the slurry feed pump requirements to date, they have many years experience in building custom designed pumps. The Ingersoll-Rand "AM" coal slurry pump is a new, untested design. This pump shows promise but will require more study to determine if the overall design will handle the feed slurry application. As was stated above, flame spraying the pump casing has proven marginal when handling SRC coal slurry. The Durco pumps are working in the Fort Lewis Pilot Plant, but high maintenance is required. Because the slurry feed pump will be a large expensive pump, a flame sprayed casing should only be considered if no other erosion protection is practical.

4.2.8 Study Continuation

The biggest problem which needs immediate attention is finding a reliable means of correcting pump head, flow, efficiency and NPSH for viscous, non-Newtonian flows. A test program to determine efficiency, flow, head and NPSH factors on pumps in operation at the Fort Lewis Pilot Plant could be initiated if an accurate means of measuring flow and viscosity could be found. A literature search is currently being conducted to try to obtain information on the subject of corrections for non-Newtonian fluids. Until such time that corrections are known, variable speed drives must be considered to optimize performance. However, since minimum wear is likely to take place near the point of best efficiency it may not be possible to optimize for proper head, flow and efficiency simultaneously.

Contact with the above mentioned pump manufacturers will continue. Also, sealing, variable speed drives, and material selection will be further studied to obtain the best overall pump selection for the slurry feed application.

4.3 DISSOLVER CHARGE PUMP (P11.102 A thru H)

4.3.1 Equipment Service

Eight dissolver charge pumps will each be required to pump 423 gpm of coal slurry containing solids at 2400 psig to charge the dissolver. The approach using eight dissolver charge pumps, instead of four pumps as specified in Phase Zero Deliverable 1, is considered a better design because each preheater pass would be charged by its own pump, thereby eliminating the need for manifolds and valving in this difficult service.

4.3.2 Purpose of Study

Pumps have been manufactured for (1) higher capacities, (2) higher pressures, (3) higher temperatures, or (4) more abrasive slurries. However, the combination of all these conditions makes the dissolver charge pumps unique. The only pumps which are presently operating on coal slurry at elevated temperatures and high pressures are in the pilot plant. These pumps have much smaller capacities than the pumps required for the Demonstration Plant. Because the lead time to engineer and fabricate these unique pumps is estimated at 18 months they were considered long lead prototype items, worthy of early investigation.

4.3.3 Results of Work

Initial investigation disclosed that piston or plunger pumps have traditionally been used for this type of service. However, piston pumps cannot effectively handle very abrasive slurries or slurries at high pressures because the piston sealing rings are effectively destroyed by the abrasive slurry. A plunger pump, on the other hand, has its displacement mechanism, the plunger, operating against a stationary seal. It is possible to flush the stationary packing which allows the plunger to move through a film of clean fluid that isolates the packing from the abrasive slurry. Figure 4-5 shows a typical liquid end for a plunger pump.

Wilson-Snyder, Ingersoll-Rand, Aldrich, and Worthington have all proposed triplex (three cylinders) flushed plunger pumps for this application using

approximately 700 operating horsepower each. The volumetric efficiency has been estimated at 90-95% with a corresponding mechanical efficiency of 85-90%. The proposed operating speeds range between 75 and 125 rpm. From a design standpoint, lower operating speeds result in longer pump life.

A variation of the standard piston or plunger pump arrangement currently under consideration for this application is the surge pump; i.e., a pump with remote valves. This design utilizes a piston or plunger pump with a leg of piping between the valves and the pump. The pump itself contacts only a clean, cool liquid flush which fills the entire surge leg and is compatible with the slurry. The density of the surge leg fluid should be less than the density of the slurry to help prevent migration of the slurry into the pump. A portion of the piping adjacent to the valves, in contact with the hot slurry, would be heated to prevent cooling and congealing of the slurry by fluid in the surge leg. The obvious advantages of the surge pump are increased packing life due to the use of a cool flush instead of a hot flush. Possible disadvantages of the surge pump design include reduced volumetric efficiency, reduced valve life due to "slugging," and slurry settling in the surge leg piping. However, this pump design is being used successfully in a pilot plant on a very small scale. A sketch of the surge pump design is shown in Figure 4-6.

All of the vendors contacted recommended ball-type valves, with all but one indicating free-floating ball valves. Ingersoll-Rand Aldrich, uses a spring-loaded cup to house two 4-inch diameter balls for each valve, which are allowed to slightly rotate. The pilot plant at Fort Lewis utilizes a Wilson-Snyder triplex pump which was originally equipped with spring-loaded hemispherical valves. These failed due to localized wear after only three days. Elastomer soft-seated valves were also tried, but failed after eight hours. Fort Lewis' best experience has been with free-floating hard chromium balls (Rockwell C61-63 hardness) and tungsten carbide seats. Maintenance life of these valves has been estimated at 4000-8000 hours. Other materials recommended for valves and seats include AISI 440C, 4140 and carburized 4620.

In the standard plunger pump design, the item most susceptible to wear is the packing. Suggested packings for the dissolver charge pump include Grafoil, graphite filament, carbon-teflon and polyamide spring-ring types. All of these packings require some type of lubrication. Packing maintenance life has been estimated anywhere from 2 to 10 months with proper flushing.

Packing failure detection methods have also been investigated. One possible method involves the installation of a lantern ring near the atmospheric side of the packing as shown in Figure 4-7.

As the packing deteriorates, the pressure at the lantern ring pressure increases slowly and a pressure switch will activate an alarm to warn of imminent packing failure. This might allow pump shutdown and packing replacement before hot slurry is released to the atmosphere with the accompanying fire hazard.

Flushing injection is accomplished by means of a separate, smaller, and in most cases, crankshaft-driven plunger pump. This synchronized flush is injected either on the suction stroke or discharge stroke to maintain a blanket of fluid between the plunger and the slurry. Flushing injection rates have been estimated from 1/2% to 5% of total pump capacity. The charge pump at the Fort Lewis Pilot Plant uses approximately 2% flushing injection, and their experience confirms that less than adequate flushing greatly reduces packing life. Because part of the process product would be used for flushing injection, it would be desirable to hold flushing to a minimum. It is proposed to initially flush at a rate of 3% total pump capacity and then determine, by actual experience, the minimum requirement for proper pump operation.

Pulsation dampeners will be required in both the suction and discharge piping of these plunger pumps. A suction stabilizer will be required to protect the centrifugal Slurry Feed Pump from the constant fluctuations in flow and pressure. Such fluctuations would have an adverse effect on the performance

of the centrifugal pump. A discharge dampener will be required to provide a smooth flow of slurry to the dissolver. The pulsation dampener design being considered consists of a vessel with a hydrogen blanket at the top. This type of dampener is being used successfully in the Fort Lewis Pilot Plant. Due to the high temperature of the slurry, bladder-type dampeners cannot be used.

Startup and shutdown of these pumps must be performed using heated solvent for the pumpage until the pump is near operating temperature. This is required to prevent the slurry from congealing in a cold pump. On startup, the slurry concentration should be gradually increased. Valve housings should be jacketed for heating to prevent slurry congealing.

Preliminary specifications have been prepared which are based on an API draft for reciprocating pumps, but specifically modified for plunger-type pumps for slurry service. These specifications are too voluminous to be included in this report.

4.3.4 New Developments

A centrifugal pump with the potential to meet the Commercial Plant requirements for the dissolver pump application is being developed under the sponsorship of the Electric Power Research Institute (EPRI). The Rocketdyne Division of Rockwell International has performed for EPRI an extensive research and development program to develop a specialized high-volume, high pressure, centrifugal slurry pump to charge commercial sized coal liquefaction plants of the future. This program is of particular interest due to the fact that no centrifugal pump presently exists that is specifically designed to handle the flows, pressures and abrasive character of the feed slurries to be encountered in the Demonstration and First Commercial Plant.

A good working relationship has been established with Rocketdyne for evaluation of this pump design as it would relate to the specific needs of the SRC-II Plant. It appears that Rocketdyne would be capable of designing a pump

for that service. Space will be available at the Demonstration Plant so that a Rocketdyne designed centrifugal pumping unit can be installed and tested if such a unit becomes available during the Phase III operation.

4.3.5 Study Continuation

Regarding plunger pump design, further investigation will be conducted to evaluate the conventional configuration (valves directly adjacent to the pump) vs. the remote-valve configuration. A pump with remote valves should be installed in the Fort Lewis Pilot Plant if practical to evaluate its performance. In addition, different types of packings should be installed in the plunger pumps at Fort Lewis to determine the optimum type. Specifications for these pumps will be refined to incorporate results from further investigations, vendor input, and field experience.

Contact will be maintained with Rocketdyne to keep abreast of the centrifugal type pump developments and to provide input where possible.

4.4 DISSOLVER CHARGE HEATER -(H11.101 A & B)

4.4.1 Equipment Service

The Dissolver Charge Heater will provide preheat and heat of reaction for the mixture of coal, oil, and hydrogen gas in the radiant section of a fired heater. The heater will also include a convection section and an air preheater to improve its overall efficiency. The coal, oil and hydrogen effluent from this heater will feed the Dissolvers (V11.103 A/B).

4.4.2 Purpose of Study

The Dissolver Charge Heater is a unique fired heater with three phase flow in which the solid (coal) partially dissolves and reacts as it passes through the heater. This type of heater has only been used on bench scale and pilot plant operations. Data acquired must be scaled-up to a demonstration (commercial) sized operation. The delivery and field erection of the necessary equipment is estimated at 31 months.

4.4.3 Results of Work

Engineering support for this heater design was enlisted from a fired heater manufacturer. Preliminary heater design data has been generated for the latest demonstration plant material balance. The manufacturer reviewed the mechanical integrity of the preliminary design but did not completely analyze the thermal characteristics of the fluid.

4.4.4 Continued Study

An extensive program to define the fluid flow and heat transfer mechanisms in the Dissolver Charge Heater is required. This program will rely upon test data from the new Fort Lewis Charge Heater and from the various bench scale work being conducted to verify and/or correlate theoretical and established design criteria.

The complete design effort including parametric studies and firm thermomechanical design will require the expertise of a fired heater manufacturer and probably the use of proprietary design models.

4.5 DISSOLVERS (V11.103 A & B)

4.5.1 Equipment Service

The dissolvers provide the necessary contact time for the coal to react with the recycle slurry and hydrogen previously introduced into the slurry stream. The dissolvers contain hydrogen sulfide, phenols, sulfur, ammonia chlorides and hydrocarbons in addition to the feed coal and operate at a high hydrogen partial pressure.

4.5.2 Purpose of Study

The immense size of the required units, the high pressure and temperature in the presence of hydrogen and other chemicals, and the presence of solids combine to make the design of the dissolvers prototype equipment. In order to meet the Demonstration Plant construction schedule, all of the various design aspects had to be addressed as early as possible in the project life cycle to guard against the possibility of dissolver design becoming the controlling factor in a critical path. The lead time on the dissolver is estimated to be 24 months including fabrication and erection.

4.5.3 Results of Work

4.5.3.1 General Comments and Discussion

In order to define critical areas of design it was necessary to establish the approximate size and configuration of vessels and to establish the nozzle sizes and locations, as well as the operating modes, pressures, temperatures and other characteristics of each stream entering or exiting the dissolvers. This preliminary information was obtained from the process engineers and a discussion of the origin of such information and/or requirements is outside the scope of this section.

Based on preliminary information a definitive design of the vessel was conducted to expose relatively detailed, but extremely critical problem areas and allow time to adequately investigate and solve those problems.

4.5.3.2 General Description

Significant features of the vessel are its heavy wall construction and conical heads. The vessel diameter exceeds 10 feet, with a tangent to tangent length of over 100 feet. The shell thickness is 12-1/2 inches with an additional 1/4 inch stainless weld overlay. The completed vessel will weigh over 1500 tons.

4.5.3.3 Preliminary Design Conditions

The dissolver vessels are designed for the following conditions:

(a) Internal Design Pressure	2250 psig (including static head)
(b) Design Temperature	900 F
(c) Maximum Hydrogen Partial Pressure	Proprietary
(d) External Design Pressure	None
(e) Minimum Ambient Temperature	-27 F
(f) 90 mph wind load in accordance with ANIS-A58.1-1972	
(g) Newmark Blume Kapur Response Spectrum Seismic Analysis (0.06g)	

4.5.3.4 Preliminary Operating Conditions

The dissolver vessels would operate under the following conditions:

(a) Internal Operating Pressure	2150 psia at 860 F
(b) Maximum Hydrogen Partial Pressure	Proprietary
(c) External Operating Pressure	None
(d) Pressure Drop Due to Internals	40 psig
(e) Maximum Vessel Operating Temperature	860 F
(f) Minimum Ambient Temperature	-27 F
(g) Number of Startup-Shutdown Cycles	160 (assumed)
(h) Hydrogen Quench Temperature	85 F Minimum 180 F Maximum
(i) Number of Hydrogen Quench Temperature Cycles	Unlimited
(j) Hydrogen Quench Flow Rate Varies Between 0.24 MMSCFD and 1.44 MMSCFD.	
(k) Gas inlet Temperature varies from 500 F to 800 F	

4.5.3.5 Discussion of Vessel Heads

From a mechanical design viewpoint, hemispherical heads would have been superior to the conical heads. However, process considerations required that conical heads be used if possible within the code requirements. Although normal slurry flow would be upward, duplicate slurry inlet nozzles were required for the future possibility of reversing the flows.

The primary problems disclosed by selection of conical heads with numerous nozzles were:

- (a) Head to cylinder junction stresses
- (b) Discontinuity stress concentrations
- (c) Thermal and possible cyclical effects of the above
- (d) Nozzle space requirements
- (e) Vessel skirt tiepoint stress concentration

A non-axi-symmetric finite element analysis to analyze the conical heads has been started. Should serious stress problems be disclosed during this study, it may become necessary to consider other geometrics or to relocate some of the nozzles. As the project develops, rigorous design by analysis as defined in ASME code Section VIII, Division 2, Appendix 4 will continue and the best configuration will be chosen or, if necessary, major modifications will be made. At this time, several heavy wall fabricators have indicated that they can build the dissolvers with conical heads.

4.5.3.6 Nozzles

All nozzles over 4 inches inside diameter are presently designed as integral forgings meeting material specification SA336 Gr. F22. These nozzles are initially designed in accordance with paragraphs AD540, AD550 and AD212.3 of Division 2. Alternate rules and paragraph AD560, were used in designing the vessel outlet nozzle.

Welding Research Council Bulletin No. 107 will be used to determine nozzle and shell stresses if they fall within the scope of that reference. Otherwise nozzle stresses will be evaluated by analysis.

Nozzles which are smaller than 4 inches inside diameter will be designed in accordance with paragraph AD510 or Appendix 4 of Division 2. Paragraph AD520 permits the use of unreinforced nozzles for nozzle sizes smaller than 4 inches.

Insulated nozzles present a special design problem. These nozzles are being analyzed by finite element methods for both thermal and stress effects in accordance with Appendix 4 of Division 2. In addition, the results of the thermal analysis, which develops temperature gradients in the vicinity of the nozzle, are being compared to the criteria of paragraph AD160 of Division 2 to determine whether the component can be exempted from a fatigue analysis. Based on the results generated to date, it appears that an acceptable design can be developed. If not, a fatigue analysis is required, and a second problem exists in that the data necessary to conduct such an analysis is not available at the 860 F temperature level. Another possible problem exists because a change in the design hydrogen partial pressure would affect the thermal properties of the insulating refractory and thus the thermal analysis. This could trigger a redesign of the insulated nozzles and/or the vessel.

The work performed to date has been done in accordance with Division 2 area replacement methods and is of a preliminary nature. In some cases, where the separation between nozzles does not meet Code requirements, design by analysis will become necessary. In the latter case, this will require that a finite element approach in accordance with Appendix 4 of Division 2 be used.

In nozzle design, three basic configurations were examined when reinforcement replacement was considered. These were the straight shoulder, the tapered or

conical shoulder, and no shoulder. They are illustrated in ASME Section VIII, Division 2 Figures AD-540.1 (a), AD540.1 (c), and AD-540.1 (d) respectively. Each has benefits in its different application.

The straight shoulder is more beneficial for nozzles that are located on the cylindrical portion of the shell where reinforcement is added externally. The cylindrical shell contributes virtually no reinforcement to the total that is required and therefore wall reinforcement comes from the nozzle wall and the relatively large radius between the nozzle and the shell.

The nozzle configuration requiring no shoulder has basically two applications. The first is in the conical head and away from the large junction where the required shell thickness is somewhat less than the 12-1/2 inches nominal thickness. This allows most or all of the required reinforcement to be counted from the cone wall which eliminates the need for the larger nozzle configuration used in the cylindrical portion of the shell.

The second application of the no shoulder nozzle is in the design of insulated nozzles. Bringing the projection of the nozzles closer to the shell wall and increasing the outside diameter of the nozzle allows for better thermal flow within the nozzle, and therefore helps to reduce the temperature gradient in the nozzle. This is necessary in order to eliminate a fatigue analysis, which requires that the temperature gradient must be less than 50 F.

The tapered shoulder type is being considered in the design of only one nozzle, the vessel outlet. This type of configuration is beneficial in that when the nozzle is being reinforced internally and externally it was found that the resulting projection is less. The outside diameter of the forging required to make the nozzle becomes slightly larger than a straight shoulder type of configuration but approximately 6 inches is saved on the projection.

Lenape Forge Company is currently reviewing the design of several nozzles and will advise which is the most economical design in each case. The only limitations on nozzle design imposed on the vendor were as follows:

- (a) A limitation on the forging outside diameter will be required if it becomes so great it is felt that a large amount of metal is being unnecessarily removed from the vessel wall. Depending on nozzle configuration in certain instances, a hole 6 to 7 feet in diameter would be cut in the vessel wall. The most likely alternate is to design to paragraph AD560 in Division 2 Alternate Rules. This would allow the reinforcement boundary away from the vessel wall to be increased. The resulting projection from the vessel wall would be greater but the forging outside diameter would decrease due to less reinforcement needed near the vessel wall.
- (b) An optimum design must be considered when dealing with the nozzle projection and the forging outside diameter. When one decreases the other must increase to maintain the total amount of reinforcement that is required. A large projection is undesirable because of possible damage to the nozzle that might occur during shipping.
- (c) Insulated nozzles will need to be a hub type of configuration, for reasons already stated. This configuration is necessary if the temperature gradient is to be a minimum.

The current design of the horizontal thermowell is removable with a 1-inch inside diameter and is slightly skewed in order to miss interference with the 24-inch discharge pipe. A design by analysis will be performed on the nozzle because it does not meet the circular opening requirement per paragraph AD510 in ASME Section VIII, Division 2. The dissolver design requires three sets of two thermowells.

4.5.3.7. Internals

Vessel internals will most likely be fabricated from either SA387 plate overlaid with stainless type 347 or stainless type 321 pipe and fittings. Internals welded to the vessel inside diameter will have attachment welds with a 1-inch minimum radius of curvature. Internal bolting is anticipated to be SA193-B8C with SA194 B8C nuts.

The discharge pipe which extends internally from the top of the vessel down through the center and exits above the lower tangent has been preliminarily designed for an external differential pressure of 100 psig and a lateral pressure of 10 psi acting on the projected area of the pipe. This pipe is supported vertically by the outlet nozzle. Lateral supports are provided at quarter points along the length of the pipe. Thermal effects due to variations in temperature and to dissimilar materials remain to be investigated. Stresses must be within code allowables for all conditions of loading.

Other internal piping such as gas quench distributors will be designed for the same conditions as the discharge pipe.

Thermowells are being designed for the vessel pressure of 2250 psig acting on the convex surface and also 10 psig acting laterally on the projected area. Lateral supports are envisioned to assure that stresses remain within code allowables for all anticipated loading conditions. These supports would have pinned or sliding connections in order to allow essentially unrestrained thermal expansion.

The vessel fabricator will be limited to a minimum radius of curvature on internals. This also applies to fillets between the vessel wall and clips and gussets. This will provide mechanical advantage by eliminating stress risers which are crack initiators. A 1-inch minimum radius of curvature is being considered. More detailed information will be obtained before this decision is made.

The design consideration of a 10-psi pressure acting on the projected area of internals in any one direction due to process flow was used for initial design. This figure seems to be high and forces the design of some internals into an overly conservative approach. For instance the horizontal 1-inch inside diameter thermowell requires a 0.250-inch wall thickness to retain the 2250 psig external pressure acting on it but if stresses due to the 10-psi

pressure on the projected area of the pipe are superimposed, the required wall thickness becomes 0.750-inch. Besides being cumbersome this thickness may introduce an unacceptable time lag in sensing temperature. This is presently being evaluated by the instrumentation group.

All pressure retaining connections on the inside of the dissolver will be a ring type joint with an octagonal solid wire ring and a 2500 pound class flange. Internal connections which do not retain pressure will consist of a spiral wound asbestos filled gasket with 150 pound class flanges.

4.5.3.8 Vessel Supports

Supports are presently designed for operating loads acting concurrently with either a seismic event or a maximum wind load, whichever is greater. In the absence of seismic design criteria, a 0.06g maximum ground acceleration was assumed. A discrete mass model was submitted to a Newmark-Blume-Kapur response spectrum analysis. Four percent of damping was used in higher modes. Moments and shears were determined from the analysis and were used in designing the skirt and base ring. An ANSI A58.1 (1972) wind analysis will be performed later on this vessel. It is anticipated, however, that seismic forces, rather than wind forces, will control the design of heavy vessels such as the dissolver.

4.5.3.9 Access

Access is an important aspect in the dissolver design. All internals could require removal and reinstallation for maintenance with the exception of clips and some gussets. Therefore, it was necessary to establish a method in which the internals could be installed and removed when required.

A 42-inch future gas outlet in the upper conical head also serves as an access opening. It will facilitate installation and removal of any internals. There is of course a maximum limitation on the size of internals that can go through that access opening. When an internal part was too large, that part was simply flanged into several pieces. For instance, the gas quench sparger is actually composed of three flanged pieces.

The maximum height to which a crane will be able to lift limits the length of internals. Since it would not be practical to withdraw the vertical thermowell, it must be flanged into several pieces with each piece of suitable size for removal. This method of removal will also apply to the 24-inch internal discharge pipe.

4.5.4 Fabrication, Erection and Transportation

There are three alternate ways for fabricating, shipping and erecting the dissolver and all three will be evaluated. These alternatives are as follows:

- (a) Complete shop fabrication
- (b) Partial shop fabrication with the vessel completed at the jobsite while the vessel is in the horizontal position
- (c) Partial shop fabrication with vessel completed at the jobsite with vessel in the vertical position on the vessel foundation.

The selection of the best alternative will be based on the construction schedule and total cost.

Direct barge shipment of the completed vessel fabricator's plant to the jobsite is feasible because of the 9-foot minimum channel maintained on the Monongahela River. This depth is sufficient for barge shipment of the dissolver. Further, none of the structures which cross the navigated rivers present any clearance problems.

The dissolvers would most likely be shipped with crawler-type transporters as supports. The barge would be beached at the landing site and the crawlers and vessel would be driven off of the end of the barge and up an access road to the point of installation. This crawler type transporter has been shown to be a dependable method of hauling heavy loads. They are capable of hauling the dissolver up the 10 to 12 percent grades anticipated for the haul road from river to the plant site. The haul road must be capable of supporting bearing loads of approximately 7000 pounds per square foot and be about 32 feet wide.

After the vessel has been transported to the foundation, it must be lifted from the horizontal position to the vertical position and set on the foundation. Crane lifting capacity of approximately 2000 tons is currently being developed and will be available in time for use during the construction of the SRC-II Demonstration Plant.

Alternately for vessels weighing more than 800 to 1000 tons, some field fabrication must be considered even if the plant site is on a navigable river. The extent of this field fabrication would be dependent on the availability of equipment, schedule and cost of shipping and erecting a heavy vessel. In any case, cylindrical sections would be fabricated with vertical vessel seams being shop welded. It would then be necessary to make horizontal vessel welds in the field. Making these welds while the vessel is in the horizontal position permits the use of automatic welding. If the vessel is assembled on its foundation in the vertical position, the shell would be assembled on a ring-by-ring basis with girth welds made by the manual submerged-arc process. However, postweld heat treatment would be easier in the vertical position. In both cases the vessel seams which were being welded would need to be protected from the elements by an insulated weather shield. This weather shield could serve a dual purpose by acting as a postweld heat treatment furnace after the welding was completed.

Even though the welding on a vessel in the horizontal position can be accomplished in a fraction of the time that it would take for a vessel in a vertical position, there are some other considerations to be addressed. First, adequate temporary foundations must be provided for the rolls which support and turn the dissolver during the welding operation. Second, the rolls and automatic welding equipment must be transported to the field and set up. Third, the completed vessel must be lifted in one piece. This necessitates the use of special lifting equipment and thus eliminates some of the economic advantages of this option for field erection and fabrication. Fourth, a wide access path through the plant would have to be kept open until the vessels were set. The last consideration also exists for the totally shop fabricated vessel and could have enough of an impact on the overall

construction schedule to make field assembly on the foundation desirable. However, field construction poses problems with inspection of weld joints made in the field.

The ASME Code currently requires that all pressure boundary shell welds be 100 percent radiographed. Extremely heavy wall thicknesses require the use of a linear accelerator in order to produce radiographs which are interpretable in accordance with the ASME Code. At the fabrication shops these linear accelerators are in rooms with concrete walls several feet thick. Suitable methods of shielding for field use must be developed to protect workers and the environment at the construction site. This problem is not considered insurmountable, but field radiography using a linear accelerator has not been performed to date.

Postweld heat treatment of vessels completed in the field is another critical step in their construction. Vessels larger than the dissolvers have been postweld heat treated in the field. For this stress relief operation, either a fired furnace, electric resistance heaters, electric induction heaters or the vessel itself could be used as a furnace. However, use of electric resistance heaters and induction heaters in the past has created some problems which must be resolved before these techniques can be applied to the SRC-II Dissolvers.

The hydrostatic test will be performed in accordance with Paragraph AT-300 of Division 2. To insure ductility of the dissolver vessel during the hydrostatic test, the water must be heated to a temperature at least 60 F above the nil-ductility temperature of the vessel material. The test water must also be fresh water with a chloride content of less than 100 ppm. Immediately after the test all vessel parts with austenitic stainless steel exposed to the test water must be thoroughly rinsed with commercial distilled or demineralized water containing less than 10 ppm total dissolved solids and less than 1 ppm chloride. These requirements could be difficult to satisfy for a vessel hydrotested at the jobsite. Water may have to be hauled in from

a source away from the jobsite. The answer to these questions will be available when the jobsite water quality tests currently being performed are completed.

Due to concerns expressed above, it is preferable that the dissolver vessels be totally shop fabricated. However, it has been demonstrated on a number of petroleum/petrochemical and nuclear jobs worldwide that the same quality in fabrication can be achieved in the field as in the shop.

4.5.5 Materials and Metallurgy

Hydrogen partial pressure significantly influences the selection of vessel shell materials. Therefore, an upper limit of 1700 psia for 2-1/4 Cr-1Mo steel at 900 F was determined by mutual agreement with Gulf Science and Technology, as a conservative reference point taken from the Nelson Curve. However, the referenced curve is a dashed line which refers to surface decarburization only. There is no line on the Nelson Curve to delineate internal fissuring (hydrogen damage). A check with Mr. Bohner, custodian of the Nelson curve data accumulation, revealed that in 15 years of data collection, there has never been a case of hydrogen damage reported in 2-1/4 Cr-1Mo steel. In fact, API 941 states that for any given temperature hydrogen partial pressure may go as high as 6000 psi without damage.

In the case of the dissolver for this project, the internal surface which is overlayed with stainless steel, is protected from surface decarburization and therefore should be fully protected for the hydrogen partial pressure of the SRC-II process. This interpretation will be the subject of further discussion and evaluation with Gulf Science and Technology. No problem with hydrogen containment is foreseen with current design criteria, but Stearns-Roger and Gulf Science and Technology are participating in further evaluation.

The process hydrogen partial pressure at the dissolver outlet would be appreciably less than 1700 psi; however, concern has been registered because of the hydrogen purity at the inlet of the dissolver. Gulf Science and

Technology is also evaluating the effect of mixing. If the mixing test verifies that the containment vessel is not exposed to hydrogen at a partial pressure greater than 1700 psia, then the above discussion becomes academic.

The SA387 Grade 22 steel selected for this vessel can be supplied in two classes; Class 1 to a minimum of 30,000 psi yield strength; and Class 2 to 45,000 psi yield. The higher strength material is obtained by quench and tempering. The other alternative is to use ring forgings instead of plate. These forgings would be produced to SA336 Class F22. The designation is different for the forged rings but the mechanical requirements are the same. In either case the ring thus formed would be austenitized and liquid quenched for accelerated cooling. That would be followed by a temper of 1100 F minimum if the ring is made from SA336, or 1250 F minimum if made from SA387. The material would be prequalified after being subjected to 6-3/4 hours tempering and 27 hours of stress relief. (It is noteworthy that the forgings may be tempered at a minimum temperature of 1100 F, while the plate must be tempered at 1250 F minimum according to the Code.)

Work performed by Japan Steel showed that a cooling rate slower than 9 F per minute produces primary ferrite which degrades the strength and toughness. Colorado School of Mines also confirmed this critical cooling rate requirement. Cooling rates of this order cannot be accomplished without accelerated cooling, such as water quenching.

One of the documented adverse properties of 2-1/4 Cr-1Mo steel is its susceptibility to temper embrittlement. This is a steel with a transition temperature near ambient temperature; however, after service at elevated temperature, it suffers an upward rise in transition temperature.

This has been discussed in Metal Properties Council (M.P.C.) meetings, and a sponsored study by McMahon has shown residuals such as P, Si, Mn and their interaction as well as some tramp metals to be most significantly related to temper embrittlement.

Swift, of Lukens Steel reported, "Embrittlement of quenched 2-1/4 Cr-1Mo Steel Upon Tempering," and that tempering in the range of 400 to 1100 F results in temper embrittlement but tempering a higher temperature (which for this application is 1250 F) does not produce embrittlement. This is more clearly defined by the statement in that paper that "Tempering above 1100 F does not result in embrittlement and exposure to temperatures within the 400-1100 F range after tempering does not cause a reversion to the embrittled state." Further substantiation is contemplated in the current M.P.C. committee activity.

It would appear from Lukens findings that embrittlement problems do not exist. However, the vessel is intended to operate at 860 F (well within the temper embrittlement range). It is therefore important to consider temper embrittlement as a possible problem. Consideration of means to alleviate the conditions are, therefore, germane to the material selection.

The problem of temper embrittlement, if one exists, is related to residuals. In this regard vacuum degassed steel is recommended as a means of obtaining a cleaner steel with low residuals. In discussing this subject with potential suppliers, it appears that a domestic supplier, Lukens, will not guarantee sulfur and phosphorous less than 0.025 percent without a cost extra. The guaranteed impurity limit quoted from Japan and France is much lower at no extra charge.

The heat of welding raises the temperature in the solid zone immediately adjacent to the weld. If sulfur, phosphorous, manganese and silicon are segregated in this heat-affected zone, they can cause localized melting by forming a eutectic. Upon resolidification, micro-cracks which lower the toughness and strength can result.

If the residuals content is maintained at a low level, the availability of eutectic formers are restricted and the problem is alleviated. Another means

of controlling this adverse condition is to use ring forgings instead of rolled plate, for in so doing the vertical seam welds (those more critically stressed; i.e., hoop stressed) are eliminated.

It is also important to further protect against the effect of temper brittleness by heating the vessel to about 300 F minimum before applying an intentional stress to it. This is common operating practice and will be specified in the final design. Preheat must be applied during start-up also.

4.5.6 Study Continuation

4.5.6.1 Conical Heads

The analysis of conical heads, nozzles and discontinuities are being continued. Finite element program ANSYS is being used to determine stresses in accordance with Section VIII, Division 2, Appendix 4 of the ASME Code.

Pressure stresses, thermal stresses and discontinuity stresses must satisfy the conditions of the referenced Code. In the event that an overstress is indicated in some areas, it may become necessary to relocate nozzles or change the vessel head geometry. Seismic analyses must be revised when site seismic design criteria is established. External mechanical loads such as pipe loads will be addressed at a later time after these loads have been developed.

4.5.6.2 Thermal Analysis

The thermal analysis is, in a definite sense, dependent upon the heat transfer coefficients which are being developed in a separate analytical effort. ANSYS is again being used to determine both node point temperatures and thermal stresses. The present design philosophy is to obviate a fatigue analysis by meeting the exclusion provisions of paragraph AD-160 of the Code.

Specifically, a maximum differential temperature of 50 F is allowed over a shell length of $2.5 \times \text{SQRT}(R_m t)$. The Battelle Institute has developed a program under DOE auspices which calculates heat transfer coefficients for refractories in high hydrogen environments. This program has been obtained and is now being used to evaluate several refractories for their thermal properties in high hydrogen environments.

4.5.6.3 Hydrogen Partial Pressure

The hydrogen partial pressure which is to be used for the vessel design is being reviewed by Pittsburg & Midway's engineering staff in order to make a final decision on this matter. The hydrogen design pressure will substantially affect the selection of shell materials and it will also affect the thermal conductivity of refractories.

4.5.6.4 External Coke Pressure

Experience with pilot plants indicates that coke build-up can develop in annular spaces around pipes causing the pipe to collapse. Gulf Science and Technology is reviewing this problem with the intention of determining the mechanisms which caused these failures. If it is found that pressures due to coke crystal growth in a confined space are responsible, coke pressures will be determined so that internal piping can be adequately designed.

4.5.6.5 Closures and Seals

Grayloc closures are being considered for all pressure boundary nozzles largely because they are thought to be the most positive seal available. The presently proposed ring seal is made of nickel plated AISI1660 material, which has been used on several gasifiers and is now being installed in the Ft. Lewis Plant. Grayloc is a proprietary product and consequently requires an exemption from competitive bidding. Other types of closures, such as ring type joints, have given reliable service on similar installations and, in an effort to develop competition, they will also be considered for the dissolver service. Internal piping flanges will be sealed with spiral wound gaskets. Studies are continuing with the objective of developing a thoroughly reliable closure while still maintaining competition.

4.5.6.6 Materials and Metallurgy

A task group has been formed under the sponsorship of the M.P.C. to address the material problems discussed above. The study involves vessels of the next generation in size but spin-off technology is expected to become available.

A paper by Dempsey and Tunnell, "The Challenge of the Gigantic Pressure Vessels" presented to the American Welding Society should also stimulate a response in applicable welding technology improvements.

Colorado School of Mines has requested funds to study overlay welding by gas metal arc using strip filler metal. Since extensive overlay will be involved in the dissolvers, participation in that project will be important. There have been reports of type 347 weld overlay cracking transversely. This has not been reported as a problem at the Ft. Lewis Pilot Plant, but certainly this potential problem will be evaluated by CSM and Stearns-Roger will participate in their findings.

A study of hydrogen permeation through stainless steel overlay is presently being funded by M.P.C. and it is being monitored.

An evaluated comparison of plate and ring forging construction is the subject of an ongoing study but it is difficult to finalize until prices become firm.

4.5.7 Feasibility Review

Several heavy-wall vessel manufacturers have been contacted for the purpose of determining the feasibility of different aspects of the dissolver's design. This is a continuing process as new problems are often encountered at this stage of design. Some of these problems require practical application experience that only this type of manufacturer can provide.

Several of these manufacturers are currently reviewing preliminary drawings that were given to them for "review purposes only." As new problems arise drawings and/or specifications of a non-proprietary nature will be transmitted to them for review in an attempt to obtain the most practical design.

4.5.7.1 Internals

In the future, the 10 psi pressure acting on the projected area of internals due to process flow will be reconsidered. If 10 psi is an overly conservative

figure, it would be beneficial from a mechanical design standpoint to attain a more practical number, because of the extremely close spacing of supports that will be required and the oversizing of internals.

The geometry of internal clips and gussets must be determined for all conditions of loading on internals. Drawings do not show the clips or gussets but there should be no problem in developing a design for them in which interference with other internals is nonexistent.

4.5.7.2 Insulated Nozzles

A preliminary analysis on the insulated nozzles has been completed, and at this time it is felt that the present design is sufficient to meet the fatigue analysis exclusion provision of paragraph AD-160 in Division 2. A future consideration of the design will be selection of a suitable refractory, which will be determined by the CONBEC computer program already discussed. Another consideration will be the coking pressure which was discussed previously.

Installation of refractory anchors and/or strengthening needles or fibers is a possibility, but will depend on their effect on the thermal conductivity of the refractory. This will be considered in the final design of the insulated nozzles.

All considerations in the insulated nozzles design will need to be subjected to the final finite element analysis to determine the thermal profile in the nozzle, which must indicate a temperature gradient of less than 50 F. This is a rigorous and very time consuming process that must be used to eliminate the requirement for a fatigue analysis.

4.5.7.3 Blowdown Analysis

A blowdown analysis study has been made. Several concepts were considered. The prevailing concept will use the dissolver letdown system rather than pressure relief to atmosphere.

4.6 DISSOLVER EFFLUENT SEPARATOR (V11.104 A/B)

4.6.1 Equipment Service

A Dissolver Effluent Separator is immediately downstream of the Dissolver and separates the Dissolver effluent into a vapor stream and a slurry stream. This vessel operates at essentially the same temperature and pressure as the Dissolvers (Item V.11.103 A/B).

4.6.2 Purpose of Study

Many of the problems associated with the design and fabrication of a low alloy vessel with an approximately 12 inch wall thickness are present for the dissolver effluent separator. However, the length of each vessel is only 10 feet 6 inches and thus would be shop fabricated. Shipment and erection can be accomplished using methods and equipment which are readily available.

These vessels will be long delivery items with an estimated delivery of 18 months.

4.6.3 Results of Work

Since the materials, design pressure and wall thickness of these vessels are essentially the same as the Dissolvers, much of the development work on the Dissolvers is applicable to these items. However, the Dissolver problems of large overall size, many closely spaced nozzles, and cold quench nozzles are not present in these vessels. Therefore, the design and analysis is more routine in nature. Because the operation of these vessels should not cause adverse thermal gradients or cyclic loading a fatigue analysis will not be required.

In order to develop a cyclonic flow inside the separator an inlet nozzle with a diameter of 20 inches to 24 inches which is offset from one of the cardinal center lines will be required for this vessel. In addition, the inlet nozzle must be skewed at an angle of 60 degrees from the horizontal such that the Dissolver effluent entering the separator impinges of the liquid surface inside the vessel in order to dissipate the kinetic energy. A design

alternate being considered is one in which the nozzle penetrates the top head instead of the cylindrical sidewalls, and that the top head should be hemispherical. In penetrating the top head, the nozzle can be installed essentially normal to the head and still meet the offset requirements. This minimizes many problems in the design and analysis of the nozzle to shell intersection. Also, the hemispherical head will be only approximately one-half as thick as a cylindrical shell, further simplifying the nozzle installation.

These items have been studied only to the extent necessary to assure that all problems associated with the Dissolver Effluent Separators are less severe than similar problems being studied on the Dissolvers. No major problems in design, fabrication, shipment or erection are expected.

4.6.4 Continued Study

None, except as may be indicated by further Dissolver studies.

4.7 HP STEAM GENERATOR NO. B.11.101 A/B

4.7.1 Equipment Service

The HP Steam Generators are large, forged steel, thick-walled, fixed tube sheet heat exchangers which generate saturated steam using dissolver effluent as the heating media.

4.7.2 Purpose of Study

Moderate pressures and temperatures, combined with corrosive and erosive properties of effluent gases require an alloy steel material with stainless steel overlay. Choice of vendors is limited by their capability to manufacture and handle large forgings. The estimated delivery is 21 months.

The final design will be greatly dependent on the final process specifications. There is no parallel for this design in petroleum hydrogenation and some technological information can be obtained by tests only.

4.7.3 Results of Work

The work on the design of the HP Steam Generators resulted in a preliminary design. The final design of HP Steam Generators (to the final process conditions) should be essentially the same as the design discussed below. There is a high degree of confidence that the design approach presented will satisfy the process requirements. At the present time we are not aware of any unsolvable problems.

The design concept consists of a vertical heat exchanger with axial inlet-outlet nozzles. The effluent flows through the tubes with high velocities thus minimizing fouling and plugging of the tube side of the heat exchanger.

To provide positive separation between the tube side gases and shell side saturated steam, a fixed tubesheet design was proposed. The heads of the heat exchanger will be removable for maintenance and inspection.

The selection of materials was dictated by the process conditions. Forged, 2-1/4 Cr-1Mo alloy steel has been selected for the shell, tube sheets and heads of the heat exchanger. The head and tube sheet surfaces in contact with the hydrocarbon gases will be overlaid by 321 SS due to the presence of H_2S .

The tubes were the most critical part of this heat exchanger design. To minimize differential thermal expansion between the shell and tubes and still satisfy corrosion and erosion requirements on the tubes, 12 Cr alloy steel was chosen. Tests are being performed by Gulf Science and Technology Corp. to confirm the suitability of this material for the intended service. If these tests do not yield satisfactory results, the possibility of using 321 SS tubes with 321 SS shell, or the use of bimetallic tubes will be investigated.

Extensive design work was done toward providing removable heads. Seals for the heads, as well as the head design were investigated.

A self-energized Grayloc Seal was chosen because the Grayloc seal has a good service record in comparable duty. Machining of the sealing surfaces is relatively uncomplicated and the ring can be used on overlaid surfaces. Grayloc seals have been used successfully in the Fort Lewis SRC Pilot Plant.

There were three types of enclosures considered in the head design: (1) hemispherical (2) ellipsoidal and (3) conical. It appears that a conical head offers the most economical bolting arrangement and improves distribution of the inlet gases over the entire tubesheet face. Good resistance of a conical head to radial rotational moments helps to decrease the secondary forces on the head bolting. The smaller resulting outside diameter of the head and shell flanges will compensate for the increased head thickness compared to other types of heads. A "long hand" stress discontinuity analysis was performed for the preliminary design.

The dissolver effluent gas contains amounts of corrosive substances and solid particles. At the existing temperatures and flow velocities, corrosion and erosion protection is very important. A stainless steel overlay is

recommended for 2-1/4 Cr-1Mo surfaces in contact with the hydrocarbon stream. Recommended material for the tube is 12 Cr. There is indication that 12 Cr tubes will resist erosion up to velocities of 40 FPS. The actual design calculations are based on 25 FPS velocity in the tubes.

Present process data show saturated steam and water at 602 F on the shell side of the Steam Generator. The type of baffles used will influence the thermal efficiency, the pressure drop through the shell side, and the stability of the tubes under various loading conditions. Progressive rod type baffles are recommended over conventional segmented ones for improved flow distribution on the shell side. Recommended material is 304SS. The rod type baffle design will also permit use of rod type impingement baffles at the shell side inlet nozzles.

Four inlet and four outlet radial nozzles spaced at 90 degrees were specified for the shell side. Studded flange connections utilize standard 1500 lb flanges modified for the Grayloc sealing rings. The choice of this arrangement was influenced by the good service record of Grayloc seals in a similar service. The Grayloc seal also improves flange rating by decreasing the pressure diameter of the flange.

The design of the tubesheets and of the tube to tubesheet joint appears to be the most critical part of the fixed tubesheet head exchanger. The tubesheet design was based on 2200 psi of differential pressure and 850 F of design temperature. The Standards of Tubular Exchanger Manufacturer's Association (TEMA) offers a comprehensive source of the heat exchanger calculations, but these calculations are limited to heat exchangers of rather common size and service. TEMA data does not apply for heat exchangers where the product of internal diameter times the pressure exceeds 60,000. In the SRC-II case this number is 85,800, so application of TEMA formulas could give erroneous results. The ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, (later referred to as "Code") does not include design formulas for fixed

tubesheet heat exchangers. Formulas from Miller's "Design of Tube Plates in Heat Exchangers" were used which includes the effects of interaction between the tubes and tubesheet. The ligament efficiency for a square pattern from more current papers was substituted into the Millers formulas. Stresses were checked against the allowable stresses in the Code. Allowable tube loads were calculated using TEMA approach. The calculation yields tubesheets with a thickness of 8-1/2 inches. For thick tubesheet, the load on the tubes due to a differential thermal expansion will control the allowable temperature difference between the two process streams.

According to the above calculations, strength welding of the tube to tubesheet joint will be required. Rolling of the tubes into the tubesheet will not improve the joint because of the difference in tube and tubesheet coefficients of thermal expansion with the moderate temperature present. Therefore, tube rolling will not be employed. The 1-1/4-inch pitch developed as a part of the exchanger thermal rating does not allow enough space for strength welding. Therefore, the thermal rating will have to be reconsidered with a larger pitch design.

The outside surface of the steam generator would be insulated. The insulation would lower the thermal gradient through the shell, substantially decreasing the thermal stresses.

4.7.4 Study Continuation

The next phase in design of the HP Steam Generator will consist of the following:

- (a) Redesign of the heat exchanger in accordance with the final process specification. The final calculations will include the finite element method calculations for conical heads and tube sheets. A larger pitch of the tube pattern must be incorporated.
- (b) In cooperation with Gulf Science and Technology Corp., detailed material specifications will be developed.

- (c) In cooperation with vendors, the tube to tubesheet joint detail will be investigated and a proper approach selected.
- (d) If tests on 12 Cr alloy steel show negative results, different tube and shell materials will be considered.
- (e) Criteria for the practical limits in the shell and tube temperature and pressure loadings must be developed. These criteria must be compared to all possible operating and upset conditions specified by the process group and the final design must be developed and evaluated.

4.8 RECYCLE HYDROGEN PREHEATER (E11.102 A/B)

4.8.1 Equipment Service

The Recycle Hydrogen Preheaters are large, forged steel, thick-walled, floating head heat exchangers with floating tubesheets which preheat recycle hydrogen using dissolver effluent as the exchange media.

4.8.2 Purpose of Study

Moderate pressures and temperatures, combined with corrosive and erosive properties of effluent gas and with a high hydrogen partial pressure, require a combination of materials consisting of stainless steel or alloy steel with stainless steel overlay. The choice of vendors is limited by their capability to handle and manufacture large forgings. The estimated delivery is 26 months. The final design is dependent on the final process specifications. There is no parallel for this design in petroleum industry and some technological information can be obtained through tests only. The most critical area of the design appears to be the floating head seal. The design is reliable, but the life expectancy of the packing has not yet been defined.

4.8.3 Results of Work

The work on the design of the Recycle Hydrogen Preheater resulted in a preliminary design. The final design (to the final process conditions) is expected to be essentially the design discussed in the following paragraphs. There is a high degree of confidence that the design approach presented here will satisfy the process requirements. At the present time no major, unsolvable problems are apparent.

A vertical type heat exchanger with the axial inlet and outlet nozzles is recommended. This arrangement with higher velocities of dissolver effluent should minimize fouling and plugging of the tube side of the heat exchanger. Because of a substantial temperature difference between the shell and tube sides of the hydrogen preheater, a floating head arrangement is recommended. The top head of the heat exchangers will be removable. The bottom head

integral with the shell will contain a sliding tube packing assembly. The tube bundle with the upper tubesheet and with the floating head is removable through the top of the heat exchangers.

The presence of hydrogen at high temperature and pressure dictates the selection of materials. Forged, 2-1/4 Cr-1Mo alloy steel was recommended for the shell, the tubesheets, and the heads of the heat exchangers. The Nelson Curve for this material indicates that there is no danger of hydrogen attack at the design pressure of 2350 psig and at the design temperature. The upper head tubesheets, floating heads and tubesheet surfaces in contact with the hydrocarbon gases are overlaid by 321 SS. To satisfy corrosion and erosion requirements on the inside diameter of the tubes and to obtain good resistance to the hydrogen attack on the outside of the tubes, 321 SS has been selected for the tubes.

A major effort was design of the upper removable head and tubesheet area. Several different seal design approaches were considered.

The self-energized Grayloc seal was recommended because the Grayloc seal has a good service record in comparable duty. Machining of sealing surfaces on the vessel is relatively uncomplicated and a ring can be used with overlaid surfaces. The Grayloc seal has been successfully used in the Fort Lewis SRC Pilot Plant.

Three types of enclosures were considered for the upper head design: hemispherical, ellipsoidal and conical.

The conical head offers the most economical bolting arrangement and also improves distribution of the inlet gases over the entire tubesheet face. Good resistance of a conical head to radial rotational moments helps to decrease the secondary forces on the head bolting. The smaller resulting OD of the head and shell flanges will compensate for the increased head thickness compared to other types of heads. The upper tubesheet is to be sandwiched

between the upper head and shell flanges. A "long hand" preliminary stress discontinuity calculations were performed for the upper head and tubesheet assembly.

Existing process information indicates that there would always be positive pressure drop between the shell (hydrogen) and tube (hydrocarbon) sides. Under this assumption, the floating head will always be under an external differential pressure with normal operating conditions present, or under the full external pressure at upset conditions when the pressure approaches zero on the tube side.

The recommended floating head design consists of a floating tubesheet enclosed by a bolted hemispherical head with a packed sliding tube extension. This is the most efficient design for an external pressure application. A contained face gasket seal was provided for the floating head assembly. Under normal operating conditions, the gasket must seal against a differential pressure between the shell and tube sides of the heat exchanger. With upset conditions present, external pressure will increase compression of the gasket, thus improving the seal.

The floating head sliding tube packing, located inside the outlet nozzle in the bottom head of the Recycle Hydrogen Preheater, separates the hydrogen and hydrocarbon flows. Because of high pressure, high temperature and the presence of hydrogen, Grafoil packing was chosen. Of the many packing materials available, Grafoil is the only material with consistent performance in similar service. Some leakage of hydrogen past the seal into the hydrocarbon stream can be tolerated as this is not dangerous and will only result in an insignificant decrease in the process yield. However, the packing was designed to allow no leakage for all defined process conditions.

The tube pattern selected was a triangular pattern on the 1-1/4 inch pitch which was developed as part of the heat exchanger thermal rating. The tube to tubesheet joint calculations showed that rolling of the tube would not be

sufficient and that strength welding of tubes would be required. This would require increased pitch to provide room for strength welding requirements. Because of triangular pattern, segmented baffles will be used.

There were four inlet and four outlet radial nozzles, spaced at 90 degrees on the shell side. Studded flange connections which utilize standard 1500 lb flanges, modified for the Grayloc sealing rings were provided. Choice of this arrangement was influenced by the good service record of Grayloc seals in a similar service. The Grayloc seal also improves flange rating by decreasing the pressure diameter of the flange.

Design of the heat exchanger was carried out in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 (later called, "Code"). Application of the Standards of Tubular Exchanger Manufacturer's Association was limited to the "Recommended Good Practice," because of TEMA restrictions on size and pressure of the standard heat exchangers. Formulas from Miller's "Design of Tube Plates in Heat Exchangers" were used. The ligament efficiencies for a triangular hole pattern from the Code were substituted into Miller's formulas. Resultant calculated stresses compared favorably to the Code allowable stresses.

Since the outside surface of the Recycle Hydrogen Preheater will be insulated, the insulation will lower the thermal gradient through the shell, substantially decreasing thermal stresses.

4.8.4 Study Continuation

The next phase in design of the Recycle Hydrogen Preheater will pursue the following program.

- (a) Redesign of the heat exchanger in accordance with the final process specifications. The calculations will include the finite element method calculations for conical head-tubesheet combination. A larger pitch of the tube pattern will be incorporated.
- (b) In cooperation with Gulf Science and Technology Corp., detailed material specifications will be developed.

- (c) In cooperation with vendors, the tube to tubesheet joint detail shall be investigated and a proper approach will be selected.
- (d) The floating head packing selection and design will be reviewed.
- (e) The design of the floating head gasket shall be finalized after possible alternates have been investigated.

4.9 HIGH PRESSURE FLASH RECYCLE PUMPS

(2nd High Pressure Flash Recycle Pump P11.105 ABC

3rd High Pressure Flash Recycle Pump P11.108 A,B

4th High Pressure Flash Recycle Pump P11.107 A,B)

4.9.1 Equipment Service

All of these pumps handle a portion of overhead flash condensate which will contain some solids carryover, perhaps up to 1 percent by weight. The solids are believed to be 10 to 50 microns in size and highly abrasive. In addition, all of these pumped streams will contain chlorides and hydrogen-sulfide.

<u>Item</u>	<u>Capacity</u>	<u>Suction Head</u>	<u>Discharge Head</u>	<u>Temp.</u>
2nd H.P.F.R. Pump	200 gpm ea.	2000 psig	2050 psig	Prop.
3rd H.P.F.R. Pump	50 gpm ea.	2000 psig	2100 psig	115°F
4th H.P.F.R. Pump	12,800 gpm ea.	1980 psig	2030 psig	150°F

4.9.2 Purpose of Study

The major concern about these pumps is proper material selection to accommodate the high suction pressures, the erosive streams and the corrosive nature of H₂S and the chlorides.

Secondly, the 2000 psig pump suction pressure could require special seal and thrust bearing designs.

Last, the 4th H.P.F.R. pump capacity for 12,800 gpm is unusually large for a pump casing designed for 2000 psig pressure which handles erosive and corrosive material.

These three concerns combine to make these pumps long lead procurement items (≈18 months) and to a considerable extent, they are prototypes.

4.9.3 Results of Work

Of fifteen pump manufacturers contacted, only five submitted specific recommendations for this service. Only one vendor has actually manufactured a pump which has been used in similar conditions of service.

The materials recommended for the wetted pump parts included CD 4MCu, Alloy 13-4, and 12 percent chrome-iron. These materials have a Brinell hardness in the 260 to 280 range. Pumps made of these materials have required extensive maintenance in less than one year when used in similar service.

By reducing the corrosive effects of H_2S and the chlorides through the use of ammonia to adjust the pH, harder materials (over 500 Brinnell) can be specified for better erosion resistance by the pump internals. Liners of 28 percent chrome-iron or similar hardness for erosion protection would be specified inside a more ductile steel case for pressure containment. The discussion in "Results of Work" Section 4.1 is applicable to these pumps as well.

Single, double and tandem seal arrangements were studied for this service. A single seal is not recommended due to the inherent danger to operating personnel. Both double and tandem seal arrangements offer a greater degree of safety. In either case, a metal bellows-type seal would be used to accomodate the high temperature and an outside source of clean, cool flush would be required. The ability to detect a primary seal failure makes the use of tandem seals more attractive. Both tandem and double seals are described in more detail in Section 4.1, Results of Work.

4.9.4 Study Continuation

Investigations will continue to determine the specific materials of construction for these high pressure flash recycle pumps. Sealing and flushing approaches will be refined and a decision will be made to use either double or tandem seals. Thrust bearing designs proposed by the prospective pump manufacturers will be evaluated for adequacy.

In addition, canned pumps will be considered and in Phase I a considerable effort will be made to eliminate one or more of these pumps.

4.10 MOLECULAR SIEVES (V12.116 A/B)

4.10.1 Equipment Service

These vessels are located in the hydrogen recycle system and are used to remove traces of water, carbon dioxide, hydrogen sulfide and ammonia upstream of the High Pressure Cold Box. There will be two vessels in parallel.

4.10.2 Purpose of Study

The proposed concept consists of a "thermos bottle" type vessel; i.e., a thin stainless steel bottle inside a heavy-wall carbon steel vessel. The annular space between the bottle and vessel would be filled with insulation. The outer vessel would be 12 feet - 0 inch I.D. by 32 feet - 6 inches seam to seam with an outer wall thickness of approximately 8-3/4 inches.

The bottle contains a molecular sieve material which must be regenerated after approximately 8 hours of service. This regeneration would be accomplished at an operating pressure of approximately 2000 psia. The inlet gas would cycle between 6000 and 900F.

Due to a complex design and a heavy walled outer shell, the Molecular Sieve Vessels are long lead items with an estimated delivery of approximately 18 months.

4.10.3 Results of Work

Vessels employing the same design concept have been previously built. In those applications, the molecular sieves were regenerated using approximately the same temperature cycle. However, the vessels for the SRC-II Demonstration Plant are somewhat larger and the design pressure is approximately twice that of the Molecular Sieve Bed vessels previously built.

In spite of the size and pressure differences, no major problems are expected in the design and fabrication of this item. A number of vessels of 8-3/4 inch thickness (and greater) have been fabricated of carbon steel for the petroleum/petrochemical field.

The "thermos bottle" design insulates the thick vessel which forms the pressure boundary from the temperature cycles of the inner vessel which occur during the regeneration of the molecular sieve. Thus a fatigue analysis of the outer shell would not be required. The inner vessel is thin and would be made from stainless steel which should eliminate fatigue problems. The pressure would be equalized on both sides of the inner bottle; thus, the only significant stresses would be the result of the cyclical temperatures.

4.10.4 Continued Study

No significant work, other than normal evolution of the project, is planned at this time.

4.11 HIGH PRESSURE COLD BOX - (U 12.101)

4.11.1 Equipment Service

The High Pressure Cold Box will be used to remove methane and heavier hydrocarbon gases as well as excess nitrogen, argon and carbon monoxide from the recycle hydrogen stream. The unit will operate at approximately 2100 psig and will produce hydrogen of high purity.

4.11.2 Purpose of Study

The High Pressure Cold Box will be the first built for this type of service. The pressures will be higher, (2100 psig) and the size larger, 72 MSCFM feed, than existing cryogenic units. The hydrogen purification systems for coke oven gases are the most similar application of this type of equipment. Therefore, design parameters must be developed both experimentally and theoretically for the conditions required.

Also, necessary lead time for this unit is estimated to be 34 months, including eight months for program development and detailed engineering, and six months for field erection and system check-out.

The High Pressure Cold Box is a critical item because of its long delivery, because it is a prototype unit, and because if the cold box does not remove the recycle hydrogen impurities, the SRC-II process must be shut down.

4.11.3 Results of Work

An engineering subcontractor has been selected to supply process engineering data to be incorporated into the plant heat and material balance. This front-end process design allows design criteria and equipment specifications to be continuously evaluated as the project continues. The subcontractor has initiated a research program to obtain experimental vapor liquid equilibrium K-values for the conditions required.

A preliminary base case design for the Demonstration Plant Conceptual Design has been engineered by the subcontractor including the following:

- (a) Description of the Equipment
- (b) System Performance.
- (c) Utility Requirements.
- (b) Budget Cost.
- (c) Engineering and Fabrication Schedules.

4.11.4 Continued Study

A continuing program of process trade-off studies will be conducted on this critical gas cleanup equipment. Alternate methods of reducing the trace impurities in the cold box feed will be reviewed.

4.12 VACUUM BOTTOMS PUMP (P34.122 A/B)

4.12.1 Equipment Service

The vacuum bottoms pumps will be used to pump vacuum slurry bottoms from the Dirty Vacuum Flash Jug (V34.121) to the Gasifier Feed Drum (V21.101). These pumps will have a maximum flow rate of 420 gpm with a pumping temperature of 700 F and a differential head of 92.5 ft. The approximate viscosity is 70 Cp at pumping temperature. The slurry is a mixture of 41.6 percent by weight of solids plus heavy vacuum oil.

4.12.2 Purpose of Study

The vacuum bottoms slurry has several unusual properties which affect the design of the centrifugal pump used to transport the slurry. It is similar to the feed slurry in its solids content but, the erosive characteristics of this slurry are slightly less severe. The slurry is still viscous and has erosive properties. A major concern with the vacuum bottoms slurry is that it will solidify if the pumping temperature drops below approximately 500 F. Because the pumping temperature must remain above this 500 F, a more sophisticated pumping design will be required. At the present time there are no 700 F centrifugal slurry pumps in commercial service. Therefore, these pumps are considered prototype.

4.12.3 Results of Work

The discussion on material selection, found in Section 4.2 for the Slurry Feed Pump, will also apply to the vacuum bottoms pump. Hard metal liners made of 28 percent chrome iron will offer the best erosion protection. Coatings are not desirable because at a pumping temperature of 700 F, hard metal coated casings will be very susceptible to flaking and spalling caused by the large differences in thermal expansion between the coating and the base material.

At the Fort Lewis Pilot Plant, much of the vacuum bottoms pump down-time has been caused by seal failure. Two factors, which substantially increase seal life in these pumps, are maintaining a constant clean solvent flush to the

primary seal, and keeping the seal temperature above 500 F. For a discussion on possible sealing techniques for high temperature slurry applications, see "Results of Work" in Section 4.1. For the high temperature vacuum bottoms pump the tandem seal arrangement discussed in the reference above will be especially useful. Because the pumpage will solidify below 500 F, the clean solvent used to flush the primary seal must be heated to a temperature close to pumping temperature. In addition to the heated flush, the stuffing box should be jacketed with Dowtherm, or a similar fluid to keep any pumpage which may have entered the seal cavity from solidifying. To keep this 600 F to 700 F primary flush from leaking to atmosphere, i.e., in the event of a primary seal failure, a backup or secondary seal will be needed. Provided the buffer fluid used to flush the secondary seal has a high flash point, there will be less chance of causing a fire should both seals fail. To emphasize a point made earlier, the best way to insure good seal life is to make sure the seal has a constant supply of hot flush fluid.

To prevent thermal shocking of these pumps and to keep any pumpage from solidifying in the pump casing, the pump should also be jacketed. Dowtherm heated to 700 F could be used to circulate through the pump to keep this area above 500 F. During periods of shutdown, lines need to be heated to maintain the temperature above the freezing temperature of Dowtherm (+53 F).

The new "AL" and "DD" Slurry pumps manufactured by Lawrence were specifically designed to handle pumping temperatures of 700 F. Lawrence has proposed using an "AL" jacketed slurry pump for this application. The claimed operating horsepower will be 41 at a viscous efficiency of 34 percent. A 50 H.P. motor operating at 1800 rpm would be used as a driver. This pump will have a carbon steel casing, and the impeller and liners would be made out of HC-250. A tandem seal arrangement with two metal bellows seals would be used on this pump. Lawrence has received several orders for their "AL" pump, which will be used in a number of different coal conversion plants. This exact pump has not been commercially tested in a coal service, but an earlier version of the pump is currently in service at the Fort Lewis Pilot Plant.

Barrett-Haentjens & Company supplied information on their "CIP" type process slurry pump, which they believe would handle the vacuum bottom service. At a pump efficiency of 49 percent the operating horsepower is claimed to be 28. A 40 hp motor running at 1170 rpm was recommended to drive the pump. The casing for this pump would be carbon steel with a hard-surfaced volute. The impeller, wear plates and suction head liner would be 28 percent chrome iron. Barrett-Haentjens has not designed or manufactured any high temperature slurry pumps to date. In the past they have, however, devoted a significant portion of their business to custom design of specialized centrifugal pumps. They have also manufactured pumps designed to handle viscous slurries with high solids content, and several pumps with very high pumping temperatures.

Ingersoll-Rand (I-R) provided information on their new "AM" coal slurry pump. The pump casing is carbon steel, and the liners are 26 percent chrome iron. Because this is a new pump design for I-R, detailed drawings were not available. Further contact with I-R will be necessary to acquire accurate pump data.

Duriron proposed a Mark II recessed impeller pump made of CD4MCu. Duriron recommends that the wetted parts be flame sprayed with tungsten carbide. The operating horsepower of this pump was claimed to be 30 with a viscous efficiency of 50 percent. The pumping speed would be 1308 rpm. The pump would be V-belt driven with a 40-hp motor operating at 1750 rpm. The tungsten carbide coated Durco pump should not be considered for this application because, as stated above, at 700 F the difference in expansion between the coating and the base metal would cause severe flaking and spalling of the coating. That would lead to high erosion of the pump and impeller and the maintenance interval would be unacceptable.

4.12.4 Study Continuation

Further contacts and discussion to obtain detailed information regarding critical areas of design in these pumps will be conducted with appropriate manufacturers. The need for pump jacketing will be further explored.

Requests have been made to test the tandem seal arrangement in several of the services at the Fort Lewis Pilot Plant. As discussed in "Study Continuation" in Section 4.2, different types of variable speed drives will be evaluated.

Research is continuing to find the best buffer liquid to be used as a secondary seal flush in the tandem seal arrangement. Synthetic hydraulic fluids and heat transfer fluids will be studied.

4.13 MINERAL RESIDUE SLURRY PUMP (P34.136 A/B)

4.13.1 Equipment Service

The M.R.S. Pump will be used to pump slurry from the Mineral Residue Storage Tank (T34.134) to the M.R.S. Heater (H34.131). This slurry is a mixture of coal solids and heavy vacuum oil. The flow rate of this pump will be 500 gpm, with a pumping temperature of 300F and a differential head of 328 feet. A viscosity of 1.0 Cp at pumping temperature is expected.

4.13.2 Purpose of Study

The conditions of service for these pumps are less severe than the conditions described in Sections 4.1 and 4.2. With the 15% solids, there will be some erosion and, although the slurry viscosity is low, it still may exhibit non-Newtonian characteristics. Because this pump is handling a hydrocarbon slurry, the standard slurry pumps with brittle metal casings designed to combat erosion are not acceptable. A study to investigate pumps with liners capable of handling high erosion and a casing of softer metal capable of handling pressure and thermal shock was necessary.

4.13.3 Results of Work

Hardmetal liners made of 28% chrome iron will offer the best protection for the pump used in this application. The previous discussions on material selection, found in "Results of Work" in Section 4.2.3, will also apply to the M.R.S Pumps. Part of that discussion dealt with flame sprayed hard metal coatings. The problems with spalling and chipping of these coatings would be reduced at the pumping temperature of these pumps. Poor bonding is, however, related to the difference in thermal expansion coefficients and there can still be flaking and spalling of the coating. Plasma-sprayed or flame-sprayed coatings are not the best answer to the erosion problem in any slurry pumping application.

In Results of Work in Section 4.1.3, a discussion of sealing techniques for high temperature slurry pumps was presented. The recommendations suggested in that discussion do not strictly apply to the M.R.S. pumps. Because these

pumps have a maximum pumping temperature of 300 F, seals with either teflon or Viton parts may be used. However, it may be advantageous from a parts and maintenance familiarity standpoint to use metal bellows seals.

Stuffing box jacketing and 600 F seal flush will not be necessary. A primary seal flush temperature of about 250 F will be adequate. The secondary seal flush should be cooled to make the seal flush leakage to atmosphere less hazardous.

For the M.R.S. pump application, Lawrence proposed a 4-inch AL slurry pump, with carbon steel casing, and impeller and liners made of HC-250. This pump would have an operating horsepower of 109, with a pump efficiency of 40%. A 150-hp motor operating at 1800 rpm would be used as a driver. Due to the low pumping temperature, these pumps will not require jacketing. The 4-inch AL slurry pump has not yet been commercially tested, but an earlier version of this pump is currently in service at the Fort Lewis Pilot Plant.

Barrett-Haentjens and Company recommended their 4-inch J type "CTP" process slurry pump for this service. With a claimed pump efficiency of 51%, the operating horsepower would be 86. The pumping speed would be 1770 rpm. A 100-hp motor would be used to drive the pump. This pump would have a carbon steel casing, with a hard surfaced volute. The impeller, wearing plates and suction head liner would be made of 28% chrome iron. The "CTP" type pump was designed to handle high temperature, high pressure slurries. Barrett-Haentjens has previously devoted a large part of their business to custom pump designs.

Preliminary information was received from Ingersoll-Rand on their new "AM" type coal slurry pump. This pump was specially designed to handle high temperature coal slurries. I-R recommended a 4x13 "AM" pump for this service. The "AM" pump has a carbon steel casing which is lined with a 26% chrome iron liner. This pump design was recently introduced by I-R and has not been commercially tested. Therefore, details are not available.

The Duriron Company currently has two of their ANSI type pumps in service at the Fort Lewis Pilot Plant. They are the Durco Mark II standard pump and the Mark II recessed impeller pump. These pumps have casings made of CD4MCu and 316 SS but, after severe erosion, all the Durco pumps at the Pilot Plant were repaired and flame sprayed with tungsten carbide. The tungsten carbide coatings slowed the erosion process, but high maintenance and additional coating costs continue. Duriron has recommended using two 4x3R-13 Mark II recessed impeller pumps in series for this service. The casing and impeller would be made of CD4MCu, and Duriron recommended having all the wetted parts flame sprayed with tungsten carbide. Each pump has an operating brake horsepower of 39, an efficiency of 57.5%, and pumping speed of 1650 rpm. Each pump is driven by a 40-hp motor operating at 1750 rpm. This type of coated pump would only be used if no other practical means of controlling erosion can be found.

Three pump manufacturers have recommended pumps with 28% chrome liners. To date, this approach has shown good resistance to erosion. After these pumps have been tested on a commercial basis, applicable information on pump performance and the liner's wear resistance to coal slurry erosion should be available.

4.13.4 Study Continuation

Reliable means of correcting pump head, flow, and efficiency for viscous non-Newtonian fluids will continue to be studied. A literature search to find information on this topic is presently underway.

Consultation with the four pump manufacturers who supplied preliminary information will continue. Also, variable speed driver manufacturers will be contacted to obtain specific information on several types of variable speed drives. See Study Continuation in Section 4.2.3 for further discussion on variable speed drivers.

4.14 GASIFIER CHARGE PUMP

4.14.1 Equipment Service

The gasifier charge pumps will be used to feed slurry to the gasifier. Specific conditions of service are proprietary with respect to the gasification process and cannot be released in this report. However, when compared with the dissolver charge pump (Reference Equipment Service in Section 4.3), the pumping temperature of the gasifier charge pump is higher, while the operating pressure and flow are lower.

The bridging task approach of using three 50% gasifier trains (and assuming three gasifier charge pumps) is considered more reliable than using two 100% trains as specified in Deliverable 1.

4.14.2 Purpose of Study

A pump has never been built for the combination of conditions of service of the gasifier charge pumps. The high temperature of the slurry presents safety hazards which must be considered. Because the pumpage will congeal at a high temperature, additional consideration must be given to flushing and pump design. In addition, the lead time to engineer and fabricate these pumps is estimated at 18 months.

4.14.3 Results of Work

The design of the gasifier charge pump is similar in nature to the design of the dissolver charge pump. Refer to "Results of Work" in Section 4.3.3 for a discussion of the areas of concern for the dissolver charge pump.

The higher temperature of the gasifier charge pump makes the surge pump design, or pump with remote valves, more attractive. See Figure 4-6 in Section 4.3 for the schematic arrangement of this design. This design essentially isolates the pump section and packing from the high-temperature slurry. Relatively cool flush can be injected at the pump section, with the pumping action being transmitted through a fluid leg to the remote valves.

The final portion of the piping between the pump and valves must be jacketed to prevent the slurry from cooling and congealing in the surge leg piping and valves. This type pump is being used successfully on a very small scale to charge a gasifier in a pilot plant.

Both triplex (3 plunger) and quintuplex (5 plunger) pump designs have been proposed. The required pump speed is estimated at 85 rpm. Volumetric efficiency would range from 90 to 95% while mechanical efficiency is estimated at 85 to 90%. The power end, which is the part of the pump which transmits energy from the rotating shaft to the plungers by means of the crankshaft, crossheads, and connecting rods, would be the vendors' standard design. The liquid end, consisting of the cylinders, plungers and valves, would be a special design.

Meetings were held with representatives of Crane Packing Company and Durametallic Corporation to discuss the packings available for this application. Both Crane and Durametallic recommended as their first choice the use of "Grafoil" packing, a flexible, all-graphite product which contains no other lubricants or additives. It is available in ribbon form or compressed rings and is good for temperatures as high as 4000 F. The self-lubricating rings are formed under pressure to produce a continuous "W"-shaped construction which dissipates frictional heat and is not subject to thermal expansion or contraction when heated. Therefore, it is less sensitive to over-tightening of gland ring nuts than other packing. Crane recommended that we run this packing dry, i.e., without flushing or lubrication, and estimated a packing life of 8 to 10 months. Durametallic's recommendation was slightly different. They would use a combination of Grafoil and graphite filament packing with lubrication. Their experience shows that Grafoil alone tends to build up on the pump plunger.

Both end rings should be woven graphite filament to wipe the plunger clean. Otherwise, Durametallic maintains, leakage will occur. Both vendors are currently investigating applicable lubricants which could be used in high

temperature applications. Some of this lubricant which would be at a pressure slightly above stuffing box pressure, would flow into the slurry and therefore must be compatible with the pumpage. The remainder of the lubricant will flow to atmosphere and so its vaporization and ignition temperature are important. Another concern is the number of packing rings required on the atmospheric side of the lubricant injection. Other packings recommended for the high-temperature gasifier charge pump include aluminum foil and various braided asbestos types. Aluminum foil packing is good for temperatures up to 1000 F and is not corroded by hydrogen sulfide. Asbestos packings may be used up to 1000 F, provided the impregnation or lubricant in the packing is stable at that temperature. All three of these packings require some lubrication.

As with the dissolver charge pump, detection of packing deterioration prior to failure is a safety consideration. The installation of a lantern ring near the atmospheric side of the packing to detect an increase in pressure and sound an alarm before the slurry is released to the atmosphere is being considered.

Flushing fluid injection at a rate estimated between one-half to five percent of total pump capacity is provided by means of a separate pump, and in most cases, a crankshaft driven flushing pump is necessary to isolate the pumpage from the packing. If a conventional pump design is used, as illustrated in Figure 4-5 in Section 4.3, the flushing fluid will have to be heated in order to prevent the slurry from congealing. This creates another safety hazard due to heated flushing fluid leaking past the packing to atmosphere and causing a fire hazard. The injection of a separate packing lubrication which is flame resistant and less susceptible to flashing upon release to atmosphere is being investigated as a possible means of controlling flushing fluid leaking to the atmosphere.

Pulsation dampeners will be required in the suction and discharge piping of these plunger pumps. On the suction side of the pump would be a centrifugal

feed pump which must be isolated from the fluctuations in pressure and flow that the plunger pump produces. On the discharge side a smooth flow of slurry to the gasifier is required.

Variations in process requirements demand that the gasifier charge pump have a variable output. A possible means of providing this is by controlling pump speed using equipment such as Gyrol fluid couplings, eddy-current couplings, variable frequency controllers on an ac motor, and a steam turbine driver with constant ratio gearbox.

These pumps must be started up and shut down using heated solvent as the pumpage. This is necessary to prevent thermal shock in the pump, and to prevent the slurry from congealing. Also, the ball valve housings should be heated to prevent the slurry from cooling.

Special emphasis was placed on materials of construction for the gasifier charge pump. If the pump with remote valves is used, the materials for the plunger and packing would be less critical due to the low temperature flush that is injected. With the conventional design plunger pump, the packing and plunger must withstand the high temperatures of the flush and also the possibility of interaction with the highly abrasive process slurry. Plunger materials should be SAE 1020 steel coated with Colmonoy No. 6 or nickel chrome boron. Suitable packing includes Grafoil, aluminum foil and asbestos-impregnated types. Regardless of the pump design used, valve and valve seat materials are critical.

Ball type valves constructed of materials such as 440 C stainless steel, 4150 heat treated and 4620 carburized must be used. All of these materials have hardnesses exceeding Rockwell C60. Valve seat materials should be tungsten carbide, stellite, 4140 or Rexalloy, which is a tungsten carbide type metal.

Preliminary specifications have been prepared which are based on API draft for reciprocating pumps, but specifically modified for plunger type pumps for

slurry service. These specifications are too voluminous to be included in this report.

4.14.4 Study Continuation

Much of the continued investigations for the gasifier charge pump will parallel those conducted for the dissolver charge pump (Study Continuation in Section 4.3.6).

The surge pump design with remote valves will be explored further. This pump design may be installed in the pilot plant at Fort Lewis, Washington, for further evaluation.

In order to evaluate the performance of the various packing available for the gasifier charge pump, several types may be tested at the Fort Lewis Pilot Plant to determine the best packing for use in the Demonstration Plant. If these tests cannot be performed at Fort Lewis, they will be deferred until completion of the Demonstration Plant, at which time actual experience would be used to determine the best pump design and packing.

Research will continue regarding latest developments in construction materials which are resistant to the highly abrasive slurry.

The search for a packing lubricant that is flame resistant at high temperatures will also continue. Types of drivers and variable speed drives will be further investigated. The preliminary specifications which have been prepared will be revised to incorporate the latest technological developments. Work by others involved in the coal liquefaction process will be followed through current publications and applied to the gasifier charge pump.

4.15 GASIFIER

4.15.1 Equipment Service

The gasifier produces hydrogen for the dissolver area by partial oxidation of the mineral residue slurry from the Vacuum Flash Drum.

4.15.2 Purpose of Study

This is a high temperature, high pressure gasifier with a refractory system in the gasifying section. Details of the Gasifier are third party proprietaries.

This is a long lead delivery item with an estimated delivery of approximately 20 months.

4.15.3 Results of Work

Mineral residue slurry has been gasified successfully in a small gasifier. Gasification of oil is performed routinely at temperatures and pressures similar to those required in the SRC-II Demonstration Plant. The Gasifier size required is approximately the same size as for continuous operation oil-fed plants.

The only major difference between an oil-fed Gasifier and one fed by mineral residue slurry is the amount of the resultant ash. The scale-up of ash handling is not expected to pose any insurmountable problems. Experience gained in the handling of ash at coal slurry gasification plant indicates that large volumes of ash can be handled with current technology.

The refractory has created some problems in the operation of the existing Gasifiers.

4.15.4 Study Continuation

Alternate refractory systems will be studied with the intention of improving the service life. This is essential to obtain the lowest possible maintenance costs and downtime. With current refractory life expectancy, a spare Gasifier will be provided so that a Gasifier is always available for relining.

Additional test runs using mineral residue slurry from the Fort Lewis SRC Pilot Plant will be made at the Licensor's test Gasifier. This data will be used to confirm the design basis for Gasifiers to be installed in the SRC-II Demonstration Plant.

4.16 OXYGEN PLANT AIR COMPRESSORS (C44.101 and 102)

4.16.1 Equipment Service

The air supply for an oxygen plant will be provided by this compressor.

4.16.2 Purpose of Study

Larger air compressors in present oxygen plant service, compress about 60% of the air required for a 2500 tpd Oxygen Plant. Discharge pressure of these machines is about 109 psig. Therefore two of these relatively large compressors would be required. There was some indication that compressors for the total (100 percent) capacity were feasible and would be available in time for use in the Demonstration Plant. It was decided to study both the 60% and the 100% machines for possible application in the Demonstration Plant.

4.16.3 Results of Work

Both DEMAG and Sulzer have proposed very impressive combination axial-radial compressors for the SRC-II requirements. Machines for 1500 metric tons/day (based on oxygen production) are operating successfully. DEMAG has an axial compressor running which handles sufficient air for a 3000 ton/day oxygen plant but with lower head requirements. They also have proven radial compressors for that flow capacity which, when added to the axial section, would provide the overall required flow and pressure. They have not actually built a machine using both of these sections on one shaft, but the necessary design is complete and they are awaiting an application. The SRC-II Demonstration Plant 100% requirements could be handled by a machine of this type.

Sulzer has a similar machine completely designed. It is 10 cm in diameter larger than they have previously built (90 cm dia vs. 80 cm dia). The larger unit has not been built only because there have been no previous applications. Sulzer and DEMAG believe 3000 tons/day Air Separation (oxygen) Plants are feasible and both vendors are capable of providing a single axial-radial combination 100% machine. The large machines would be capable of 60 to 65% turndown by stator blade adjustment and/or speed control.

There are several technical differences in the machines which must be evaluated along with cost and delivery; however, both vendors appear capable of meeting the requirements with a single machine and they have proven installations should two 60% air machines be desired.

The following discussion applies to details of the 60% compressors; however, the 100% machines would not be significantly different.

Although both vendors offered axial blading followed by radial blading, their configurations differed somewhat. Sulzer proposed six axial stages followed by three radial stages, while DEMAG offered nine axial stages followed by two radial stages. Sulzer employed three integral intercoolers; one ahead of each radial stage. DEMAG used two separate intercoolers; one ahead of each radial stage. When the evaluation of firm quotations is made, examination of efficiencies, speeds, temperatures and other related parameters will be conducted.

Both vendors employ the technique of adjustable stator guide blades on all axial stages to accomplish approximately 65% turn down. Sulzer operates the guide blades hydraulically using a high pressure oil system. DEMAG uses pneumatics to drive the guide blades. DEMAG'S machine would operate between the first and second lateral critical speed. Sulzer's machine would operate between the second and third lateral critical speed.

There is nothing particularly special about items each vendor would monitor for control of the machines. However, it should be pointed out that the inlet to an axial compressor forms a natural flow measuring device.

Axial inlet flow is preferred by both vendors and leakage of oil in the front end bearing to compressor inlet is prevented by compressed air being fed between the double walled bearing housing and then leaking across labyrinths into the inner bearing housing. The techniques used by both manufacturers appear similar.

The equipment seems particularly well suited for mezzanine mounting with the compressor intercoolers located beneath the compressor.

Sulzer employs lobe-type radial bearings in conjunction with double acting tilting pad thrust bearings. DEMAG indicated that in some applications tilting pad radial bearings are used.

Both use conventional labyrinth seals.

DEMAG's casings are all cast iron while sulzer uses cast iron axial section casings with fabricated steel radial section casings. Their internals of alloy steels are comparable.

4.16.4 Study Continuation

Enough is now known to issue a project specification and solicit firm quotations for these compressors. A decision must soon be made to use 60 or 100% machines in the Demonstration Plant.

4.17 OXYGEN COMPRESSOR (C44.103)

4.17.1 Equipment Service

This compressor will be used to compress about 2500 tpd of oxygen from the air separation oxygen plant to about 1600 psia.

4.17.2 Purpose of Study

This compressor is critical because it is prototype, in that a machine operating at this discharge pressure (1572 psia) and flow (2500 tpd) has never been built and operated before. (The above numbers differ from the Phase Zero Deliverable 1, because the rated conditions were used rather than normal conditions which are ordinarily used on process flow diagrams.)

Further, it is a long lead delivery item, requiring about twenty-one (21) months lead time.

4.17.3 Results of Work

The subjects of handling oxygen, machine design, metallurgy and prior experience were studied, with two manufacturers and a preliminary specification was drafted and reviewed.

The conclusions resulting from this effort are as follows:

- (a) With the exercise of reasonable care in the service and operation of centrifugal machines, successful and reliable operation can be expected.
- (b) A multicaser centrifugal machine would appear to be a better choice than a hybrid of two centrifugal cases followed by reciprocating machines.
- (c) The test program being undertaken by the Department of Energy to evaluate DEMAG'S high pressure (3rd case) barrel type compressor should be closely monitored.

The "Turbo Compressor for Oxygen Service, Code of Practice" published by the European Working Panel was the basis for the work. This publication led to the evaluation of the following subjects:

- (a) The effect of temperature, pressure and velocity when compressing oxygen.
- (b) Other possible causes of safety hazards when compressing oxygen.

- (c) Necessary instrumentation to minimize catastrophic failures in oxygen compressors and related machinery.
- (d) Materials of construction for oxygen compressors, piping and auxiliary machinery.
- (e) The necessity for and application of special layouts and/or enclosures for safe and efficient installation, servicing, and operation of the machinery.
- (f) The application of good turbomachine practices in the area of design, auxiliary systems, inspection, testing and preparation for shipment.
- (g) Equipment sparing policy and philosophy.

Published data establish that higher pressures, temperatures and velocities do increase the likelihood of ignition and burning. See Appendix 4A for a list of references on this matter.

The literature also establishes that fires are most likely when hydrocarbons (such as lubricants) come in contact with oxygen, a foreign particle being transported by the oxygen strikes something with sufficient force to cause ignition, or when a rub of machine parts generates sufficient heat to start a fire.

The literature also establishes that silver, copper and nickel are more favorable materials for potential areas of friction because of good thermal conductivity and low melting points.

Installation, service and operations were covered in the European Working Panel Code of Practice. This Code along with appropriate API Standards, were the basis for the preliminary specifications which specified or solicited suggestions relating to:

- (a) Mezzanine installation.
- (b) Enclosures to protect personnel and adjacent equipment from fire, to reduce noise, to limit access, to maintain cleanliness and to provide for exhaust of any accumulation of oxygen.
- (c) Fire-fighting equipment, including a deluge system.

- (d) Isolation of the system by venting oxygen and purging with nitrogen.
- (e) Clean room environment for servicing parts and subassemblies as well as protecting opened machines.
- (f) Spares provisioning including complete compressor cases and gear boxes.
- (g) Intercooling requirements along with monitoring of oxygen temperatures.
- (h) Methods of shaft sealing of oxygen and isolation from bearings.
- (i) Machine monitoring systems.
- (j) Performance and mechanical run tests.
- (k) Materials of construction.
- (l) Torsional and lateral critical speed analyses and limitations.
- (m) Overspeed requirements and limitations.
- (n) Rotor stability at high pressures.
- (o) Couplings
- (p) Review types of bearings and their lube oil systems.
- (q) Rotor balancing
- (r) Piping requirements including gas velocities.
- (s) Preparation for shipment.

The two companies that were determined to have the most experience in high pressure oxygen compression were contacted. They are DEMAG (centrifugals) and Sulzer (centrifugals and reciprocating machines). They were provided preliminary specifications and asked to express their views.

Since 1960, Sulzer has supplied 109 oxygen compressors. Their highest pressure installation is a two case, 12 wheel machine at Messer Griesheim, Dillingen, F.R. Germany operating at 728 psia discharge. The capacity of this machine is 17,700 scfm. Their highest capacity machines are at Sasol, South Africa, and are 39,400 scfm with a discharge pressure of 535 psia.

DEMAG has supplied over 160 oxygen compressors since 1951. Their highest pressure machines are at Veba-Chemie Gelsenkirchen and Brunsbuttel F.R. Germany, operating at 957 psia with brief operation up to 1189 psia. The capacity of these machines is 28,000 scfm, which approximates the highest capacity machines DEMAG has built.

DEMAG's and Sulzer's approach to machine design and material selection is similar. Shaft seals are labyrinth with silver running next to nickel. Overboard oxygen leakage is prevented by a series of chambers between the labyrinths. The first chamber (highest pressure) is returned to the train at a point of lower pressure. The third chamber introduces an inert gas, such as nitrogen, which flows toward the second chamber where it mixes with oxygen and is carried away in a closed system. Inert gas also leaks to the atmosphere. The intent is to minimize oxygen being lost, prevent inert gas from entering the machine and prevent any oxygen leakage to atmosphere.

The thrust and radial bearings are tilting pads and they are in housings outboard of, and separate from, the seal housings. The lube oil system is held at a slight vacuum to prevent oil mist from escaping the bearing housings.

Both vendors propose three case compressors. Some of the characteristics are shown in the table below.

	<u>Number of Compression Stages</u>	
	DEMAG	SULZER
Low Pressure Case	6	6
Intermediate Pressure Case	4	6
High Pressure Case	3	4
Total Stages	<u>13</u>	<u>16</u>

	<u>Number of Intercoolers</u>	
	DEMAG	SULZER
Low Pressure Case	3	3
Intermediate Pressure Case	2	2
High Pressure Case	0	1
Total Intercoolers	<u>5</u>	<u>6</u>

	<u>Shaft Speeds</u>	
	DEMAG	SULZER
Low Pressure Case	7500	7500
Intermediate Pressure Case	14,500	12,500
High Pressure Case	14,500	12,500

The low pressure casings and the intermediate pressure casings of both vendor's machines would be horizontally flanged cast iron with rather conventional internals. The high pressure cases of both proposed machines would be vertically opening barrel-type compressors of alloy steel with bronze and nickel alloy internals.

Relative to machine protection, the following monitoring devices are considered vital: proximity probes (to anticipate instability and rubs), temperature controls (limiting normals to 350 F and maximum to 390 F) and seal cavity differential pressure measurement (to detect possible loss of

lubricants to the atmosphere). Equipment for machine surveillance including the ability to recall data, evaluate trends and document various combinations of data are being evaluated.

DEMAG and Sulzer have different thrust bearing philosophies. Sulzer uses solid couplings and gears with thrust collars in order to take the thrust of the entire train on one bearing located on the low speed shaft of the gearbox. They feel this gives greater latitude in dealing with thermal growth and assures adequate thrust capacity. DEMAG uses a more conventional combined thrust and radial bearing in each case.

The compressors should be mezzanine-mounted because of the merits of locating the steam turbine condenser, lube oil console, and intercoolers beneath the train and permitting proper ventilation under the train. The mezzanine itself should be enclosed, covered, air conditioned and vented to protect against fires, control noise, limit access and maintain cleanliness.

A cleanroom work area should be part of the enclosed mezzanine. Such an environment is in order because of the potential for coal dust in the ambient air. Although the "European Code of Practice" speaks of water drench systems for fire fighting, users are not employing them.

Although the possibility of losing all three cases to fire is remote, loss of any one case could result in a protracted shutdown. Therefore, a warehouse spare of all three cases plus the gearbox is envisioned and may be necessary.

Although a technical evaluation of reciprocating machines was also done, only the reasons for not recommending their use will be presented. Sulzer has considerable experience in reciprocating high pressure oxygen machines, and manufactures some impressive reciprocating compressors but they are not considered applicable for the following reasons.

- (a) Reciprocating machines have not previously been applied downstream from two centrifugal cases.
- (b) Because of (a) above, there seems to be considerable complexity relative to control and other complexities related to multiple drives.

- (c) To handle 2500 tpd the reciprocating compressors offered would have displacements larger than any existing reciprocating compressors in oxygen service.
- (d) Sulzer conceded that 2500 tpd was about the end of the line for reciprocating machines. Therefore, attention should be directed to centrifugal machines because the trend has been to go to higher and higher capacities.

4.17.4 Study Continuation

Enough information is now available for preparation of firm design specifications and to solicit firm quotations for the compressor service.

4.18 HYDROGEN MAKE-UP COMPRESSOR (C23.101)

4.18.1 Equipment Service

This compressor would handle hydrogen produced in Shift Conversion and further treated in the Hydrogen Purification Area. The treated gas would be compressed and sent to the Dissolver Area.

Service conditions involve compressing a 2.8 molecular weight gas from a suction pressure of 1130 psia to a discharge pressure of 2450 psia.

4.18.2 Purpose of Study

The study was made to further define the equipment proposed in the Demonstration Plant Description and investigate the availability of such equipment.

4.18.3 Results of Work

For the centrifugal machine included in the conceptual design, it was found that 24 to 30 stages would be required to meet the operating conditions. Three manufacturers proposed three cases with eight and ten stages per case. The three cases would be driven by one driver.

As alternates, one manufacturer offered a single stage reciprocating compressor with four cylinders in parallel. Another manufacturer offered a single stage reciprocating compressor with six cylinders in parallel.

The approach of using two 60% capacity reciprocating compressors appears attractive.

The advantages of this approach are listed below:

- (1) The cost of two 60% capacity reciprocating compressors would be less than one 100% centrifugal.
- (2) The oil system would be simpler with reciprocating compressors because the seal oil system for the centrifugal installation would require separation from the lube oil system because of the possibility of the presence of H_2S in the compressed stream.

- (3) The efficiency of the reciprocating compressors is approximately 80% while the efficiency of the centrifugal compressor is about 71%. This means there is a considerable energy saving using the reciprocating compressors.
- (4) Overall reliability would be higher with the reciprocating machines because failure of any one of the six seals in the centrifugal train would result in shutdown of the entire unit. Thus, while shutdowns for valve maintenance on the reciprocating machines would be more frequent, these shutdowns would normally only involve one machine and it would be possible to continue operation of the plant at 60% capacity.

There is, however, another option at higher cost, using three 60% reciprocating compressors to increase probability of plant operation at full capacity during maintenance of any one reciprocating compressor.

However, this option should probably be evaluated against one operating centrifugal compressor with one warehouse spare to provide a similar overall high reliability. In that case the cost of three 60% reciprocating compressors is approximately the same as the one installed 100% centrifugal plus the centrifugal warehouse space.

4.18.4 Continuation of Study

The advantages and life cycle cost of each type compressor will be further evaluated to determine the best application for this service.

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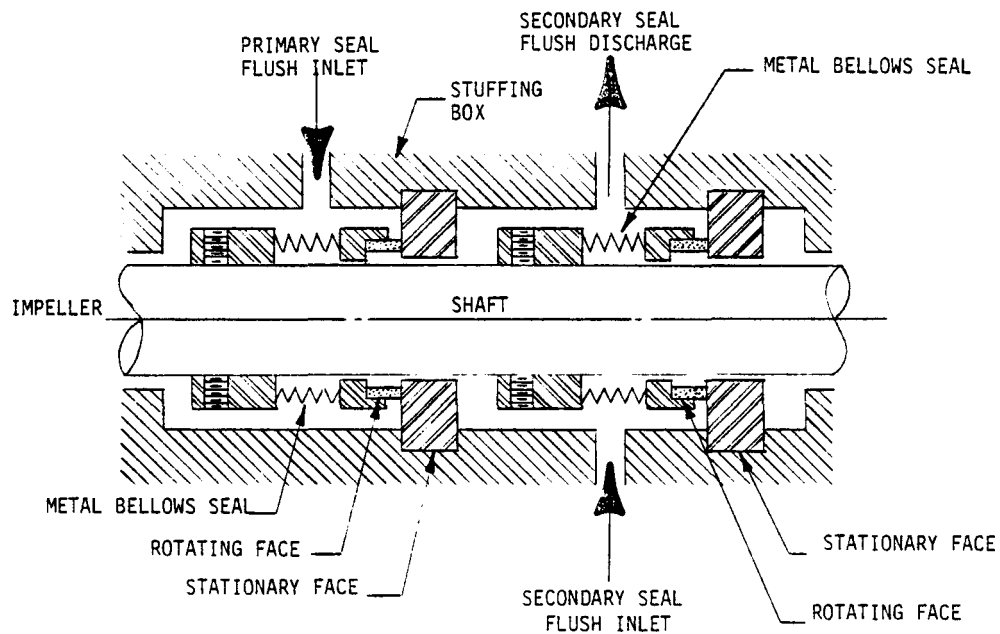


Fig. 4-1. Tandem seal arrangement

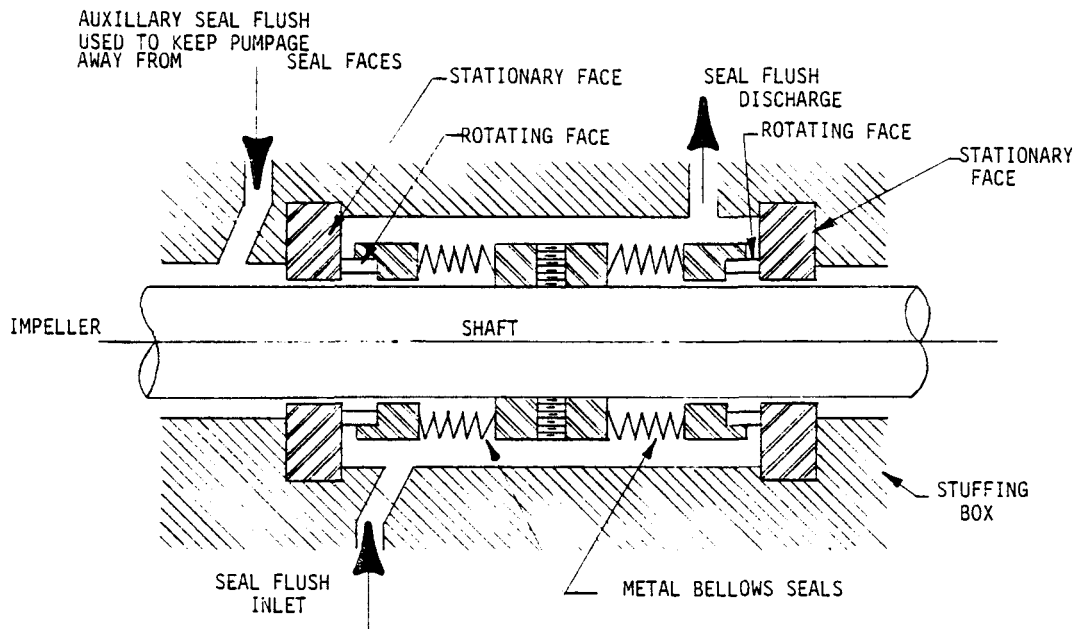
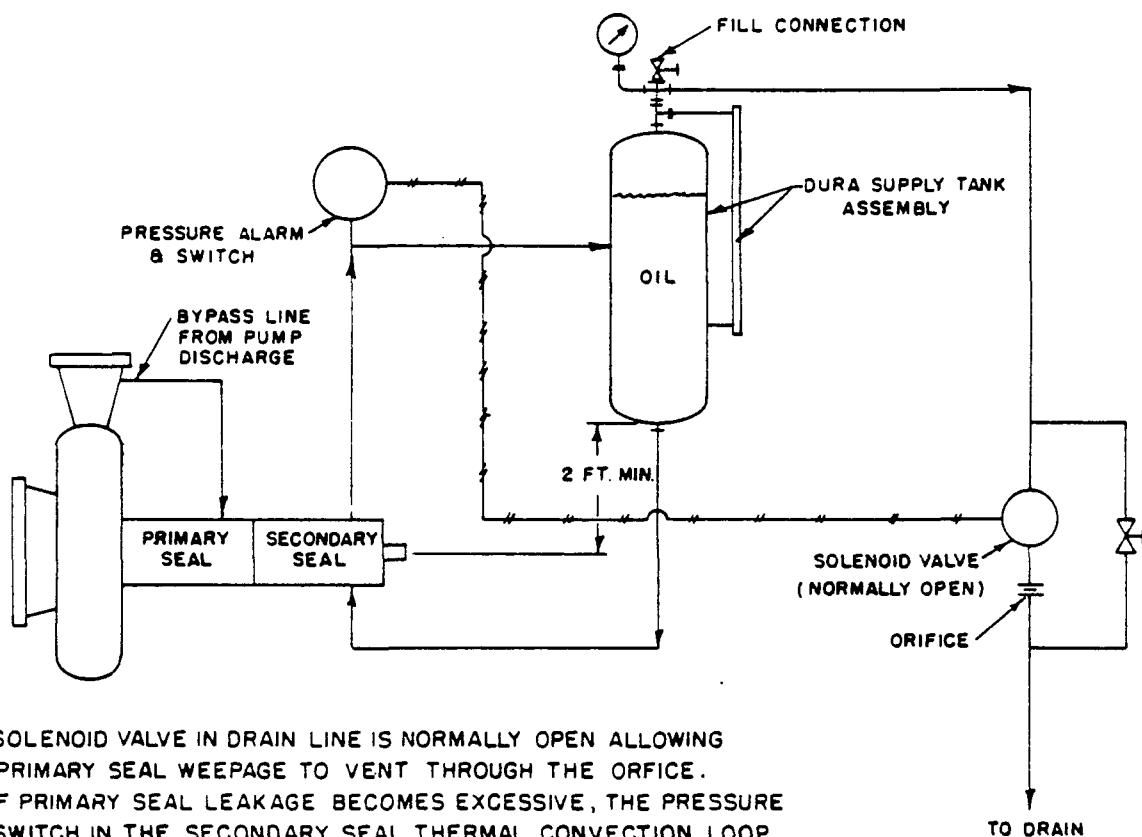


Fig. 4-2. Double seal



1. SOLENOID VALVE IN DRAIN LINE IS NORMALLY OPEN ALLOWING PRIMARY SEAL WEEPAGE TO VENT THROUGH THE ORFICE.
2. IF PRIMARY SEAL LEAKAGE BECOMES EXCESSIVE, THE PRESSURE SWITCH IN THE SECONDARY SEAL THERMAL CONVECTION LOOP WILL ACTIVATE ALARM AND CLOSE SOLENOID VALVE IN THE DRAIN LINE.
3. BYPASS LINE AROUND SOLENOID VALVE IS NORMALLY CLOSED BUT IS USED TO BLEED SYSTEM PRESSURE

NOTE: REPRODUCED FROM DURA SEAL MANUAL, SEVENTH EDITION. (SECTION IV- ENVIRONMENTAL CONTROLS, PAGE 17) DURAMETALLIC CORP.

Fig. 4-3. Recommended piping diagram for double tandem dura seals

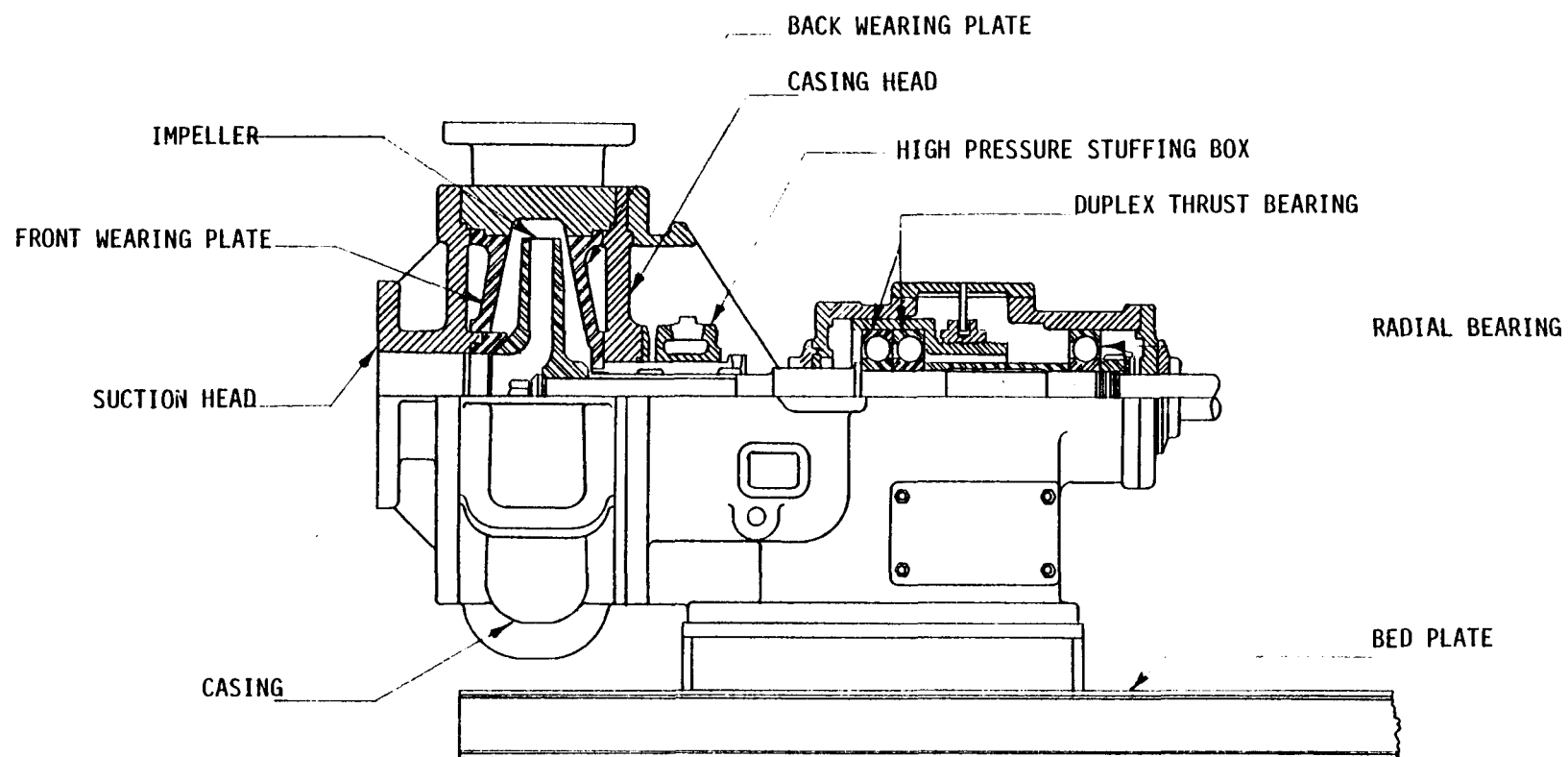


Fig. 4-4. "Hazleton" type "CTP" pump for hot slurries

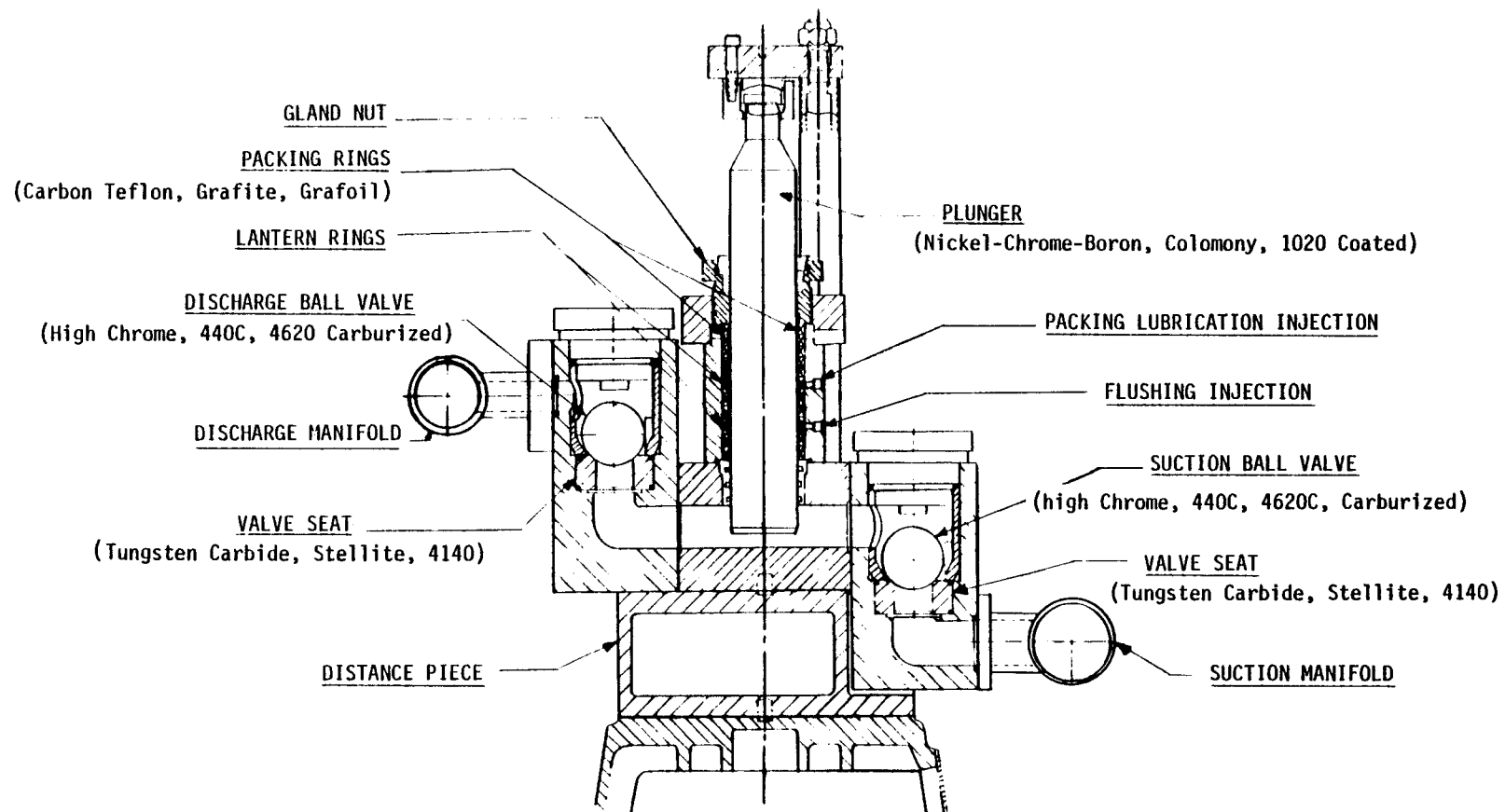


Fig. 4-5 Typical plunger pump, liquid end

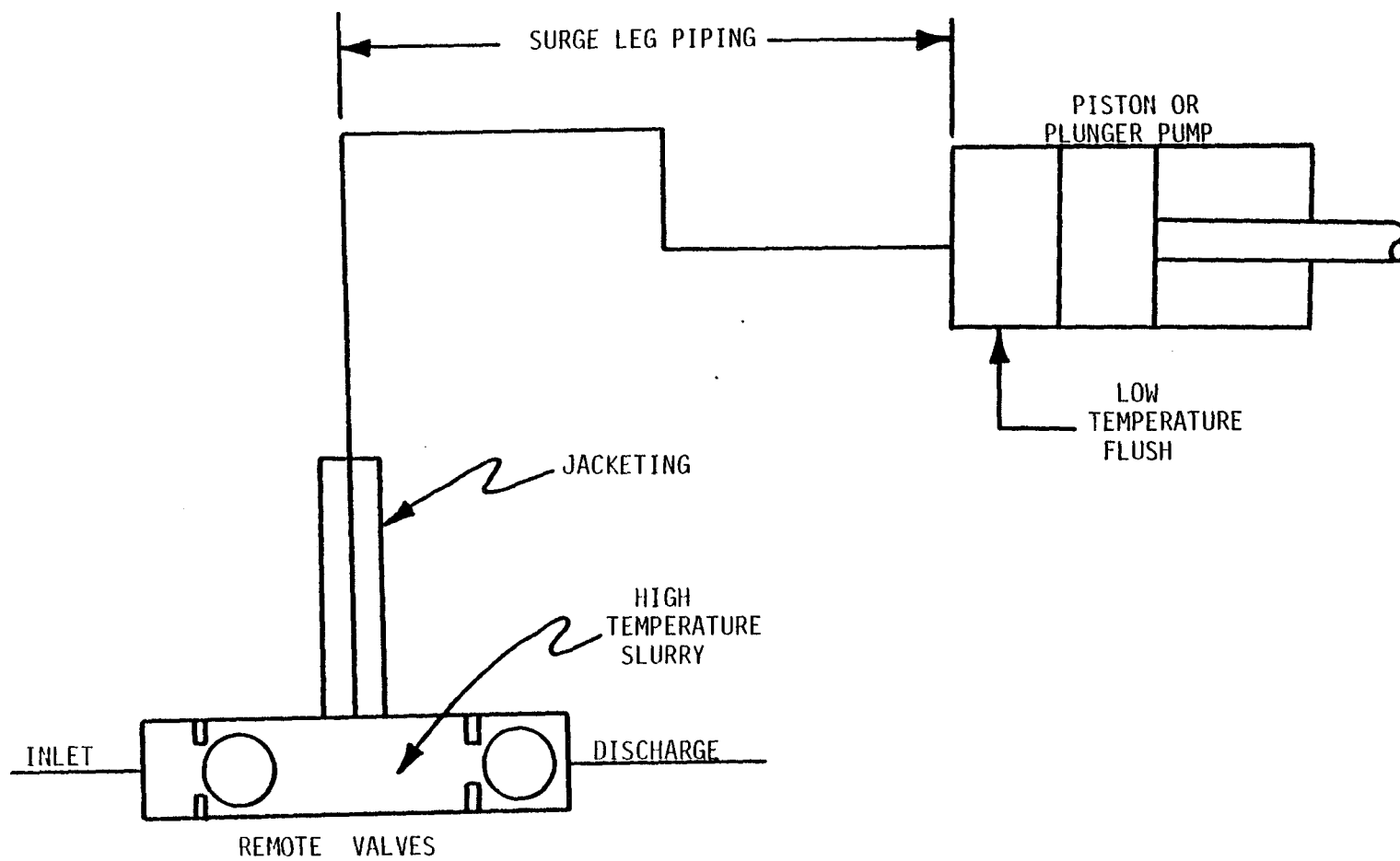


Fig. 4-6 Sketch of surge pump with remote valves

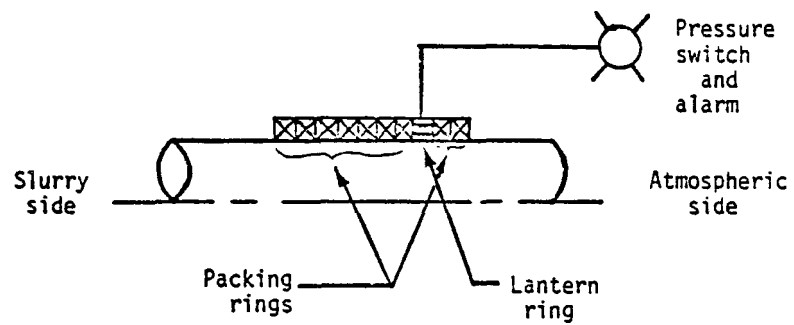


Fig. 4-7 Installation of lantern ring on packing

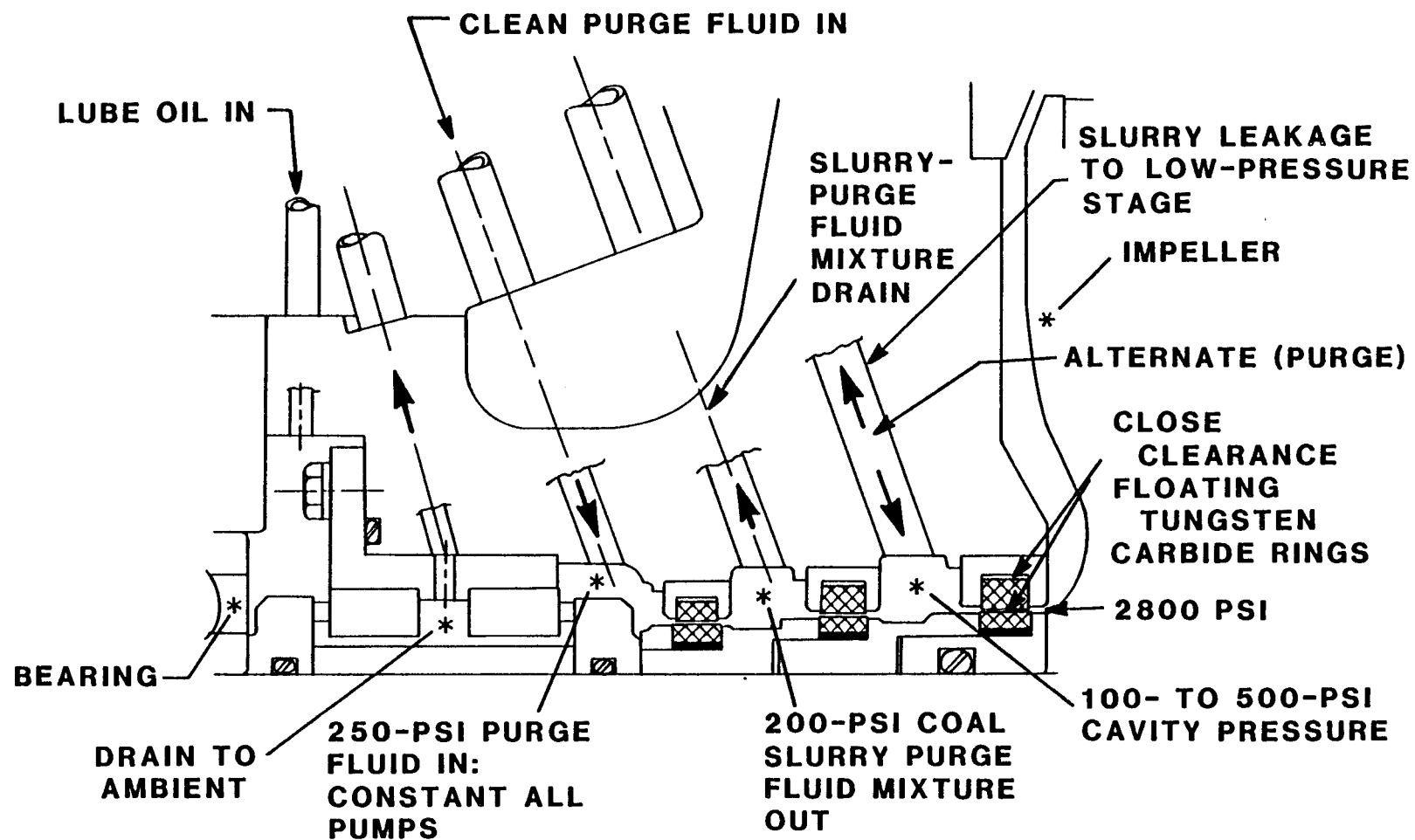


Fig. 4-8 Slurry pump main seal for high pressure stage

SECTION 5

ENVIRONMENTAL AND SAFETY REGULATIONS

The Statement of Work asks for discussion of these topics in more than one place. To avoid duplication these topics will not be addressed here but appear as follows:

Environmental regulations and the ability of the plant to meet them is part of Deliverable No. 18, Environmental Suitability Report.

Safety regulations and compliance are discussed in Section 6 of this report.

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SECTION 6

SAFETY AND HEALTH PROTECTION

6.1. SAFETY

The ultimate goal of safety is the complete prevention of personal injury, loss of life and destruction of property as a result of accidents, fires, explosions or other hazardous situations.

The approach to accomplishing this important aspect of the SRC-II Demonstration Plant is:

- Design to avoid hazards during startup, operations, maintenance and upset conditions.
- Operate to prevent accidents and catastrophes.
- Prepare to handle catastrophes.

In addition, it is important to give early attention to design considerations that facilitate safe disposal of plant-produced materials, wastes, and plant equipment.

6.1.1 Design to Avoid Hazards

Accepted standards and codes, plant layout and special aspects of the process have been and will continue to be considered in the design of the plant, with the objective of providing a plant which can be operated and maintained safely.

6.1.1.1 Standards and Codes

The design of the SRC-II Demonstration Plant to date has been in accordance with applicable industrial and Government standards and codes, plus regulatory requirements such as those included in the Occupational Safety and Health Act of 1970. These will continue to be used in the future until they are superseded by the Occupational Safety and Health Program which is being formulated by the Department of Energy for DOE owned and operated facilities.

6.1.1.2 Plant Layout

Safety considerations and fire protection were considered in the layout of the Conceptual Demonstration Plant. Some of these considerations are listed below.

- a. A grid type of layout is deemed essential with road and fire water systems serving at least two sides of each hazardous area. The water system for each hazardous area will be sectionally valved, isolatable and dually fed.
- b. Hazardous liquid storage tanks will be spaced and diked in accordance with National Fire Protection Code 30.
- c. Open fires (furnaces, flares, etc.) are preferably located on the prevailing upwind side of the plant, based on the calculated radiant heat zone from the flame to the process unit battery limit. The source of ignition should be placed so that the dip of the flame and the calculated radiant heat zone, under full flare conditions, would not represent a source of ignition for flammable vapors within the process unit or process battery limits.
- d. Isolated storage areas are provided for:
 - Coal
 - Liquid products
 - By products -- sulfur, tar acids, ammonia
- e. The more hazardous units are isolated from the rest of plant, such as:
 - SRC-II High Pressure Equipment
 - Oxygen Plant
 - Texaco Gasifier

6.1.1.3 Process Considerations

The SRC-II Demonstration Plant has several process hazards which must be addressed during the design of the plant. Among them are:

- a. The interrelationship between the various areas of the plant which causes a potentially unsafe domino effect, resulting in difficulty in maintaining proper control of the plant.
- b. Flammable, explosive and toxic properties of components of many of the plant streams.
- c. Potential line plugging due to high solids content, coking tendency and high freezing points of some of the liquid streams and the potential of formation of solid ammonium compounds in some of the vapor streams. Plugging can result in inadequate or difficult control of the plant and blocking of flow to pressure relief devices. Plug removal work will result in increased exposure of employees to potentially carcinogenic materials and could create adverse environmental effects.
- d. Corrosive and erosive properties of many of the plant streams, which could result in the unplanned release of flammable and/or toxic materials.
- e. High pressures.
- f. High temperatures.
- g. Large volumes of plant streams with high kinetic energy and major fire and explosion potential.
- h. Potential for hydrogen embrittlement and stress corrosion cracking which could lead to catastrophic failure of vessels and/or lines.

Among the design actions to be used to mitigate these process hazards are:

- a. A very sophisticated control system will be provided to aid in the proper control of the process.
- b. The corrective actions taken at the Ft. Lewis SRC Pilot Plant for similar problems will be studied and used where applicable.
- c. Safety aspects will be given high priority when evaluating alternate processes and equipment.

- d. Vapor recovery systems, enclosed pressure relief systems, liquid drainage systems and waste recovery systems for both normal operating and emergency situations will be provided.
- e. Sources likely to produce significant noise, heat or other physical agent hazards will be carefully scrutinized for the degree of risk and the type or nature of control measure required.
- f. Local exhaust control systems will be utilized where adverse breathing zone risk to plant personnel may exist.
- g. Each processing area will be scrutinized to evaluate hazards and degrees of risk and to determine methods, types, extent and amounts of safety and protective measures and equipment to be provided and used. Tables 6-1* and 6-2 summarize the evaluation which has been made to date.

6.1.2 Operate to Prevent Accidents and Catastrophes

Accident prevention programs at the Demonstration Plant will reflect the following philosophy:

- Safety is a management responsibility that cannot be delegated.
- The initiation and maintenance of safe occupational practices and safe working conditions is the responsibility of all levels of management. All levels of supervisory personnel will actively support the safety effort.
- Employees are responsible to utilize safe occupational practices and will be expected to assist management whenever possible in the elimination of unsafe working conditions.
- Loss producing events result from management or supervisory failure to correct habitual and occasional unsafe behavior or to recognize and correct unsafe conditions. Management will be responsible for developing procedures to identify

*Tables appear at the end of the text.

unsafe behavior through the use of critical incident recall, job hazard analysis and safety sampling. Unsafe conditions will be eliminated through the use of safety review, change analysis and system safety.

- Accidents and near miss incidents are a prolific source of data concerning weakness in plant safety performance. Management will insure that all accidents and near miss incidents are reported and are thoroughly investigated utilizing standard methods such as MORT (Management Oversight Risk Tree).
- Information concerning results of accidents and near miss incidents will be widely disseminated and well understood to preclude unnecessary recurrence. Management will insure that all employees attend compulsory safety meetings at least monthly. Tool box or tail gate safety meetings held by first line supervisors will also be held.

Procedures, training, monitoring and maintenance all will be utilized in an effort to prevent accidents and catastrophes such as fire, explosion, equipment failure, etc.

6.1.2.1 Procedures

Detailed safety, operating and maintenance procedures will be developed and published in manuals for the various plant areas. Special procedures, practices and methods will be included such as those for:

- Unusual and dangerous operating conditions.
- Safety work permits
- Equipment lockout
- Equipment tagging
- Hot work permits
- Vessel entry
- Handling of hazardous and toxic materials or agents
- Operation and repair of radioactive sources

- Purging, flushing and blinding
- Respiratory and special protective equipment
- Personal hygiene

Experience gained at the Ft. Lewis SRC Pilot Plant relative to the SRC process will be utilized, in addition to experience gained in the operation of large refineries and chemical plants by Gulf and other industrial firms.

6.1.2.2 Training

An intensive training program will be conducted for operating, maintenance, laboratory, and support personnel, including supervision, prior to plant commissioning. Additional training will be conducted for new or modified procedures as the need develops. Refresher training sessions will be on a regular basis, at least annually. In these safety oriented meetings, the importance of following established safety, operating and maintenance procedures will be stressed. Suggestions and recommendations by the workers will be a vital part and will be utilized to improve procedures.

The original cadre will contain a large number of experienced personnel - those with SRC experience from the Ft. Lewis Pilot Plant and those with commercial refining and chemical plant experience. A training period at the Ft. Lewis Pilot Plant is planned for key Demonstration Plant personnel who have no SRC experience.

6.1.2.3 Monitoring

Process conditions will be monitored continually by operating personnel, aided by the instrument control system, to detect as early as possible the development of a potential problem so that corrective action can be initiated.

As much as is practicable, onstream monitoring will be performed to determine the extent of corrosion and erosion to allow shutdowns for repairs to be made in an orderly manner, rather than after a major leak

or rupture has occurred. During periods in which the plant or individual equipment is shut down, inspections will be performed which cannot be performed while the plant or equipment is operating. Unless shutdowns occur for other reasons, the need for these inspections may require rather frequent plant shutdowns during the early phase of operation for this purpose. Subsequently, shutdowns for inspections can be scheduled based on the historical corrosion and erosion data collected.

6.1.2.4 Maintenance

Preventive maintenance will be performed on a regularly scheduled basis. Major emphasis will be given to high energy rotating equipment and equipment operating at high pressures and temperatures. Highest priority will be given to equipment and systems which are required during emergency and/or upset conditions.

Regularly scheduled plant turnarounds will be conducted to inspect and repair that equipment for which such work cannot be performed while in operation.

6.1.3 Prepare To Handle Catastrophes

Since the SRC-II Demonstration Plant handles large quantities of hydrocarbon materials and toxic compounds, and contains large equipment operating at high temperatures and pressures, the potential of a catastrophe occurring must be realized and preparations made to deal with such an occurrence.

Preparations for handling catastrophes in the Demonstration Plant will consist of written procedures, personnel training, special safety equipment, inspections of that equipment and periodic scheduled and unscheduled disaster or catastrophe drills.

6.1.3.1 Procedures

Well planned emergency procedures are the most important procedures for a plant such as this. In addition to specifying the actions to be taken, the responsibilities and authorities of various individuals and

groups must be clearly defined, including coordination with off-plant emergency assistance such as fire departments, police, ambulance and helicopter service, hospitals and doctors. A high priority will be assigned to the preparation of these procedures.

6.1.3.2 Personnel Training

Training programs for personnel will be conducted to prepare them to take the proper plant operational actions in the event of a catastrophe. Training programs also will be conducted in catastrophe plan responsibilities, first aid, fire fighting and the use of protective equipment. Refresher training will be performed on a regularly scheduled basis.

6.1.3.3 Equipment

In addition to the permanently installed equipment such as firewater piping and hydrants, foam systems, etc., mobile firefighting, ambulance, and protective equipment, including various types of breathing apparatus, will be provided.

6.1.3.4 Equipment Inspection

All safety and firefighting equipment will be inspected on a regularly scheduled basis and necessary repairs made to ensure their proper performance and availability when needed.

6.2 HEALTH PROTECTION

The ultimate goal of health protection is the complete prevention of exposure of personnel to toxic materials produced in the plant.

The approach to accomplishing this important aspect of the SRC-II Demonstration Plant is:

- Design and operate to avoid exposure
- Provide health protection program

6.2.1 Design and Operate to Avoid Exposure

The plant will be designed and procedures will be developed to avoid exposure to toxic gases and coal chemicals.

6.2.1.1 Toxic Gases

Some of the health hazards associated with the SRC-II Demonstration Plant will be similar to those encountered in a large petroleum refinery. Specifically, each handles large quantities of the highly toxic gases, hydrogen sulfide and carbon monoxide. Each also has the potential, under certain conditions, of producing the highly toxic gas, nickel carbonyl. The same types of procedures will be followed in the Demonstration Plant as is used in refineries to protect employees from these materials.

Data collected in the Ft. Lewis Pilot Plant health protection program has shown that the normal airborne concentrations are so low that there is no hazard due to long term exposure to hydrogen sulfide or carbon monoxide. However, the quantities handled in the Demonstration Plant will be much greater and, if a large leak occurs, a larger area of high concentration will result which will increase the potential of exposure. In addition, the Demonstration Plant will have many more elevated operating areas, some with numerous levels, which will make evacuation more difficult. As a result, a more comprehensive program will be required for the Demonstration Plant than for the Pilot Plant in order to protect personnel from these two toxic gases. Such a program may include restriction of the number of persons allowed above ground level at any one time and requirements that personnel have gas masks on their person when in certain areas, especially when above ground or inside vessels.

6.2.1.2 Coal Chemicals

There has been considerable speculation about the potentially adverse health effects of organic compounds, primarily polynuclear aromatics. However, there is a lack of appropriate data developed through epidemiological studies which could be used to better define the hazard, but very preliminary bioassays have provided limited evidence indicating potential for irritative, fetotoxic, and carcinogenic effects. Definitive characterization of these effects should be provided by the planned toxicology program which is discussed briefly in paragraph 6.2.2.1.4, Toxicology Program.

Commercial processing experiences in the past with coal liquefaction methods similar to the SRC process are very limited and provide little in comparative health effects information.

During World War II, Germany produced synthetic fuels from coal. However, no medical records are available from these operations which could be used to properly assess potential health risks. During the period 1952-1956, a medical surveillance program was conducted at the Union Carbide Chemicals Company coal hydrogenation plant at Institute, West Virginia, with subsequent continuing examination of the workers. A statistical evaluation of the data led to the conclusion that an increased incidence of skin cancer was found in workers exposed nine months or more to contact with coal hydrogenation chemicals.

Based largely on the results of the Institute study, it was concluded, prior to the startup of the SRC Pilot Plant at Ft. Lewis, Washington, that an effective health protection program was necessary. A program was developed and placed in operation in 1974. During the five years of operation of the Ft. Lewis Pilot Plant there has been no discernible change in the medical profile of any of the plant personnel.

6.2.2 Provide Health Protection Program

A comprehensive health protection program will be developed for the Demonstration Plant consisting of employee training, monitoring and medical surveillance. It will be patterned after the Ft. Lewis Pilot Plant program and should ensure that personnel will be adequately protected.

6.2.2.1 Ft. Lewis Pilot Plant Health Protection Program

The principal objectives of the Ft. Lewis Pilot Plant Health Protection Program are:

- Protecting the workers from exposure to materials which could potentially result in adverse health effects.
- Monitoring of the worker environment to measure the extent and nature of exposure, both from a health standpoint and to identify needs for additional engineering controls or process modifications.
- Assessing the toxic characteristics of the SRC materials through extensive bioassay studies.

The program consists of:

- An industrial hygiene monitoring program
- An employee hygiene and education program
- An occupational medical and epidemiology program
- A toxicology program

6.2.2.1.1 Industrial Hygiene Monitoring Program

This program is an air sampling and analysis program to attempt to determine the health hazard to workers as the result of airborne materials.

It has been determined that:

- The benzene soluble fraction of particulate matter collected by high volume air samplers in the SRC solidification and coal-slurry mixing areas have been found at times to be at or above 0.15 mg/m^3 . Such values are marginal in terms of current OSHA standards.
- Free silica in mineral residue dust is a potential health problem. (This may also apply to gasifier slag dust in the Demonstration Plant).
- Airborne concentrations of hydrogen sulfide, carbon monoxide and phenols are very low except for vapor phase hydrogen sulfide concentrations of raw naphtha (storage tanks and tank trucks). In the SRC-II Demonstration Plant, the raw naphtha will be stabilized, stored under an inert gas blanket and then hydro-treated, which will greatly reduce its hydrogen sulfide content.
- Due to their presence in various plant streams, phenols pose a serious occupational skin contact hazard necessitating preventive measures and good personal hygiene.

- Settleable particulate concentrations in the plant generally are lower than in nearby communities.
- Fumes generated while cutting or welding parts which are contaminated with coal derived materials pose a potential health hazard.

6.2.2.1.2 Employee Hygiene and Education Program

This program has the following objectives:

- To inform the employee of the known and potential hazards in the work environment, particularly those associated with exposure to coal-derived materials.
- To motivate the employee to use the protective measures available.
- To provide the employees with the protective equipment, clothing, facilities, and techniques needed to minimize the potential hazards.

The employee educational program consists of new employee orientation and continuing education. The new employee orientation consists of an audio visual slide presentation describing the plant, potential exposures in the plant and appropriate protection techniques. After the slide presentation, the new employee is given the SRC Health Protection Manual and required to read it. Then the employee is taken through the locker room and change house area and shown the proper entrances and exits within the area, proper disposition of soiled clothing, and proper storage of clean work clothing and street clothes.

Each process area employee is issued rubber boots and/or leather safety shoes, work uniforms, underclothing, socks, work coats, hard hat, barrier cream and skin emolient.

Process area employees are required to change into the company-supplied clothing before going into the work area and to remove that clothing, shower and change to street clothing before leaving after their shift. Each change facility is divided into a clean area, dirty area, and a shower area to minimize contamination of individuals and their clothing when leaving the plant.

A more limited program has been followed for contractor personnel working in the process area since their degree of potential exposure is less. The adequacy of the contractor personnel protection program is periodically evaluated. Changes will be made to expand its scope if this action appears to be warranted.

6.2.2.1.3 Occupational Medical and Epidemiology Program

Each process exposed employee at the Pilot Plant is given a detailed pre-employment medical examination and an annual followup examination. This is supplemented by a quarterly skin examination by the plant nurse and the referring of any observed skin problems to a dermatologist on an as needed basis.

The pre-employment and annual examinations consist of a medical history, a complete physical examination, a complete blood count, blood chemistries, urinalysis, chest x-rays, and careful examination of the skin for lesions. Pulmonary function tests are performed by a plant nurse.

Evaluation of the findings of the occupational medical and epidemiology program has indicated no discernible changes in the medical profiles of the exposed employees.

Treatment of occupational injuries and illnesses has been carried out by physicians as needed.

Mild transient dermatitis from skin contact with coal derived materials has been encountered at the Pilot Plant. There have been 50 to 60 cases of eye irritation, approximately ten of which involved substantial quantities of coal-derived solvent contacting employee's eyes. In all cases, these eye irritations responded satisfactorily to first aid treatment consisting of eye irrigation with saline solution. Followup medical examinations by an ophthalmologist confirmed the absence of any prolonged or permanent eye damage.

Folliculitis is the most common occupationally related medical effect at the Pilot Plant. It manifests as a mild irritation caused by the accumulation of small quantities of coal-related material in the hair follicles of the skin. Complete removal of this material is difficult. This condition responds well to temporary suspension of exposure.

The experience at the SRC Pilot Plant has revealed none of the problems experienced at the Institute plant, where 60 skin lesions were excised from a group of 359 coal hydrogenation workers during a five-

year period. The intensive employee health program which has been in effect at the SRC Pilot Plant, essentially since startup, is felt to be the major difference between the plants.

6.2.2.1.4 Toxicology Program

In early 1975 a toxicology program on SRC materials was recommended to the Energy Research and Development Administration, DOE's predecessor. The proposed work included various acute and subacute tests and chronic skin painting studies. The scope of this work was subsequently expanded to include chronic inhalation studies and teratogenic studies. Animal testing at a contract laboratory began early in 1977. This initial program was devoted to SRC-I products and process materials. It was terminated in June, 1978, due to several problems experienced by the contract toxicology laboratory. A revised toxicology program, which includes SRC-II materials, has been proposed to DOE and funds have been allocated. A complementary program has been developed at the Battelle Pacific Northwest Laboratory.

6.2.2.2 Demonstration Plant Health Protection Program

The health protection procedures and results developed in the Ft. Lewis Pilot Plant health protection program to date, and those obtained in the future, will be utilized as a guide in the preparation of a health protection program for employees and contract workers in the SRC-II Demonstration Plant. The Pilot Plant program has indicated that, with a sound health protection program, no major health problems should be encountered during the operation of the Demonstration Plant.

TABLE 6-1
PROCESS SAFETY EVALUATION
DEFINITIONS OF HAZARDS, RISKS AND PROTECTIVE ACTIONS

HAZARD CODE	HAZARD	RISK	PROTECTIVE ACTIONS ⁽¹⁾
a	High temperatures	Burns, leak potential	A,B,C
b	High pressures	High energy release, leak potential	A,B,C
c	Large reactors	High energy release, maintenance exposure	A,B,C,D
d	Flammable materials	Fire, explosion	A,B,C,D,E
e	Fired heaters	Ignition source	C
f	Acidic liquids, gases, solids	Poisoning, burns	D,E
g	Compressors, pumps, valves	Leaks, noise, maintenance exposure	D,E
h	Dynamic fluctuations	Equipment damage	B,D
i	Toxic gases and chemicals	Personnel exposure	A,B,C,D,E
j	Pollution, air and water	Personnel exposure, exceed regulatory limits	A,B,C,D
k	Weather	Freezing of process and instrument lines, poor visibility, slipping	C,D,E
l	Plugging and coking	Loss of control, maintenance exposure, pollution potential	D,E
m	Moving equipment (conveyors, elevators)	Injury to operating and maintenance personnel	C,D
n	Hydrogen embrittlement	Catastrophic failure of vessels and/or piping	D
o	Stress corrosion cracking	Catastrophic failure of vessels and/or piping	D

(1) Definitions of Protective Actions:

- A- Extensive use of systems for vapor recovery, enclosed pressure relief, liquid drainage, and waste recovery for both normal operating and emergency situations.
- B- Highly automated equipment with elaborate instrumentation to aid in control of the process and to minimize the number of personnel subject to exposure.
- C- Carefully planned equipment locations and overall plant layout arrangement.
- D- Special and specific design, operational and maintenance procedures, practices and methods.
- E- Protective clothing and gear, monitoring equipment.

TABLE 6-2
PROCESS SAFETY EVALUATION
SUMMARY OF PLANT HAZARDS AND PROTECTIVE ACTIONS

<u>PLANT AREA</u>	<u>DEGREE OF RISK</u>	<u>HAZARDS</u> ⁽¹⁾
11-Dissolver Plant	High	a,b,c,d,e,f,g,h,i,j,k,l,n,o
12-Hydrogen Treating and Recovery	Medium high	a,b,d,f,g,h,i,j,k,n,o
21-Syngas Production	Medium high	a,b,c,d,e,f,g,h,i,j,k,l,o
22-Syngas Shift Conversion	Medium	a,b,c,d,f,g,h,i,j,k,o
23-Hydrogen Purification and Compression	Medium	b,d,f,g,h,i,j,k,o
24-Syngas Purification	Medium	b,d,f,g,h,i,j,k,o
25-Methanation	High	a,b,c,d,g,h,k
31-Low Pressure Gas Compression & Treating	Medium	d,f,g,h,i,j,k
32-Product Gas Plant	Medium	b,d,f,g,h,i,j,k
33-Sulfur Recovery	Medium	a,c,d,e,f,g,h,i,j,k,l
34-Refining Plant	Medium	a,d,e,f,g,h,i,j,k,l,o
35-Hydrodesulfurization Unit	Medium	a,b,c,d,e,f,g,h,i,j,k,m
41-Ammonia Recovery	Medium	d,f,g,h,i,j,k
42-Tar Acids Recovery	Medium	d,f,g,h,i,j,k
43-Plant Water Reclamation	Medium	d,e,f,g,h,i,j,k
44-Oxygen Plant	High	b,d,e,g,h,i,j,k
51-Steam Generation	Medium	a,b,e,g,h,j,k
52-Raw Water System	Low	f,g,i,j,k
53-Cooling Water System	Low	d,f,g,i,j,k
61-Coal Supply System	High	d,i,j,k,l,m
62-Coal Crushing System	High	d,e,i,j,l,m
63-Fine Coal Handling System	Medium	d,g,i,j,l,m
64-Slag Handling System	Medium	f,g,i,j,k,l,m
65-Slag Disposal System	Medium	f,g,i,j,k,l,m

(1) Refer to Table 6-1 for hazards codes

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7. OPERATIONAL PROBLEMS

7.1 DESIGN AND OPERATING PHILOSOPHY

Due to the high degree of process integration, the incorporation of many prototype processes and equipment items and the potential toxicity of some of the reaction products, very careful attention will be given throughout the Phase I design period of the SRC-II Demonstration Plant, with the objective of providing a plant that can be operated in a controlled manner during startups, normal operation, shutdowns and reduced rate operations. This capability, as well as carefully planned procedures for handling emergencies, is imperative for the safety of operating personnel, to prevent equipment abuse (which in itself creates safety hazards) and to improve onstream time of the plant. In order to achieve this capability, a great degree of attention will be given to the preparation of precommissioning, commissioning and operating procedures for all modes of operation.

The initial operating philosophy will be to aim for reliable, well controlled operation. During this time, emphasis will be placed on maintaining continuous operation at a reduced rate, rather than achieving a high throughput. When continuous, well controlled operation at reduced rate has been demonstrated, rates will be increased gradually.

A good onstream factor, achieved by starting at reduced rate and increasing rate slowly as controlled operation is maintained and demonstrated, minimizes the possibility of those unexpected incidents, with harmful consequences, which most often occur during startup, shutdown or emergencies of units or plants.

7.2 PLANT DESCRIPTION

Figure 7 - 1* is a schematic flowsheet of the Conceptual SRC-II Demonstration Plant. Coal is received by rail and stored in chevron

*Figures appear at end of contents.

type piles in order to provide a uniform coal feed to the plant. It is recovered from the storage pile by front end loaders and conveyed to the coal preparation area where it is dried and ground. It is mixed with hot recycle slurry, pumped to reaction pressure and then mixed with hydrogen. This coal slurry-hydrogen mixture flows through a fired preheater where it is heated to reaction temperature. In the preheater, the coal partially dissolves in the recycle slurry, which is an endothermic reaction. Hydrogenation and hydrocracking reactions begin in the preheater and continue in the dissolver, which necessitates the addition of cold hydrogen to the dissolver to control the reaction temperature at the desired level.

The major reactions occurring in the preheater and dissolver are:

- Solution of the coal in the solvent, accompanied by formation of a gel as the coal begins to dissolve.
- Hydrogenation and depolymerization of the gel and of the coal in solution.
- Hydrocracking of the dissolved coal to lower molecular weight hydrocarbons ranging from liquid middle distillates to methane.
- Conversion of organic sulfur by hydrogenation to hydrogen sulfide.
- Conversion of iron pyrites to ferrous sulfide.
- Hydrogenation of oxygen in the coal to water.

The dissolver effluent goes first to a hot high pressure separator. The liquid (slurry) from the hot high pressure separator, after flashing to lower pressure, is split into two major streams. One of these streams goes to the vacuum flash system while the other comprises the recycle

slurry for the process. This recycled slurry, which is peculiar to the SRC-II process, contains substantial concentrations of ash which is a catalyst for the process. The catalytic effect of ash on the degree of coal conversion is shown by Figure 7E-3, Appendix 7E.

The hot overhead vapor stream from the hot high pressure separator is cooled in a series of heat exchangers and additional vapor-liquid separation steps. Water injection is required to solubilize ammonium compounds to prevent their deposition as solids with resulting plugging and possible corrosion. The condensed hydrocarbon liquid from these separators goes to the fractionation system. The non-condensed gas consists of unreacted hydrogen, methane and other light hydrocarbons, plus H_2S and CO_2 . The gas is first sent to an oil wash tower to remove heavy hydrocarbons and then to an acid gas treating unit for removal of H_2S and CO_2 . The treated gas then is further processed in a cryogenic unit for removal of argon, nitrogen, methane and other light hydrocarbons. The recovered hydrogen is mixed with fresh make-up hydrogen from the gasifier train. This mixture comprises the hydrogen fed to the process.

A mixture of methane and ethane recovered in the cryogenic unit is processed through a methanator for sale as pipeline gas, while propane and butane are recovered as separate streams. The H_2S removed in the acid gas treating unit is converted to elemental sulfur in a sulfur recovery unit equipped with a tailgas treating unit to ensure compliance with environmental standards.

In the vacuum flash system, distillate is separated as an overhead product from the high boiling organic components and the mineral residue bottoms. The bottoms stream goes to an oxygen-blown gasifier where the hydrocarbon content is converted to synthesis gas and the ash is converted to slag. The synthesis gas produced in the gasifier is split into two streams. One goes through a shift conversion step for conversion of steam and carbon monoxide to hydrogen and carbon dioxide, then to an acid gas removal step for removal of carbon dioxide and hydrogen sulfide. The hydrogen then is compressed and fed as makeup hydrogen to the preheater-dissolver of the SRC-II process. The other stream of synthesis gas, the excess of that necessary to provide makeup hydrogen, is processed

to remove acid gases and then is used as plant fuel and possibly as feed to a methanator.

The overhead product from the vacuum flash system and the condensed liquid streams from the various flash vessels downstream of the high pressure, high temperature separator are combined and fed to a fractionation system for separation of fuel oil product, naphtha and a hydrocarbon gas stream which flows to a methanator for conversion to pipeline gas.

The various sour water streams throughout the plant are combined and processed to remove ammonia and tar acids. The water is further processed, after which the major portion is recycled to the process and the remainder, which contains a high solids content, is incinerated.

7.3 NORMAL STARTUP

The precommissioning, commissioning and initial startup of the plant will require a great deal of detailed thought and planning. Since it is expected that substantial changes will be made to the present conceptual design as the detailed design effort progresses, extensive work on this phase of operation is not warranted at this time. However, as the design becomes more firm, a very high importance will be assigned to the initial plant checkout and operation. Up to this time, startup evaluation has been limited primarily to normal startups.

Due to the highly integrated nature of the overall Demonstration Plant, an orderly, well-planned startup will be required so that each unit and area can be started up safely and in proper sequence. Appendices 7A and 7B are a preliminary startup sequence description and a preliminary startup logic diagram, respectively, for the process equipment. To ensure that adequate utilities are available during all modes of plant operation, much attention will be given during Phase I to the design of the utilities systems, especially the steam and fuel systems which are so greatly interrelated with the process. Appendix 7C is a preliminary evaluation of the utilities requirements of a normal startup.

During startup of the Demonstration Plant, dissolver yields may vary over a wide range until the plant operation has lined out at normal operating conditions. Since yield changes have a marked effect on stream compositions, rates and temperatures throughout much of the equipment downstream of the dissolver, the magnitude and rate of these changes must be determined in order to plan for and properly control a Demonstration Plant startup. A preliminary analysis of SRC-II startups at the Ft. Lewis Pilot Plant has been completed and used to make predictions of the changes which will take place in various streams downstream of the dissolver during startup of the SRC-II Demonstration Plant. This overall analysis is included as Appendix 7D. More thorough evaluation will be made as the definitive design progresses.

7.4 NORMAL OPERATION

Of prime importance in normal operation of a process plant is the continual monitoring of the process and equipment in an effort to detect potential problems when they begin to develop and to take corrective action soon enough to prevent their developing into serious problems, upsets or plant shutdowns. Among the tools that are beneficial is the plotting of key operating conditions, such as temperature, pressure and composition, over an extended period of time. In this manner, developing problems often can be detected which are not obvious when evaluating hour-to-hour or day-to-day data. This technique also can be utilized to predict when a specific unit may cause a shutdown and the information so developed can be used to prepare for and schedule an orderly turnaround, rather than being forced into an emergency shutdown for which repair work has not been planned. This type of monitoring will be an integral part of the normal operating procedures of the Demonstration Plant.

Even during routine normal operations of the Demonstration Plant, some variations will occur which will require corrective actions. As an example, fluctuation in the ash content of the coal fed to the process may require compensating actions. Further studies are planned to determine the effects of various changes and their duration.

A study has been made to determine the effect on the vacuum flash drum operation of variation of ash content of the feed coal through the design ash range of 9% to 14%, assuming no yield compensating action is taken. This study is summarized in Appendix 7E.

7.5 NORMAL SHUTDOWN

Extensive planning will be done to develop a sound shutdown sequence. Careful attention will be required in conducting the shutdown to minimize risk to personnel and damage to equipment.

A preliminary shutdown sequence and a preliminary shutdown logic diagram have been developed for a normal shutdown of the Conceptual Demonstration Plant. They are included as Appendices 7F and 7G, respectively.

As the detailed definitive design proceeds, a great deal of effort will be expended, aimed at providing the equipment, controls, and procedures which will allow for a safe, controlled and orderly shutdown, followed by a similar startup. Since one of the major problems at the Ft. Lewis Pilot Plant has been plugged lines, especially during plant startups, major emphasis during the design and operation of the Demonstration Plant will be placed on eliminating or minimizing plugs in equipment and piping during startups by proper flushing and cleaning procedures during the previous shutdowns.

7.6 REDUCED RATE OPERATION

There are many advantages of having the capability of operating any plant at rates substantially below design and it is an essential design requirement for any unit or plant. This is especially true of a complex, interrelated, new process like the SRC-II Demonstration Plant. A large degree of turndown capability is needed for:

- Maintaining proper control of the process by allowing more response time for the operators. This is especially important

during the initial period of operation when operating personnel are gaining experience in this new process, in order to avoid upsets and emergencies.

- Maintaining the plant onstream at a reduced rate during some unusual situations, such as limitation of power or water supply and during some repairs.
- Preventing unnecessary complete plant shutdown since shutdowns increase the safety hazard to personnel, shorten equipment life due to temperature and pressure cycles and subject certain equipment and piping to a high potential for plugging.

It is expected that there will be a considerable amount of time when the Demonstration Plant will be operated with only one dissolver, either by choice or by necessity. However, several processes such as the recycle hydrogen cold box, the oxygen plant and the gasifier, can be turned down to only 50% to 60% of design rate. Consequently, operation with only one dissolver at full rate would be marginal and continued operation at less than full rate would not be attainable.

It is important that the Demonstration Plant has the capability of one-dissolver operation at less than design rate. Consequently, an investigation of ways to provide this turndown capability for one-dissolver operation, at least to one-half to two-thirds of design rate, is being pursued in the Bridging Tasks and will continue during the Phase I design period. The investigation will be extensive and may impact the plant cost considerably since essentially all process units and equipment are involved.

The upflow, constant volume dissolvers presently planned for the Demonstration Plant cause an operating problem during reduced coal feed rate operation. Reduced coal feed rates can be achieved in such a system by either increased slurry residence time at normal coal concentration or by decreased coal concentration at normal slurry residence time. Either method causes coal conversions substantially in excess of design. Over-conversion results in abnormal compositions of the dissolver

effluent stream and thus abnormal compositions and temperatures throughout the downstream equipment which could result in poor process control, imbalance of various heat exchange streams, upset of the fuel system composition and such problems as plugging of the vacuum bottoms stream due to excess solids content. Consequently, from an operational and control standpoint, it would be desirable to have the capability of adjusting other operating variables during reduced coal feed rates so that the percent conversion of the feed coal remains at or near design.

Only limited experimental data have been obtained at conditions substantially different than the Demonstration Plant design conditions. Based on a few selected runs, the general effect on yields of temperature, coal concentration and slurry residence time are shown by Figures 7 - 2 through 7 - 4. These data indicate the possibility of maintaining yields at reduced rates similar to those at design rate by proper adjustment of variables. For example, if rates are reduced to one-half of design by decreasing coal concentration to one-half of design rate and maintaining design slurry residence time, these curves indicate hydrogen usage and yields of hydrocarbon gas, distillate and organic vacuum bottoms can be maintained relatively close to design values by decreasing the dissolver temperature about 20°F.

Experimental tests are planned specifically to obtain additional yield data at reduced rates and to determine the optimum yield control methods. In addition to determining the interrelationship of temperature, coal concentration and residence time, the effect of decreasing the degree of slurry recycle, with its resultant decrease in ash concentration in the dissolver, will be investigated as a means of yield control at reduced rates.

During reduced rate operations, velocities in piping and vessels will be less than normal. Therefore, during these periods, it may be desirable to have the capability to produce a finer grind of coal to minimize settling. Additional data is needed relative to the relationship between coal grind, slurry velocity and the degree of settling.

7.7 UPSETS AND EMERGENCIES

Any plant requires that a great deal of attention be given to designing for and developing operating procedures for upset and emergency conditions since the potential for personnel hazard and equipment damage increases substantially during such periods. Preliminary matrix tables have been prepared to show the effect of a considerable number of abnormal events on the operating systems in the plant and to identify potential problems. These are included as Appendix 7H. As definitive design progresses, these tables will be refined and will be utilized in the design and operational planning to identify and develop solutions to potential problems.

7.8 OPERATING PROBLEMS AND POTENTIAL SOLUTIONS

The Conceptual SRC-II Demonstration Plant contains several prototype processes, as well as a number of prototype equipment items. The prototype equipment items are covered in Section 4 of this Deliverable No. 3. Even though mechanical problems with these equipment items could create operational problems, most of them will not be discussed in this section. However, the following potential operating problems and their potential solutions are discussed: coal-slurry mixing, coking and plugging, preheater coking and erosion, dissolver yield control, slurry pressure letdown, vacuum flash system, gasification system, methanation, recycle hydrogen purification, corrosion/erosion, fuel system and steam system.

7.8.1 Coal-Slurry Mixing

PROBLEMS

The operability and dependability of this processing step is one of the more important in the entire SRC-II Demonstration Plant since upsets, especially major ones, will cascade throughout much of the plant, making it difficult to maintain proper control of the downstream operations.

Several factors affect coal-slurry mixing:

a. Coal Size

The ease of mixing increases with coal particle size. However, it has been determined at Ft. Lewis that excessively large size increases settling and erosion problems in the mixing system and in other areas of the plant. The effect of intermediate grinds needs to be established.

b. Water Content of Coal

Excessive water content of the feed coal may cause foaming problems in the mixing system. If it is determined that a very low water content is required to eliminate foaming, it will be necessary to use a small particle size coal in order to achieve the required degree of dryness.

e. Slurry Flow Measurement

Although progress has been made at the Ft. Lewis Pilot Plant in the ability to measure slurry flow, no device is currently available which assures accurate measurement of slurry for extended periods of time. Such a device is needed for adequate control of the flow of the recycle slurry stream to the coal-slurry mixing system, to aid in mixing control and to maintain a constant composition slurry to the dissolver.

f. Turndown

g. Types of Coal-Slurry Mixing Equipment

Two types of mixing devices have been utilized at the Ft. Lewis and P-99 SRC Pilot Plants and another has been tested to a very limited degree at Ft. Lewis.

Eductor

This is the original mixing device installed at Ft. Lewis. Coal is educted into a high velocity stream of circulating slurry. This type of mixing uses a large amount of energy for slurry circulation. Sustained high slurry circulation is mandatory for proper operation. Recurring coal buildup and plugging problems were encountered in the coal feed funnel.

This type of system is considered to be unsuitable for the SRC-II Demonstration Plant.

POTENTIAL SOLUTIONS

In order to ensure an operable coal-slurry mixing system for the SRC-II Demonstration Plant, the following program should be executed:

- a. The Demonstration Plant coal-slurry mixing system will be definitively designed. A small scale replica, preferably skid mounted, should then be manufactured and tested at the Ft. Lewis Pilot Plant.
- b. For the definitive design, it will be necessary to make some judgmental decisions, such as those relative to coal size and method and degree of drying. These decisions will be guided by the additional data currently being developed at Ft. Lewis
- c. Flexibility will be designed into the mixing system to allow operation at various temperatures. The ability to operate at less than normal design temperature is important during reduced rate operation since the rate of viscosity growth is decreased. A study performed at Ft. Lewis investigating the effect of residence time and temperature on the degree of oil absorption by coal particles is included as Appendix 7I. More information is needed to determine the effects on viscosity of temperature, residence time, degree of agitation, coal particle size and type of coal.
- d. In addition to the above work, the slurry flow measurement test program at Ft. Lewis will be continued.

PROBLEMS

Line plugging has been a major problem at the Ft. Lewis Pilot Plant, requiring frequent hydroblasting. It has been especially severe in the vacuum flash area where the slurry is hot, the hydrogen partial pressure is very low and the potential exists for air (oxygen) to leak into the system. The plugging is due to one or a combination of the following: coking, high ash content and polymerization to very high molecular weight material.

Vapor phase plugging due to ammonium compounds also has been a problem in the pilot plants.

The coking tendency of various streams at their normal processing temperature limits the capability of providing the amount of surge capacity desired.

POTENTIAL SOLUTIONS

Extreme care will be given to the design of the Demonstration Plant to minimize plugging problems. The design will include an improved line flushing and cleaning system based on experience gained at Ft. Lewis. Basic information is being developed in the Pilot Plants to define the conditions which cause coking and plugging. This additional information, careful design and well planned operating procedures should alleviate the plugging problems.

Recently, the Ft. Lewis Laboratory personnel have initiated a program to study the effects of residence time and temperature on coke formation and viscosity growth in the vacuum flash area. Preliminary data are plotted in Figure 7 - 5. These curves show that the rate of viscosity growth, which may be due to polymerization or coking, or both, increases dramatically with temperature. They also show that the growth

is gradual for a period of time and then increases rapidly. This preliminary information will assist in the design and operation of the Demonstration Plant vacuum flash system. More detailed information on more plant streams will be developed.

The Demonstration Plant is being designed with a water wash system aimed at solubilizing ammonium compounds. Special care will be given to maintaining the temperature of dead legs, especially those leading to relief valves, above the melt or sublimation point of the ammonium compounds expected to be present. A vapor phase wash system recently has been installed in the P-99 Pilot Plant to gain more information in this area. Operation, to date, has been encouraging.

7.8.3 Preheater Coking and Erosion

PROBLEMS

Coking and erosion have not been problems in the preheater at the Ft. Lewis Pilot Plant. However, in the Demonstration Plant, increased heat flux will increase the potential of coking and increased velocity will increase the potential of erosion.

Good slurry flow control is vital to minimize plugging potential. The ability to increase the inlet pressure of individual passes also is important so that incipient plugs can be blown out.

POTENTIAL SOLUTIONS

In order to provide dependable slurry flow and high inlet pressure potential, the number of slurry pumps has been increased in the Bridging Tasks so that each pass is served by an individual pump.

A new preheater which more nearly approximates the heat flux and velocities of the Demonstration Plant preheater is being installed at Ft. Lewis. Testing is scheduled for late summer, 1979.

PROBLEMS

A number of factors affect the yield of the various products from the dissolver, such as temperature, residence time, coal concentration, ash content of the coal, ash concentration in the feed slurry, ash buildup in the dissolver, hydrogen partial pressure and coal reactivity. Fluctuations in yields in the pilot plant operations have been indicated, possibly due to variations in one or more of these factors. However, it has not been a major operational problem since the downstream processing in both pilot plants is very simple compared to the Demonstration Plant. Fluctuating yields in the Demonstration Plant dissolver will be more critical due to the integration of downstream equipment and the more sophisticated product slate.

POTENTIAL SOLUTIONS

Procedures will be developed to store and reclaim coal so that the coal fed to the plant will be blended as much as is practicable, thus minimizing sudden and major changes in feed coal composition.

Dissolver modeling studies will be expanded to predict the effects on dissolver yields of expected variations of the various factors that affect these yields. Additional pilot plant data probably will be needed in order to improve the results obtained from this modeling program.

A computer process simulator program is planned to aid in operator training and in determining the interrelated process and utilities effects throughout the plant. This program will help determine the effects of variable dissolver yields on the control of the downstream processes and the corrective actions to be taken.

7.8.5 Slurry Pressure Letdown

PROBLEMS

There have been recurring problems in the slurry pressure letdown system during operation of the Ft. Lewis and P-99 Pilot Plants. The problems primarily are erosion of valve parts, separation of the plug from the stem in the letdown valve, plugging of the valve due to pulsing of ash from the dissolver and plugging of the valve due to coke breaking loose from upstream piping. There is no question that the requirement to let down the pressure from about 2000 psi to atmospheric of a hot slurry containing a large amount of erosive ash (about 60 tons per hour per letdown train) is very severe and that some mechanical and operating problems must be expected.

Designing the slurry letdown system with assurance of continuous satisfactory level control, and confidence in maintaining the physical integrity of the piping and valves, will be one of the most difficult design problems for the Demonstration Plant. The degree of success will impact plant operability.

POTENTIAL SOLUTIONS

Discussions have been and will continue to be held with commercial valve suppliers, seeking solutions to the mechanical design problems.

The Bridging Task activity has produced preliminary process designs utilizing parallel spare valves with a downstream configuration which decreases the potential for erosion. Although this type of installation introduces some additional problems, such as dead leg plugging, as well as more complicated piping and flash vessel construction, it does have the potential of extending the length of operating periods.

7.8.6 Vacuum Flash System

PROBLEMS

The vacuum flash system of the Ft. Lewis and P-99 Pilot Plants have not operated at the conditions planned for the Demonstration Plant. The more severe Demonstration Plant conditions of higher temperature and greater solids content may result in increased coking and plugging problems.

POTENTIAL SOLUTIONS

In order for the Demonstration Plant vacuum flash system to be designed with adequate assurance of acceptable operation, it is planned that either the Ft. Lewis or P-99 Pilot Plant be modified as soon as possible so that conditions approximating those of the Demonstration Plant can be piloted. Such operation would provide confirmation of vapor-liquid equilibria data and determine the magnitude of the potential coking problem.

7.8.7 Gasification System

PROBLEMS

For proper integration into the SRC-II process, the Demonstration Plant gasifier should be of the slagging type, have the capability of operating at a pressure in the order of 1,000 psi, utilizing a hot, high ash, high freezing point slurry feed.

Several problems may be encountered in the operation of such a gasifier system. Among them are:

a. Slurry Feed Control

Several factors will make it difficult to maintain a constant flow of constant composition in the bottoms stream from the vacuum

flash drum, which will be the feedstock for the gasifier. Providing sufficient feedstock surge to smooth out vacuum tower bottoms fluctuations may be difficult since surge residence time will be limited, due to the tendency of the material to coke and to increase in viscosity at its high temperature. Changes in feedstock composition to the gasifier will result in the need to adjust other streams to maintain the desired temperature. It is expected that control will be difficult if more than moderate changes in feedstock composition or rate occur. Lack of adequate temperature control will result in shutdown of the gasifier.

The pumping system required to pump a high solids, erosive slurry at about 650°F and with a freezing point around 400°F to a pressure in the order of 1,000 psi in a dependable and well controlled manner is a design, maintenance and operating challenge.

b. Burner Erosion

A gasifier utilizing slurry feed probably will utilize a burner somewhat similar to those used in oil-fired boilers.

Due to the large quantity of erosive ash, burner erosion is a distinct possibility. Erosion eventually could necessitate shutdown of the gasifier for burner replacement.

c. Refractory Corrosion/Erosion

Throughout the thirty years of development of various slagging gasifiers, refractory corrosion/erosion has been a serious problem. Major advances have been made in the development of suitable refractories. The severe environment to which the refractory will be subjected during operation and the potential for thermal shock during startups and shutdowns result in a potential for refractory damage with resulting detrimental effect on operability.

d. Slag Removal

The gasifier slag removal system must remove approximately 800 tons per day of slag from the high pressure gasification system in a dependable and safe manner.

POTENTIAL SOLUTIONS

During initial operation of the Demonstration Plant, the pressure in the vacuum flash system could be increased above the design point. This would increase the solvent content of the gasifier feed stream and thus decrease potential pumping problems. After establishing acceptable operation at these conditions, the severity in the vacuum flash system could be increased gradually toward design conditions.

Bridging Task work to date has added a 30 minute vacuum bottoms inventory to aid in smoothing out the variations in the gasifier feed.

It is expected that a large pump of a design similar to that planned for the Demonstration Plant will be installed in a pump-around mode on the Ft. Lewis vacuum drum. It is believed that testing of such a system would add greatly to reliability of the Demonstration Plant pumping system design.

In order to provide more dependability of hydrogen production, and more flexibility for operation at reduced rates, Bridging Task work has changed the gasification system from two 100% gasifier systems, with one operating and one on standby, to three 50% units so that one gasifier can be available for relining.

7.8.8 Methanation

PROBLEMS

Methanation reactions are exothermic--extremely so for some materials. Variability in feed composition results in very difficult temperature

control. Since these methanation reactions are carried out in a gas phase, residence time is short so temperature changes occur rapidly. For example, a one percent change in CO content of the feed gas will result in an almost instantaneous temperature change of about 130°F.

The heat of methanation of compounds in the methanator feed stream are:

	Heat of methanation, <u>Btu/lb. mole</u>
Carbon Monoxide	107,000
Methane	0
Ethane	28,000
Propane	34,000

Since the composition of the feedstream to the methanator may be difficult to control, it is imperative that a system be provided for rapid and accurate analyses of this stream so that:

- The methanator temperature can be controlled adequately
- A stoichiometric ratio of hydrogen can be maintained
- The product gas consistently meets pipeline gas specification.

POTENTIAL SOLUTIONS

Bridging Task work has eliminated from the methanator the most exothermic stream, the excess synthesis gas from the gasifier. It is planned to utilize it as plant fuel. If the final design requires that it be methanated, a separate methanator should be installed to handle only synthesis gas.

A surge drum of sufficient capacity to allow for analytical response time and to smooth out the composition to the methanator feedstream should be considered.

An emergency system should be provided, such as an inert "sweep" gas, to cool the methanator in the event of an uncontrolled temperature rise to prevent loss of strength of the pressure shell.

7.8.9 Recycle Hydrogen Purification

PROBLEMS

All cryogenic units require meticulous cleaning of the feed gas stream in order to prevent freezeups and resultant downtime for deriming. In order to properly design the gas purification system, analysis of the feed gas stream under all modes of operation must be known, including trace quantities of materials that could freeze out in the cold box, some of which may cause a safety hazard when deriming. For example, in the design and operation of coke oven gas purification by a cryogenic system, extreme care is taken to limit the nitric oxide (NO) composition to a few parts per billion, and special deriming procedures are used, since nitric oxide, or complexes of it, is temperature and shock sensitive. Explosions have occurred during deriming of these units.

Cryogenic units operating on coke oven gas, which is somewhat similar to the Demonstration Plant feedstream, are sensitive to changes in composition of the feed gas stream. Fluctuations in feed gas composition in the Demonstration Plant are anticipated. However, it is impractical to provide gas surge upstream of the cold box to aid in smoothing out fluctuations in gas composition at the design flowrate of about 240 million standard cubic feet per day, since a vessel to provide ten minutes of surge would be almost identical in size and wall thickness to one of the Demonstration Plant dissolvers.

Plugging in the cryogenic unit will require shutdown of the entire Demonstration Plant. The cryogenic unit will be designed to be bypassed so an orderly plant shutdown can be accomplished. However, continued operation in this manner will not be practicable because the rapid buildup in concentration of hydrocarbon gases in the hydrogen recycle

stream will result in an excessive reduction of hydrogen partial pressure in the dissolver. Theoretically, acceptable hydrogen partial pressure could be maintained by flaring large amounts of recycle gas and increasing the rate of makeup hydrogen. However, the makeup hydrogen capacity of the Demonstration Plant is inadequate for this type of operation and flaring of such large quantities of gas for the extended periods required for cold box deriming would be economically unattractive and could violate environmental standards.

POTENTIAL SOLUTIONS

Air Liquide, the designer of the cryogenic unit, has been selected to a large extent because of their demonstrated ability to design highly operable systems for similar applications. Additional experts will be utilized if necessary or desirable.

A program has been initiated at the P-99 Pilot Plant to:

- Obtain detailed analyses of the SRC-II dissolver off-gas stream, with special attention given to those components, even in trace amount, which could cause freezing problems or safety hazards in the operation of a cryogenic system.
- Determine the variation in the composition and quantity of dissolver off-gas under various modes of operation.
- Confirm the effectiveness of the gas cleaning system upstream of the cryogenic unit which is planned for the Demonstration Plant and determine any changes which should be made.

Consideration will be given in the Phase I design to replacing the single gas purification and cryogenic system of the Conceptual Demonstration Plant with two - - one for each dissolver train - - for the following reasons:

- The single cryogenic unit is a prototype, substantially larger than any previously built and operated for a similar feedstock.
- The cryogenic unit has a maximum turndown capability of 50%, which would make "one - dissolver" operation of the Demonstration Plant very marginal at best and probably not attainable.
- The effects of upsets in one dissolver train on the operation of the other train would be greatly reduced.

7.8.10 Corrosion/Erosion

PROBLEMS

Corrosion and erosion have been serious problems in the development of all coal liquefaction processes. Much progress has been made in determining the causes and in selecting more resistant materials. However, such problems certainly will be experienced to some degree in the Demonstration Plant.

POTENTIAL SOLUTIONS

Shutdowns of the Ft. Lewis Pilot Plant have been sufficiently frequent so that inspections to determine the location and extent of corrosion and erosion could be made, as well as the effectiveness of corrective actions. This information will be utilized fully in the design of the Demonstration Plant.

In order for the Demonstration Plant to operate continuously for long periods of time, e.g. for six months or more, with assured safety of personnel and integrity of equipment, an extensive onstream wall thickness measurement program will be needed. For such a program to be satisfactory, it will be necessary to perform these tests frequently at

high temperatures, for which equipment is not currently available. The development of such equipment must continue to be given high priority. It will be needed for any coal liquefaction process, not just SRC-II.

7.8.11 Fuel System

PROBLEMS

The Demonstration Plant will have a mixed fuel system since none of the streams available for fuel are produced in sufficient quantity, under all operating conditions, to provide the fuel needs of the plant. Fuels will vary from liquid naphtha to synthesis gas and will have widely varying heating values as shown below:

	<u>BTU/LB</u>	<u>BTU/SCF</u> <u>OF GAS</u>
Synthesis Gas	7,000	300
Low Pressure Flash Gas	20,000	900
Naphtha	17,000	-

If the ratios of the quantities of the various materials to be used as fuel did not change, design and operation of the fuel system would not be too difficult since individual burners could be designed to operate at all times on liquid naphtha or on the gas fuel, which could be blended to a relatively constant heating value. Unfortunately, large fluctuations in the ratio of available fuels may occur. As indicated above, one of the components in the fuel system will be the synthesis gas produced in excess of that required for providing the hydrogen needed for the dissolver. Changes in dissolver yields will result in changes in the amount of synthesis gas available and used as fuel. The impact can be significant since reduced conversion in the dissolver results in a lower hydrogen requirement but a higher production of organic vacuum bottoms which is the feedstock for synthesis gas production. The variation of synthesis gas production and the excess available for

plant fuel through the design yield range of coal is shown by Figure 7 - 6. Referring to this figure, it can be seen that, within the design range of coal, the excess synthesis gas available for fuel varies from 0% to 80% of the plant total fuel requirement. This also means that, at the same time, some other fuel or fuels, with a different heating value, requiring different burner design characteristics, would provide 100% to 20% of the plant fuel requirement.

POTENTIAL SOLUTIONS

The most effective method of maintaining good control of the fuel system probably will be to vary dissolver conditions, which may include coal feed rate, to maintain that quantity of organic vacuum bottoms production which results in a relatively constant excess synthesis gas production.

Dual burners are planned for some of the heaters. The overall system will be evaluated to determine if additional dual firing capability is needed.

A closely controlled gas blending system, with an adequately sized mix tank, will be provided which will help maintain the heating value of the gaseous fuel header within an acceptable range.

7.8.12 Steam System

PROBLEMS

The plant steam system has four separate pressure levels. A substantial part of the steam requirement is produced from waste heat from the process. This waste heat steam is produced at all four pressure levels. Fluctuations and upsets in the process will affect the steam system operation and vice versa, resulting in operational control problems.

POTENTIAL SOLUTIONS

Particularly during a demonstration program, operability must be given more consideration than efficiency. In this regard, reducing the number of steam pressure levels and reducing recovery of process heat by boiler feed water exchange will be thoroughly studied.

Detailed evaluations of the interrelationship of the steam system and the process under all modes of operation will be made. Utilization of Appendix 7H, System Event Matrix, will be beneficial, as will the previously mentioned process simulator since it will be programmed to predict the interrelated effects of the process, steam system and fuel system.

7.9 CONCLUSIONS

At the present stage of process and design development of the SRC-II Demonstration Plant, several potential operational problems have been identified as a result of operability evaluation activity. Work already is underway in the Bridging Tasks directed toward providing solutions to some of these problems. For others, however, a substantial amount of additional experimental testing, primarily at the P-99 and Ft. Lewis Pilot Plants, is needed to develop basic information so that equipment for the Demonstration Plant can be designed with an acceptable degree of safety and operating confidence. In order to prevent extensive schedule delays to the project, a high priority must be given to these test programs. When the need for program changes becomes apparent, such changes must be made with minimum delay.

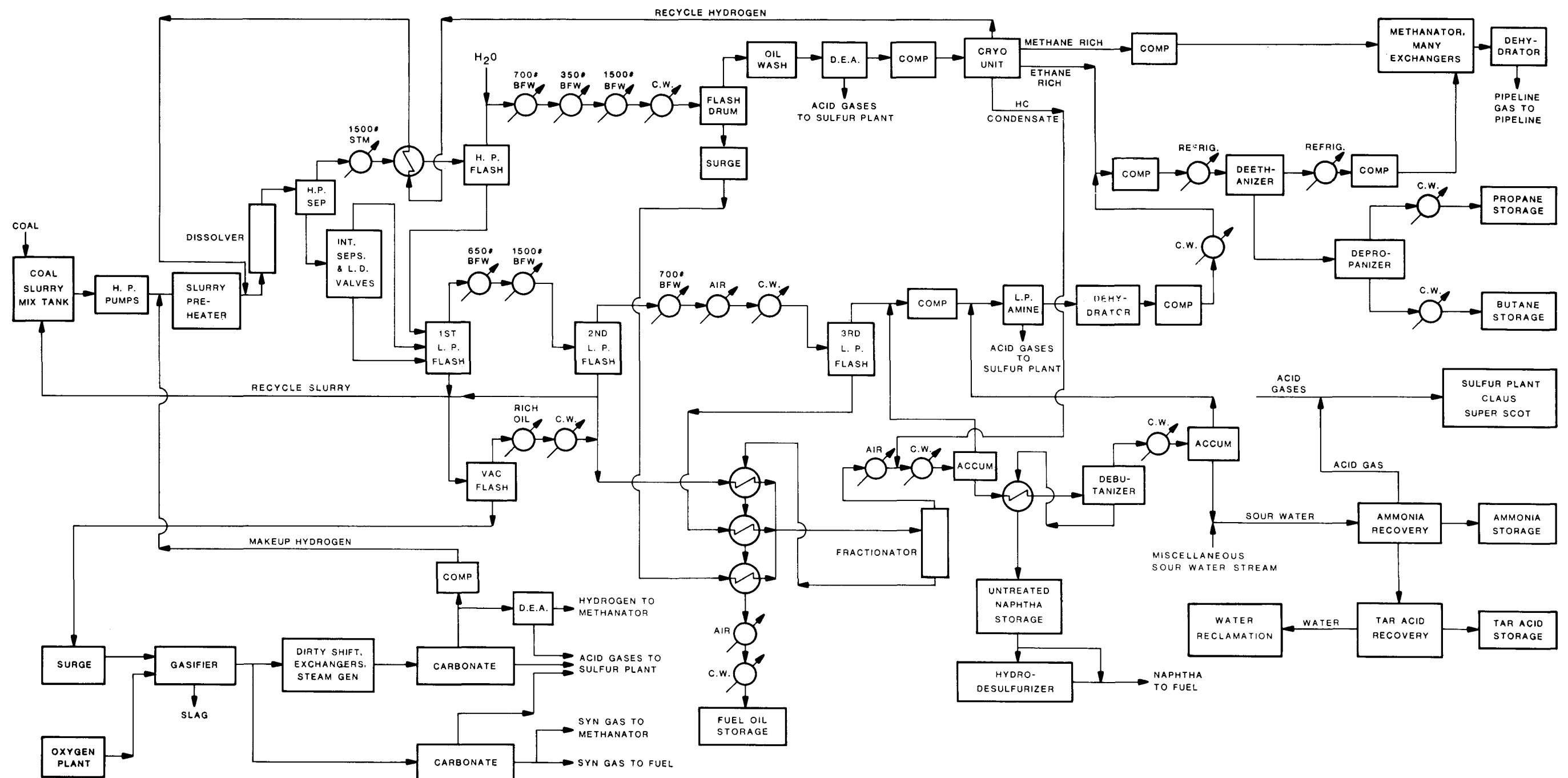


Figure 7-1. Simplified flowsheet of SRC-II demo plant

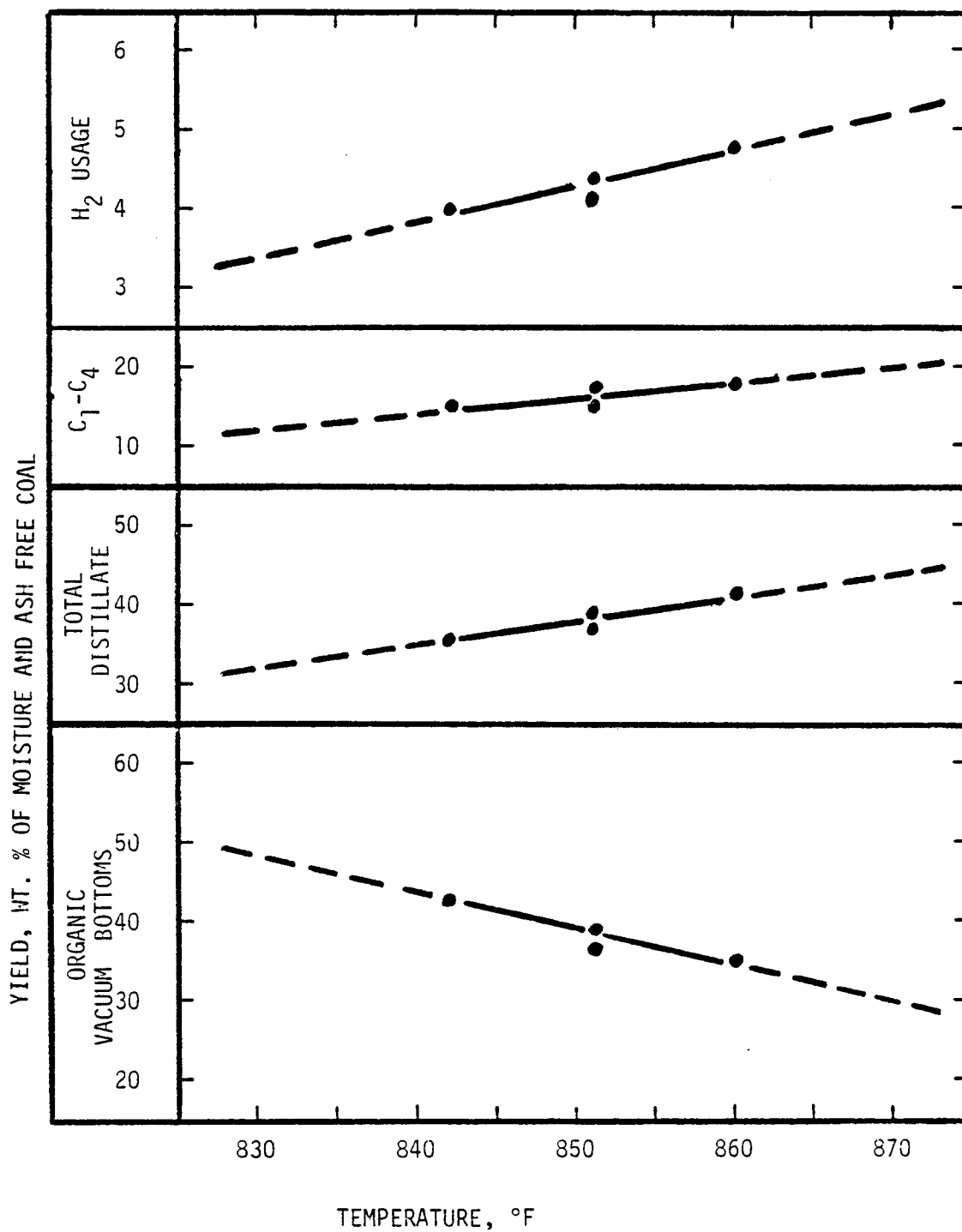


Figure 7-2. Effect of temperature on SRC-II process yields.
(Basis: P-99, Pitt Seam Coal, Powhatan Mine)

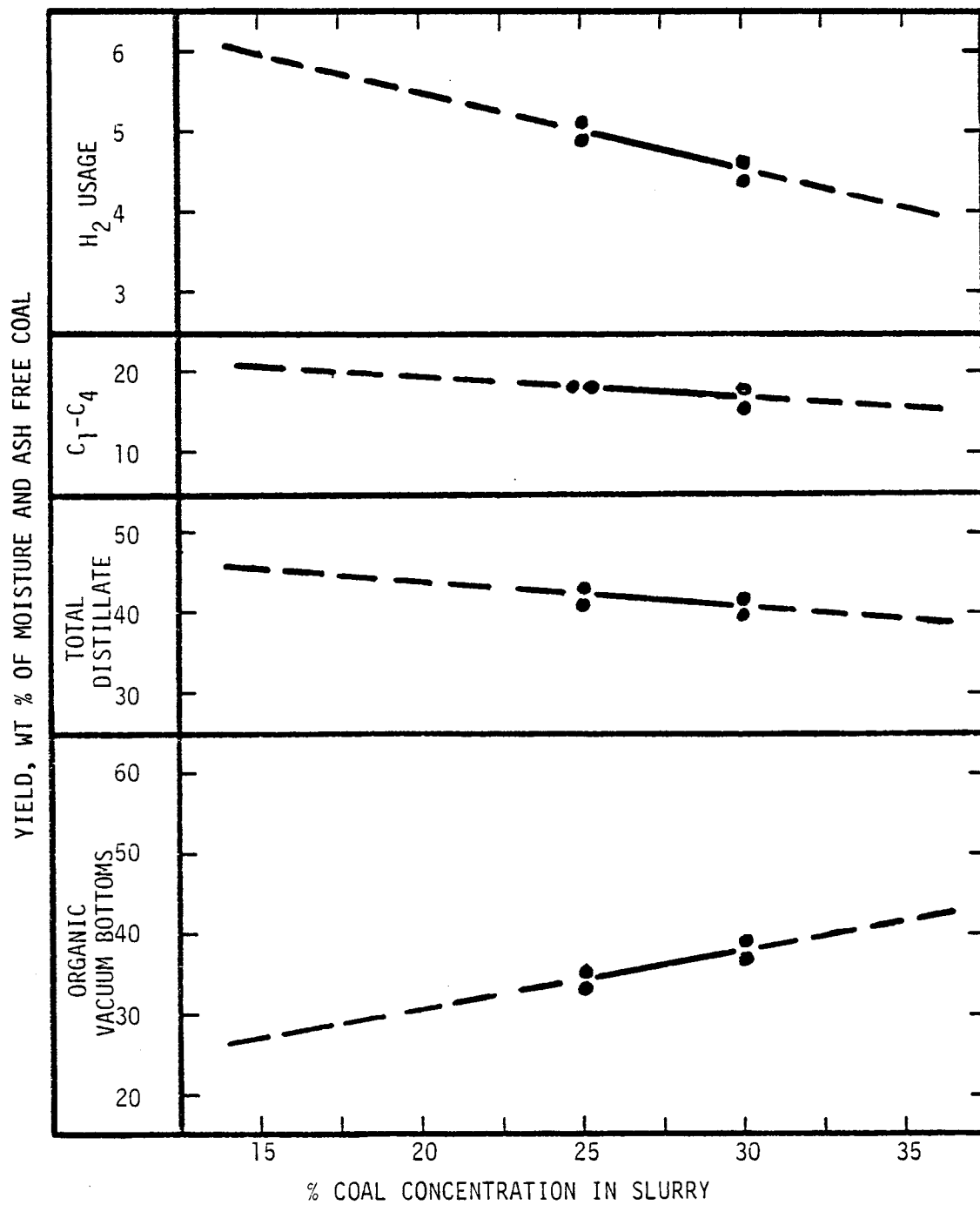


Figure 7-3. Effect of slurry coal concentration on SRC-II process yields.
(Basis: P-99, Pitt Seam Coal, Robinson Run Mine)

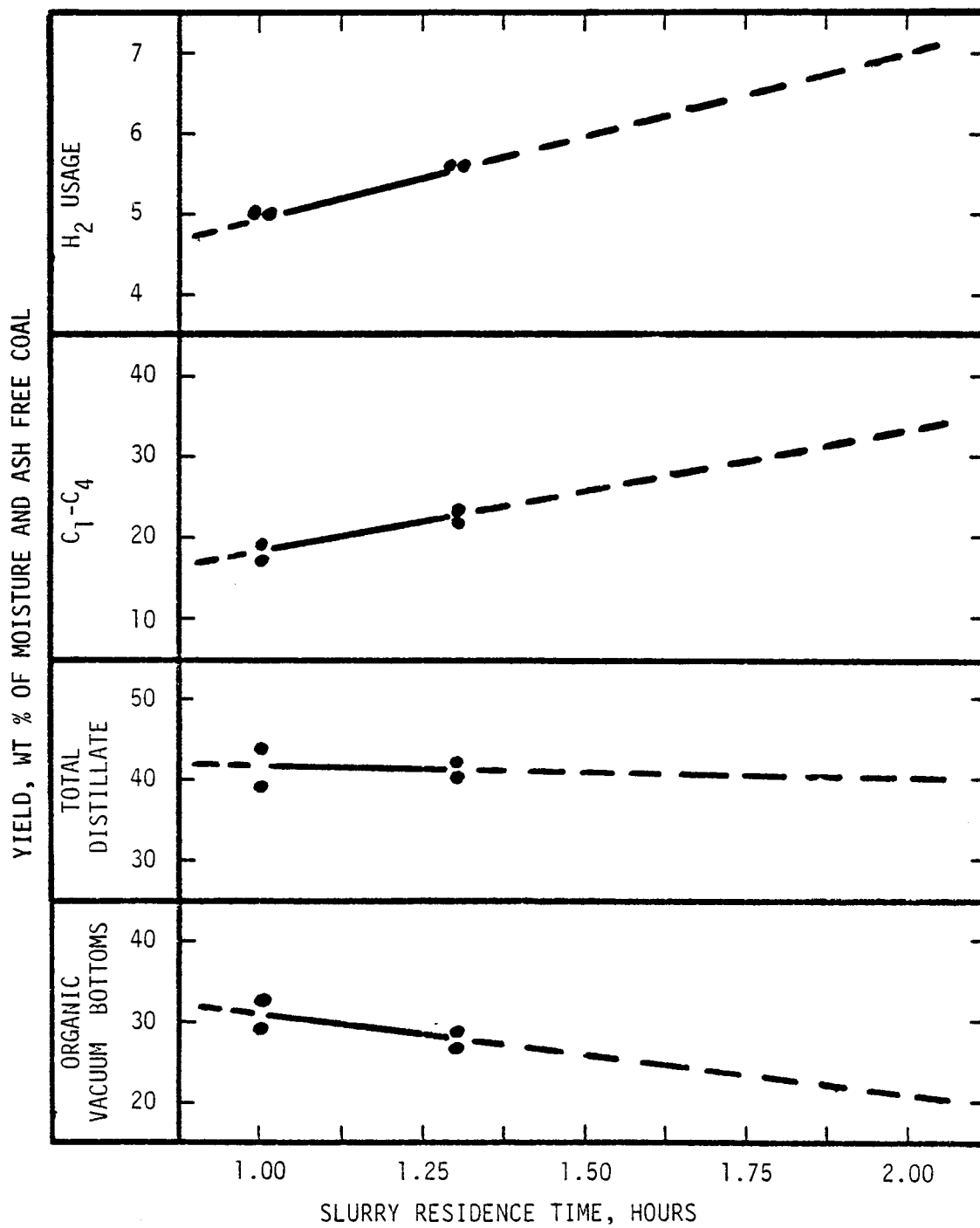


Figure 7-4. Effect of slurry residence time on SRC-II process yields.
(Basis: P-99, Kentucky Coal, Colonial Mine)

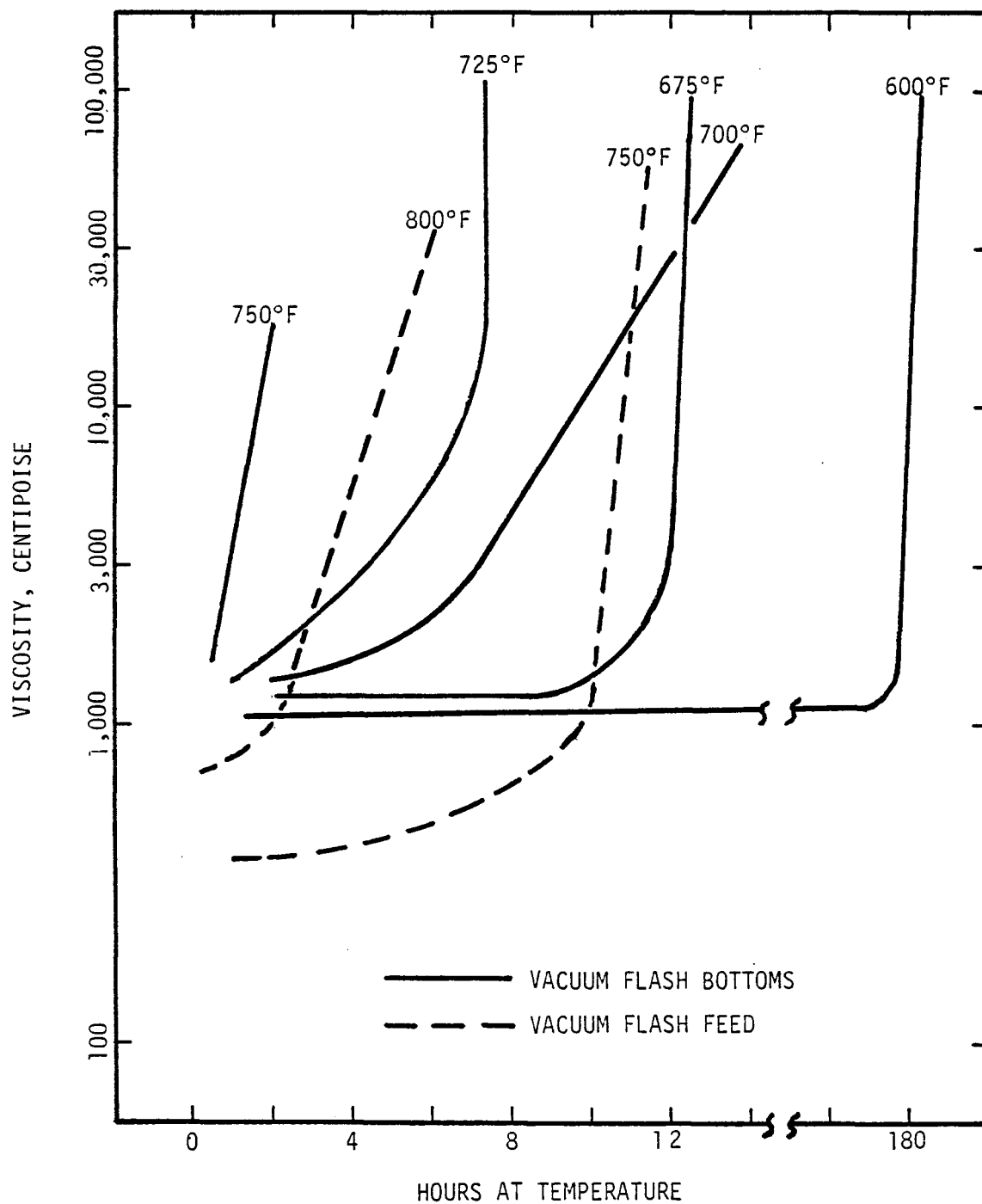


Figure 7-5. Viscosity growth of vacuum flash feed and bottoms as a function of time at temperature

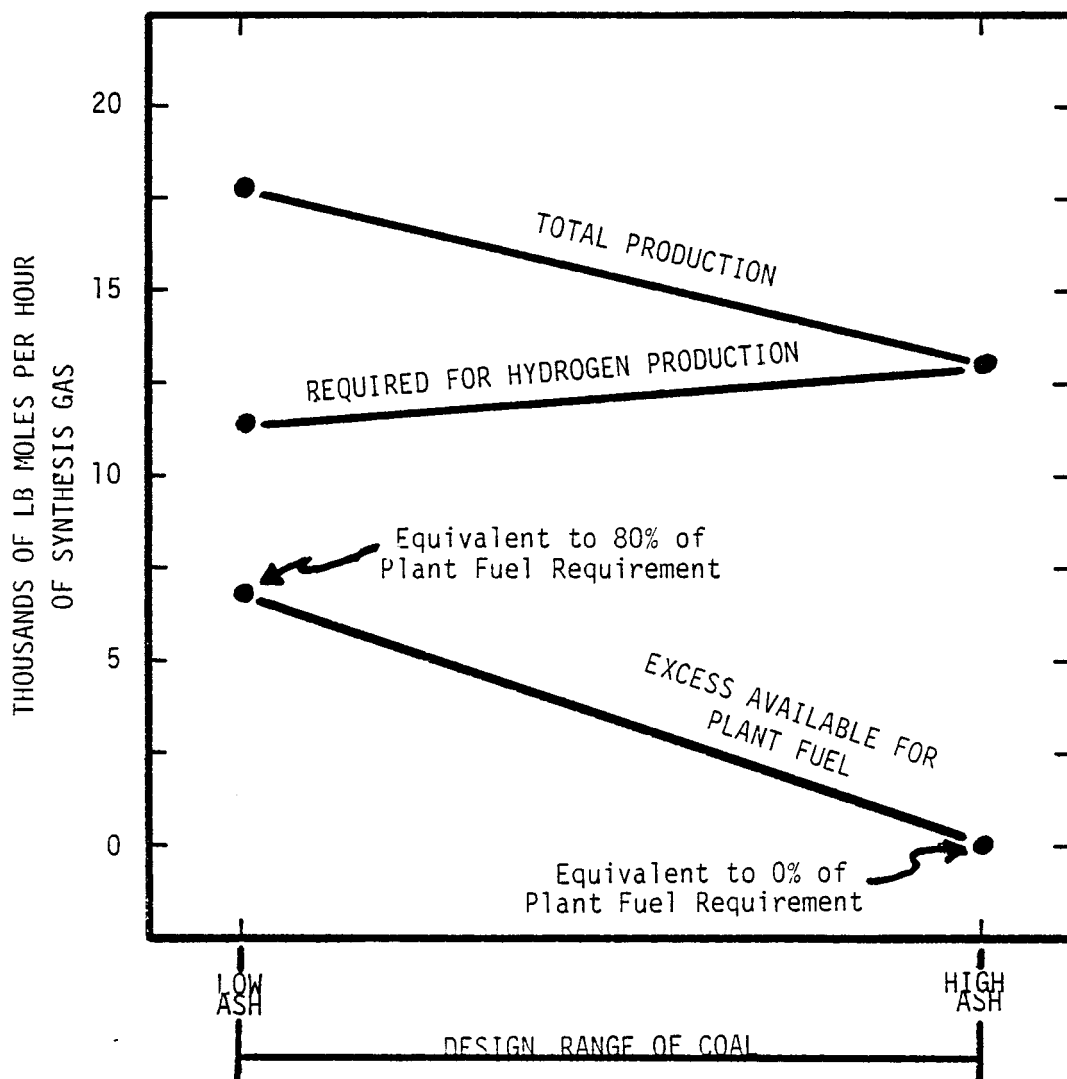


Figure 7-6. Effect of design coal range on the quantity of excess synthesis gas available for plant fuel

APPENDIX 7A

SRC-II DEMONSTRATION PLANT PRELIMINARY STARTUP SEQUENCE

I. ASSUMPTIONS

The following basic assumptions were used in the development of this startup sequence:

1. The plant process unit configurations were assumed to be those shown in Phase Zero Deliverable No. 1, Demonstration Plant Description. Figure 7-1 of this report is a simplified flowsheet of the plant.
2. All preconditioning activities had been completed. Boil-outs, chemical cleaning, equipment run-in, hydrostatic testing, etc., fall into this category.
3. All utility systems were operative.
4. All the process units had been opened to the atmosphere except the following:
 - The oxygen plant cold box - Area 44.
 - The hydrogen purification plant cold box - Area 12.
 - The catalyst beds in the shift and COS converter - Area 22 and the methanator - Area 25.

(These items would not normally require repair or replacement and could involve considerable extra work if opened.)
5. There were sufficient stocks of coal, plant product liquids such as LPG, butanes, naphtha, light fuel oil, heavy fuel oil, but not necessarily mineral residue slurry, liquid oxygen or liquid nitrogen to start the plant.
6. Each dissolver train can be turned down to 50% of design rate.

II. NORMAL STARTUP PROCEDURE

A. Summary

In order to make it easier to follow the steps of the startup, a capsule summary of the procedure follows:

1. The oxygen area will start first because of the need for gaseous and liquid nitrogen for inerting, preheating and precooling, in addition to the need for oxygen.

2. The other areas will be made oxygen free.
3. Oil and solution circulations and nitrogen flow will be established, equipment warmup and cold box cooloff will be accomplished. Liquid levels will be established wherever required and reflux circulations set.
4. Hydrogen production will be established.
5. Operating pressures will be established with hydrogen flow through the gas plants.
6. Coal feed will start in one train.
7. Gas and liquid plants will be adjusted as feedstock becomes available.
8. The gasifier will switch to vacuum column bottoms feed.
9. In the meantime, all the auxiliary areas such as sulfur, ammonia and tar acid recoveries and water reclamation will have been put into service as feedstocks became available.
10. The other dissolver train will be started and rates increased accordingly in downstream units.
11. The throughput of the plant will be increased to design rate.

B. Detailed Procedures

1. Start O₂ Plant First - Area 44
 - a. Oxygen Plant Air Compression
Commission and start both air compressors, venting to the atmosphere.
 - b. Oxygen Plant
Commission by cooling and filling system from stock in storage. Start oxygen and nitrogen production. Produce to liquid O₂ and N₂ storage tanks.
 - c. Oxygen Compressors
Commission and run the oxygen compressor.
2. Entire Plant
 - a. Clear all process units of oxygen by purging, evacuation or steaming and maintain positive pressure of gas or nitrogen in all equipment.

3. Shift Conversion - Area 22
 - a. Preheat the shift and COS catalyst using gaseous nitrogen.
 - b. Hold both catalysts ready for syngas.
4. Hydrogen and Syngas Purification - Area 23 & 24
 - a. Pressure up with N₂.
 - b. Establish carbonate solution circulation.
 - c. Hold on circulation ready for syngas.
5. Sulfur Production - Area 33
 - a. Establish Scot Unit solution circulation.
 - b. Heat up the Claus Unit.
 - c. Hold ready for acid gas.
6. Ash handling - Areas 64 & 65
 - a. Prepare slag handling facilities.
7. Gasifier - Area 21
 - a. Prepare slag handling facilities.
 - b. Establish process water flows.
 - c. Heat up gasifier with natural gas.
 - d. Start gasifier on stored vacuum bottoms or oil-coal slurry.
 - e. Raise to normal operating pressure.
 - f. Vent syngas to flare until lined out at a minimum rate.
8. Initiate syngas flow through shift conversion (Area 22), Hydrogen Purification (Area 23), Syngas Purification (Area 24). Vent hydrogen to flare after purification. Send acid gases from purification plants to Sulfur Production (Area 33).
9. Hydrogen Compression - Area 23
 - a. Start hydrogen compressor.
 - b. Vent to flare until Area 11 is ready to receive hydrogen.

10. Dissolver - Area 11 (one_train)
 - a. Establish levels with startup oil.
 - b. Pressure oil to the fractionator system (Area 34).
 - c. Drain water at low points until dry.
 - d. Establish solvent circulation in all of Area 34 and to Area 11.
 - e. Pressure up with hydrogen from Area 23.
 - f. Start oil heat up.
11. Recycle Gas System - Area 12.
 - a. Initiate hydrogen flow from Area 23 for pressure testing.
 - b. Test to operating pressure with hydrogen.
 - c. Start DEA circulation and hold.
 - d. Start the hydrogen recycle compressor on H₂.
12. Dissolver - Area 11
 - a. Establish circulation of oil from one dissolver to fractionation and back.
 - b. Heat up fractionation.
 - c. Start heatup of slurry.
13. LP Gas Treating - Area 31
 - a. Start up LP Gas Compressors on nitrogen.
 - b. Initiate DEA circulation.
 - c. Initiate hydrogen flow from dissolver.
 - d. Initiate hydrogen flow through LP gas treating to flare until normal outlets are ready to receive flow.
14. Product Gas Plant, Gas Dehydration and Compression - Area 32
 - a. Start up Deethanizer Feed Compressor on recycle.
 - b. Initiate glycol circulation.
 - c. Establish levels in the deethanizer and depropanizer from startup stock and put on total reflux.

15. Fuel Gas System - Area 54
 - a. Initiate syngas flow to fuel gas when ready and convenient.
16. Fine Coal Handling System - Area 63
 - a. Establish an adequate inventory of fine coal.
 - b. Prepare to operate coal preparation continuously.
17. Dissolver - Area 11

Go up to approximately 800°F on the preheater outlet temperature. When the dissolver temperature reaches 750°F, start coal feed at minimum rate.
18. Cryogenic Purification - Area 12
 - a. Establish liquid nitrogen levels in the cryogenic unit.
 - b. When recycle process gas contains enough hydrocarbons, initiate feed to the cryogenic unit.
 - c. Then initiate feed to the gas plants as separated hydrocarbons are available.
19. Fractionation - Area 34
 - a. When increasing levels indicate net production, initiate flow to slops tankage.
 - b. Heat atmospheric fractionator toward operating temperatures.
 - c. Initiate flow of gas to L.P. Gas Treating - Area 31.
 - d. When naphtha production exists, establish levels in the debutanizer.
 - e. Heat the debutanizer and initiate flow to intermediate storage when levels indicate.
 - f. Establish full vacuum on the vacuum vessel and run bottoms to mineral residue storage for future start-up or upset inventory, then send to Area 21 for gasification.
 - g. Send products to storage when on specification.
20. Gas Plants - Areas 31 & 32
 - a. When feed gas is available, start once-through to flare

with gases.

- b. When levels indicate LPG and butane production, run down to storage and direct to normal outlets when ready.

21. Establish normal operating conditions and allow the units to stabilize at minimum rates.

22. Methanation - Area 25

- a. Prepare the area to receive gas feed by preheating the catalyst bed to 660°F with gaseous nitrogen.
- b. Analyze gas streams to be methanated.
- c. Initiate DEA circulation.
- d. Initiate methanator feed.
- e. Test methanator product for quality and deliver to pipeline when on specification.

23. Stabilize the entire plant.

24. Hydrodesulfurization - Area 35

- a. Start the HDS unit when the inventory positions allow it.

25. Ammonia Recovery - Tar Acid Recovery - Areas 41 & 42

- a. Hold sour water in tankage while starting other areas.
- b. Start Area 41 and 42 as time and inventory indicate.

26. Waste Water Treating - Area 43

Start up the various units as the types of waste water feeds allow.

27. Oxygen Plant - Area 44

- a. Increase Oxygen Plant rate to 75%.
- b. Begin extraction of 600# steam from air compressor to supply 600# and 250# steam needs.

28. Gasification - Area 21

- a. Bring second gasifier on at 50% rate.

- b. 1500# steam required for gasifier and high pressure water pumps to supply quench boot.
- 29. Shift Conversion, Hydrogen and Syngas Purification - Areas 22, 23, 24, 33
 - a. Increase flows.
- 30. Recycle Gas Treating - Area 12
 - a. Increase rates through the system, including the Methane and H₂ Recycle Compressors and the high pressure lean DEA pump.
- 31. Dissolver - Area 11
 - a. Follow the same basic steps as used for startup of the first dissolver up to the point of coal injection.
- 32. L.P. Gas Treating - Area 31
 - a. Increase rates.
- 33. Product Gas Plant - Area 32
 - a. Increase rates.
- 34. Dissolver - Area 11
 - a. Start coal feed to mix system.
 - b. Start slurry to dissolver.
 - c. Increase firing rate of preheater.
- 35. Cryogenic Unit - Area 12
 - a. Increase rate.
- 36. Fractionation - Area 34
 - a. Increase rate.
- 37. Gas Plant - Area 31 and 32
 - a. Increase rate.
- 38. Stabilize entire plant
 - a. Switch boiler feed water pump drives from electric to steam.

- 39. Methanator - Area 25
 - a. Increase rates. Steam production increases.
- 40. Stabilize Plant
- 41. Hydrodesulfurization - Area 35
 - a. Increase rates.
- 42. Ammonia and Tar Acid Recovery - Area 41 and 42
 - a. Increase rates.
- 43. Waste Water Treatment - Area 43
 - a. Increase rates.
- 44. Entire Plant
 - a. After stabilized at half rate, gradually increase rate of the entire plant to 100%.

APPENDIX 7C

STEAM AND PLANT FUEL BALANCES DURING

SRC-II DEMONSTRATION PLANT STARTUP

Preliminary steam and fuel balances for a normal startup of the Conceptual SRC-II Demonstration Plant have been made. The Startup Sequence shown by Appendix 7A was used as the basis for the step by step evaluation.

Tables 7C-1 and 7C-2 summarize the steam and fuel balances, respectively.

TABLE 7C-1
PLANT STARTUP STEAM BALANCE (PRELIMINARY)
(Units are Thousands of Pounds per hour)

Startup Sequence Step (1)	Area Starting Up	% of Area Design Capacity	Steam Used				Steam Produced				Utility Boiler (2) Production 1500#	Comments
			1500#	600#	250#	75#	1500#	600#	250#	75#		
1	44	100	200								200	No extraction
2	--	--									200	Inerting plant
3	22	20									200	Nitrogen Use
4	23,24	--				100					278	approx. 300 TPD
5	33	20		20	6	10				6	304	Warm up
6	64,65	--									304	
7	21	38	135								439	O ₂ @ 800 TPD, Start gasifier
8	22,23,24	38		30		50	35	19	70	58	351	
9	33	38		12		40		12		8	376	
10	23	38									376	Pressure up
11	11	--									376	
12	12	60	40	20	12					60	398	Heat up
13	11	--		2		2					401	Compressor only
14	31	60									401	Compressor only
15	32	60		25	90	1				90	437	
16	54	--									437	
17	63	--									437	
18	11	25					25	20			394	Start coal feed
19	12	25									394	Liquid nitrogen required
20	34	25		1		4					398	
21	31,32	25	(80)								398	
22	--	--									318	Stabilize. Cut Area 44 to 60%
23	25	25					22	2	4		291	
24	--	--	(40)								251	Stabilize. Cut Area 44 to 40%
25	35	25									251	
26	41,42	25				6					256	
27	43	25				30					279	
28	44	75	150					110			326	Begin extraction
29	21	75	50		46					46	378	Start gasifier
30	22,23,24	75		168	50	50	45	19	213	108	291	
31	33	75		10		50		12		8	321	
32	12	75	10	20	7					30	333	
33	11	--		2		2					336	Heat up
34	31	75		10						10	337	
35	32	75		7	10	4				10	347	
36	11	50					25	20			303	Start coal feed
37	12	--									303	
38	34	50		2		4					308	
39	31,32	--									308	
40	--	--			114	50					439	Stabilize
41	25	50					22	2	4		412	
42	--	--									412	Stabilize
43	35	50									412	
44	41,42	50				6					417	
	43	50				30					440	
	Full Plant	100	430	229	158	452	131	372	203	431	591	Brought entire plant to full rate

- (1) Please refer to Appendix 7A of this section, Startup Sequence
(2) Capacity of utility boiler is 700 M lbs per hour

TABLE 7C-2
PLANT STARTUP FUEL BALANCE (PRELIMINARY)
(Units are Millions of BTU per hour)

Startup Sequence Step (1)	% of Area Starting Up	Area Design Capacity	Step Production	Total Production	Total Use	Excess ⁽²⁾	Deficit ⁽³⁾	Comments
1	44	100			274		274	
2	--	--			274		274	
3	22	20			274		274	
4	23,24	--			381		381	Nitrogen Warmup
5	33	20			417		417	
6	64,65	--			417		417	
7	21	38			603		603	Start gasifier
8	22,23,24	38	163	163	482		319	
	33	38		163	516		353	
9	23	38		163	516		353	Pressure up
10	11	--		163	516		353	
11	12	60		163	546		383	
12	11	--		163	550		387	Heat up
13	31	60		163	562		399	
14	32	60		163	600		437	
15	54	--		163	600		437	
16	63	--		163	600		437	
17	11	25		163	665		502	Start coal feed
18	12	25	290	453	665		212	
19	34	25		453	691		238	
20	31,32	25	96	549	691		142	
21	--	--		549	581		32	Cut area 44 to 60%
22	25	25	265	814	544	270		Cut area 44 to 40%
23	--	--		814	489		325	
24	35	25	145	959	495	464		
25	41,42	25		959	503	456		
26	43	25		959	547	412		
27	44	75		959	620	339		
28	21	75		959	691	268		Start gasifier
29	22,23,24	75	163	1122	572	550		
	33	75		1122	614	508		
30	12	75		1122	633	489		
31	11	--		1122	637	485		
32	31	75		1122	639	483		
33	32	75		1122	653	469		
34	11	50		1122	718	404		Start coal feed
35	12	--	290	1412	718	694		
36	34	50		1412	744	668		
37	31,32	--	96	1508	744	764		
38	--	--		1508	924	584		
39	25	50	265	1773	887	886		
40	--	--		1773	887	886		
41	35	50	145	1918	887	1031		
42	41,42	50		1918	894	1024		
43	43	50		1918	926	992		
44	Full Plant	100		2707	1458	1249		Brought entire plant to full rate

- (1) Please refer to Appendix 7A of this section, Startup Sequence
 (2) Requires the production of L.P.G., inventorying of naphtha or flaring
 (3) Requires use of import pipeline gas or naphtha from inventory

APPENDIX 7D

ANALYSES OF FT. LEWIS PILOT PLANT AND

SRC-II DEMONSTRATION PLANT STARTUPS

As part of a study of startup characteristics of the SRC-II Demonstration Plant, two SRC-II startups of the Ft. Lewis Pilot Plant have been evaluated. Both startups occurred after the reaction area had been thoroughly flushed with heavy distillate and, therefore, the concentration of solids in the recycle slurry was initially very low (approximately one wt.%). Both startups occurred toward the conclusion of the Powhatan SRC-II studies at Fort Lewis.

Typical examples of the data used in the evaluation are shown graphically in Figures 7D-1 through 7D-5 for the first startup. Determination of the time required to achieve equilibrium compositions in the slurry and gas streams was of interest in this study. Evaluation of the data for both runs indicate that the lineout period is about twenty-four hours for the slurry stream and about six hours for the gas streams.

Slurry lineout times were estimated from observation of the concentration of solids in the recycle slurry while the gas lineout time was estimated from analysis of the methane production rate. The substantial difference in the lineout time of slurry and gas streams probably is due to the high superficial gas velocity in the reaction area (gas velocity is estimated to be nearly an order of magnitude greater than liquid velocity at Fort Lewis dissolver conditions). The estimated mean residence times of gas and slurry in the Fort Lewis reaction system (including coal-slurry mixing and slurry preheating) are approximately seven minutes and two-and-one-half hours, respectively. The short gas residence time results in frequent turnover of the gas volume in the system, and hence, a fast approach to equilibrium. The rapid gas lineout suggests that hydrocarbon gas production is not as heavily dependent on the composition of the recycle slurry as are the yields of distillate of organic vacuum bottoms. This may indicate that hydrocarbon gas yields are primarily derived from the coal, and may not be produced substantially from reaction of the recycle slurry.

Utilizing data from this analysis, preliminary estimates have been made of the changes in flow rate and composition of several streams downstream of the dissolver during a startup of the SRC-II Demonstration Plant. These estimates are shown by Figures 7D-6 through 7D-10.

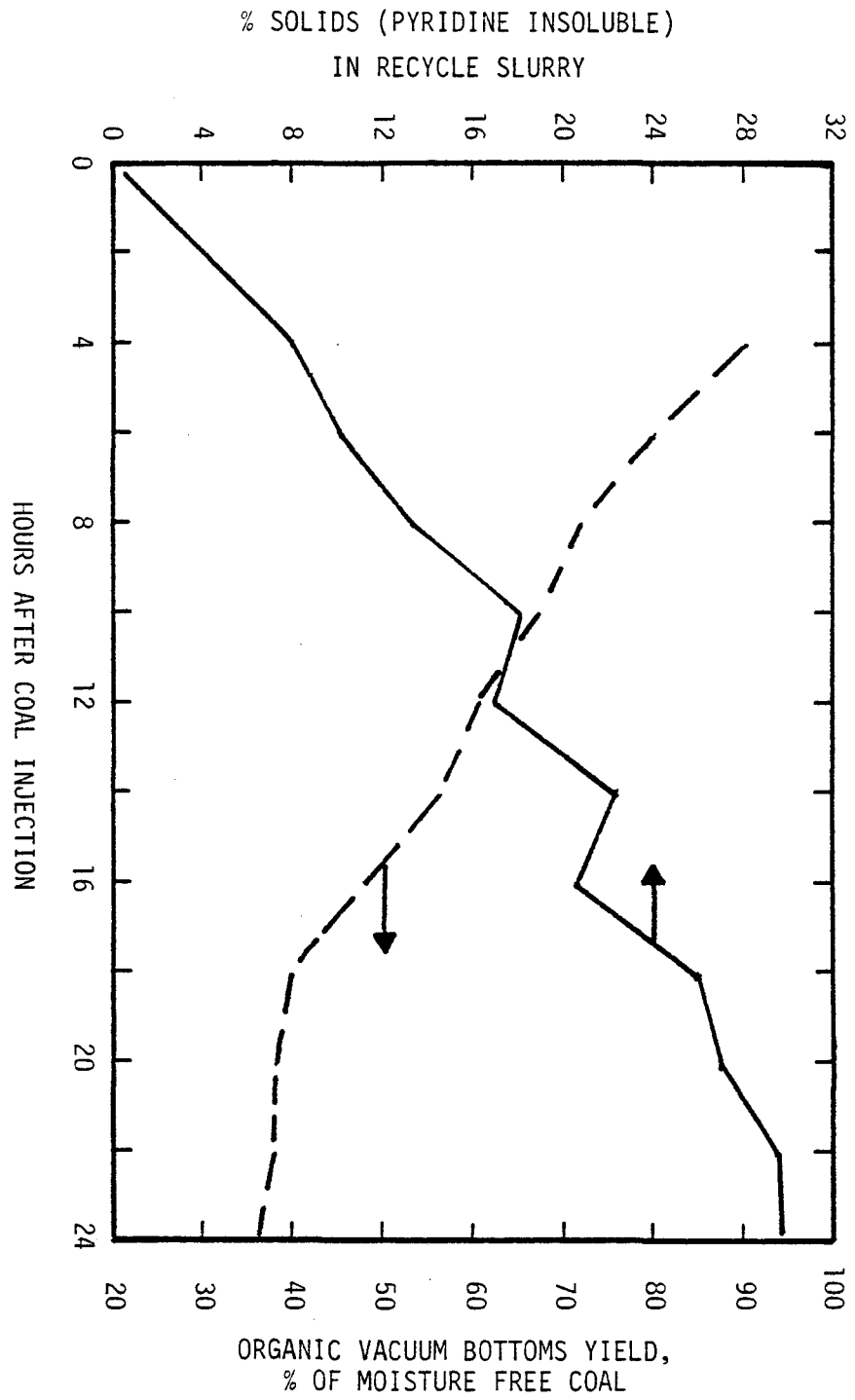


Figure 7D-1. Typical Ft. Lewis pilot plant SRC-II startup

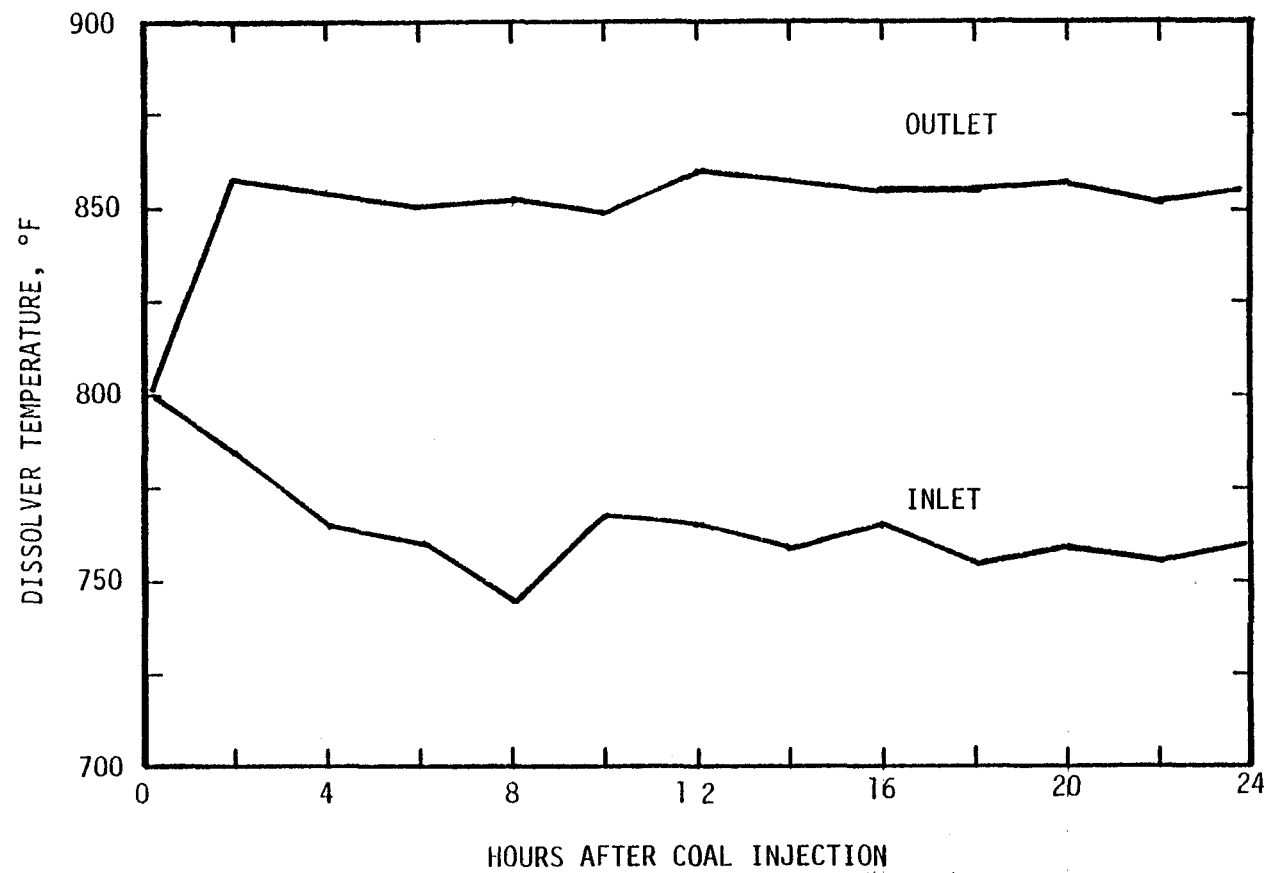


Figure 7D-2. Typical Ft. Lewis pilot plant SRC-II startup

7D-4

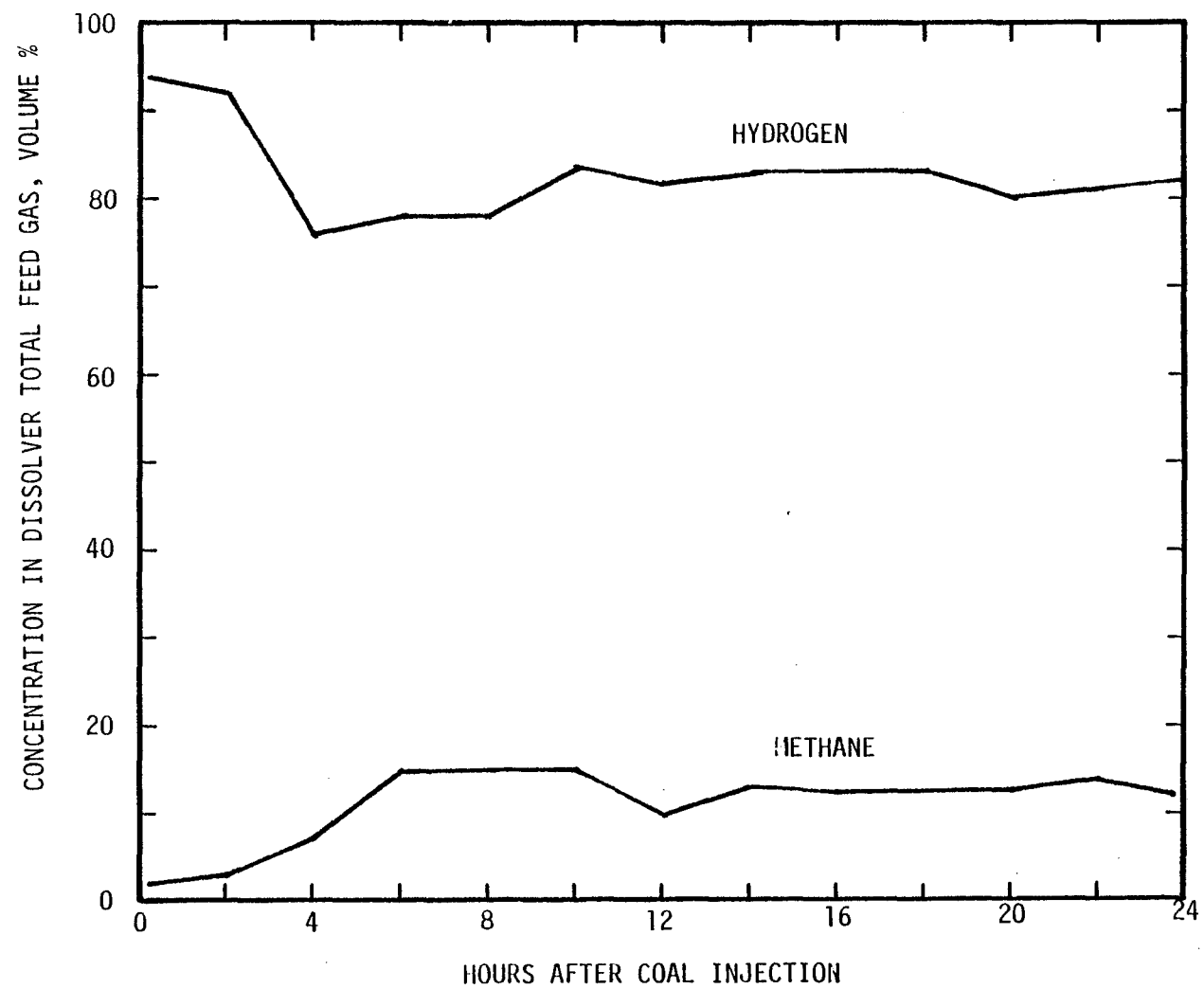


Figure 7D-3. Typical Ft. Lewis pilot plant SRC-II startup

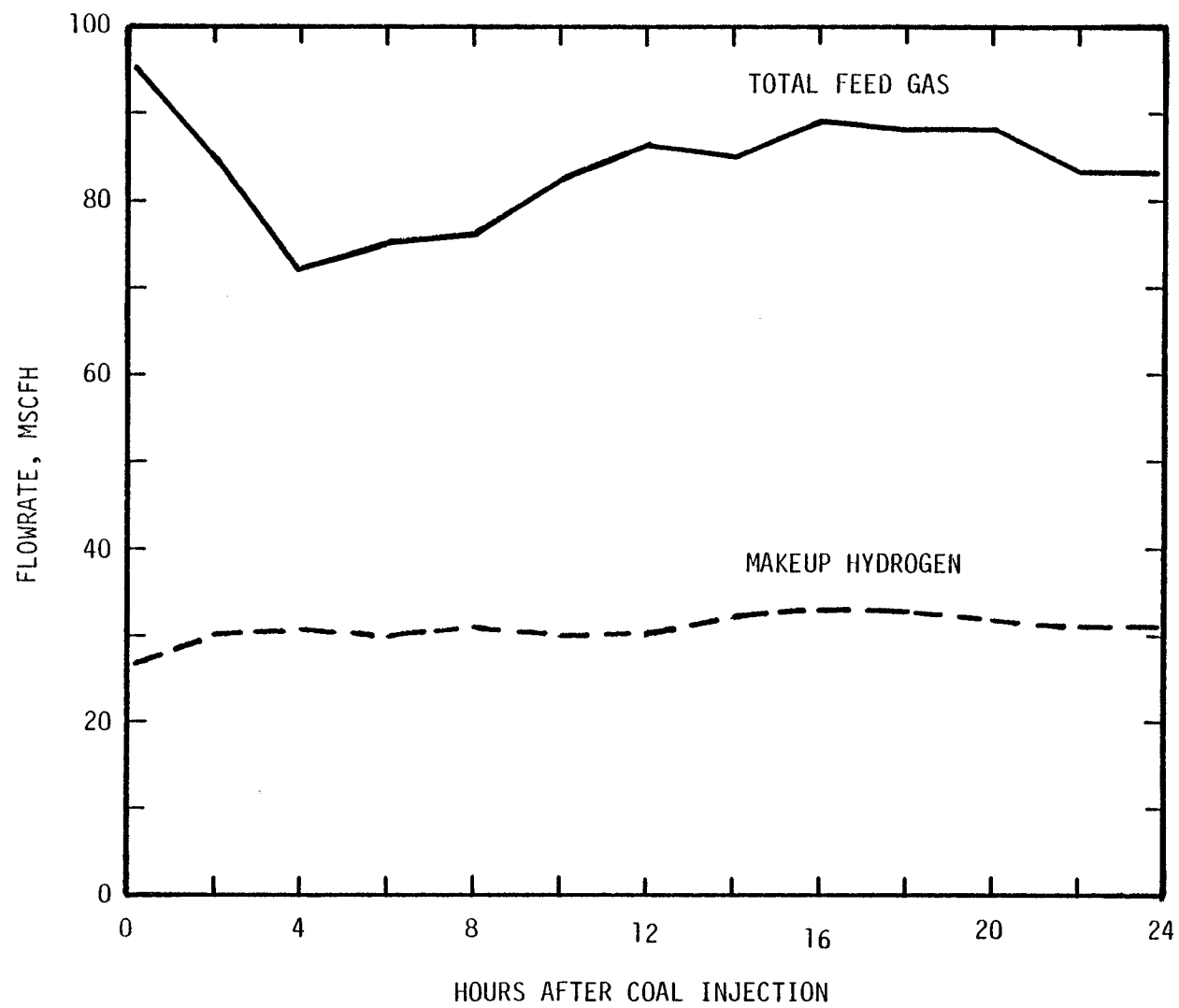


Figure 7D-4. Typical Ft. Lewis pilot plant SRC-II startup

7D-6

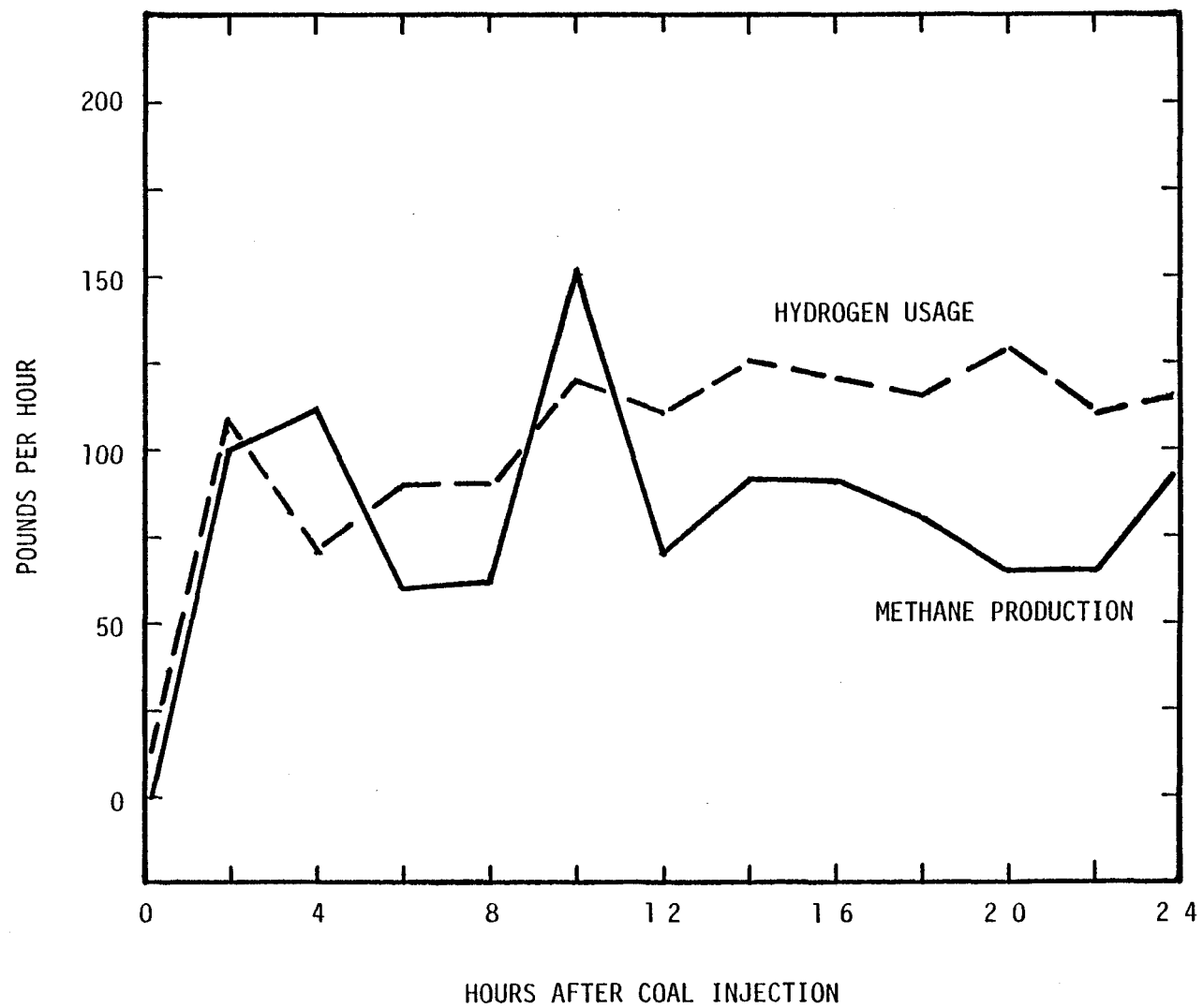


Figure 7D-5. Typical Ft. Lewis pilot plant SRC-II startup

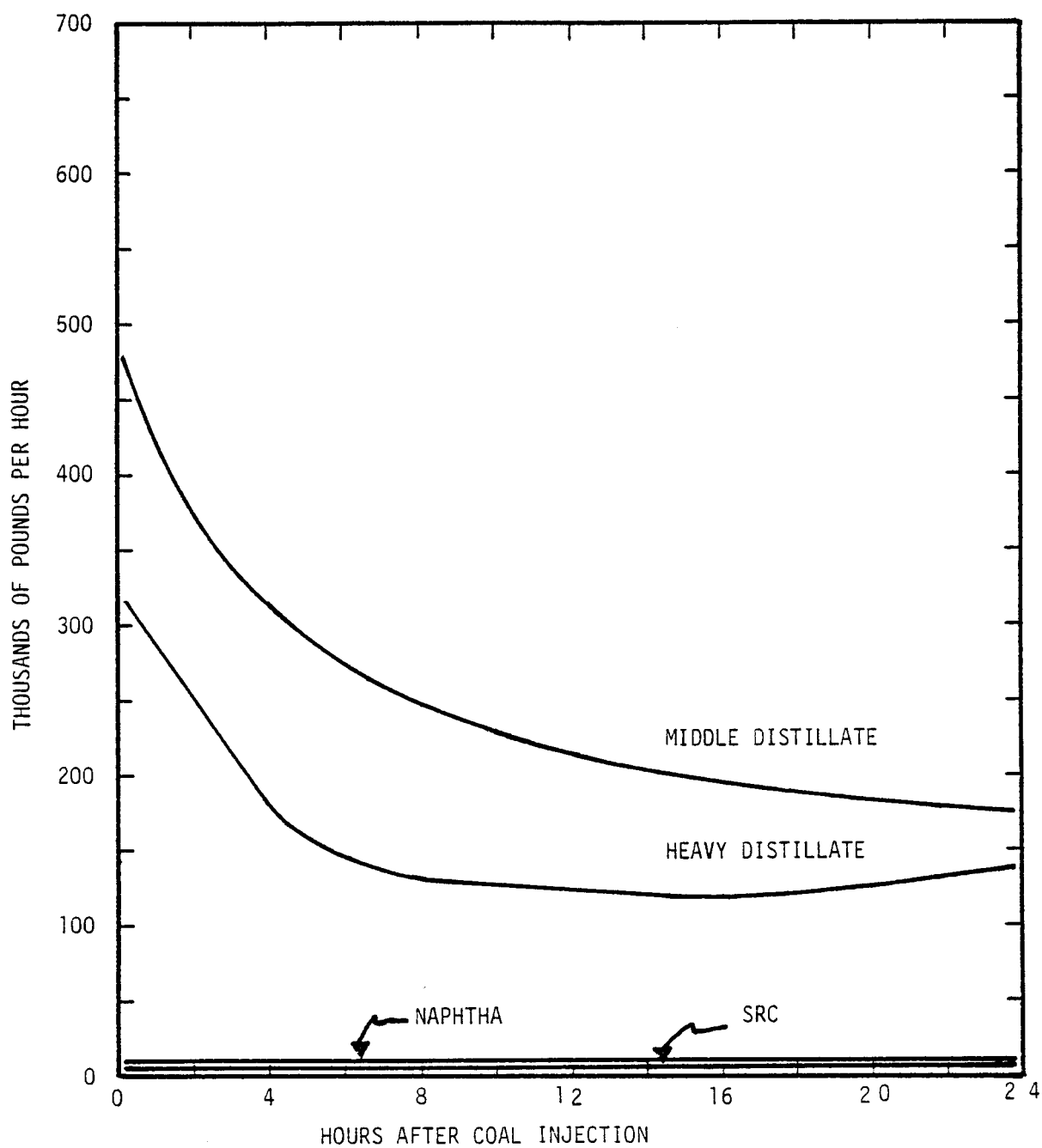


Figure 7D-6. Estimated flowrates SRC-II demonstration plant startup. First low pressure flash drum overheads

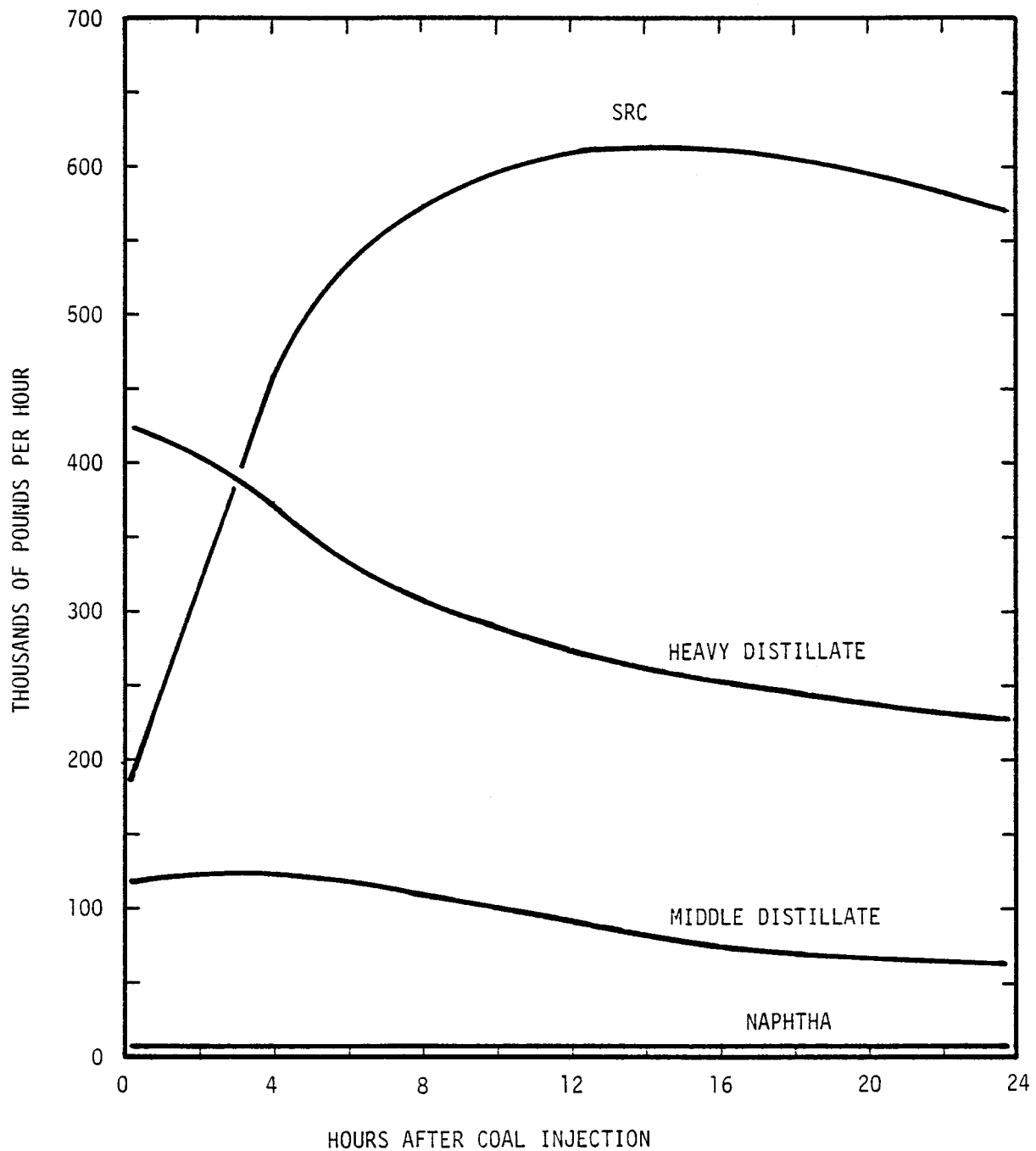


Figure 7D-7. Estimated flowrates SRC-II demonstration plant startup.
First low pressure flash drum bottoms (vacuum flash feed/
slurry recycle)

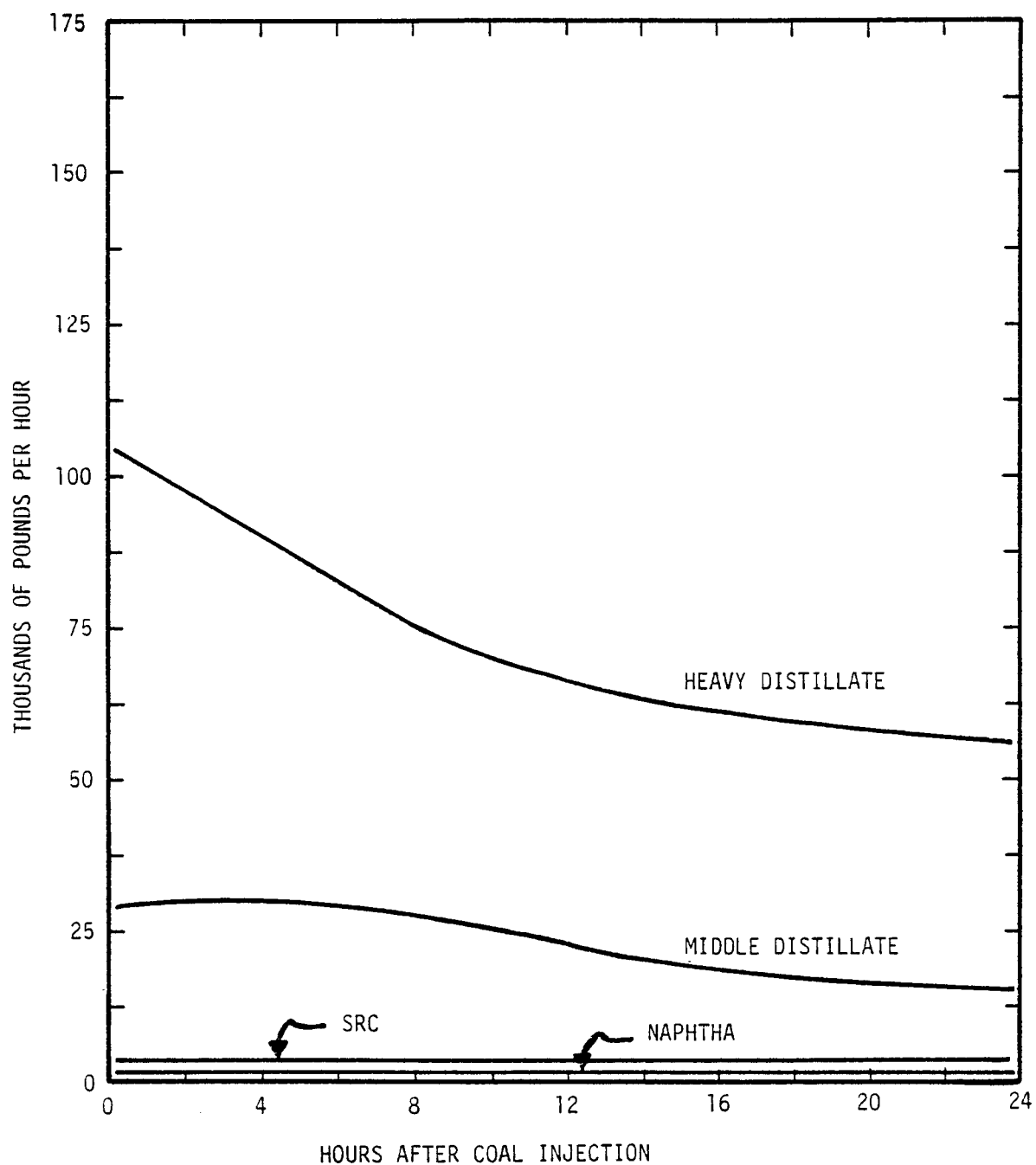


Figure 7D-8. Estimated flowrates SRC-II demonstration plant startup - vacuum flash overheads

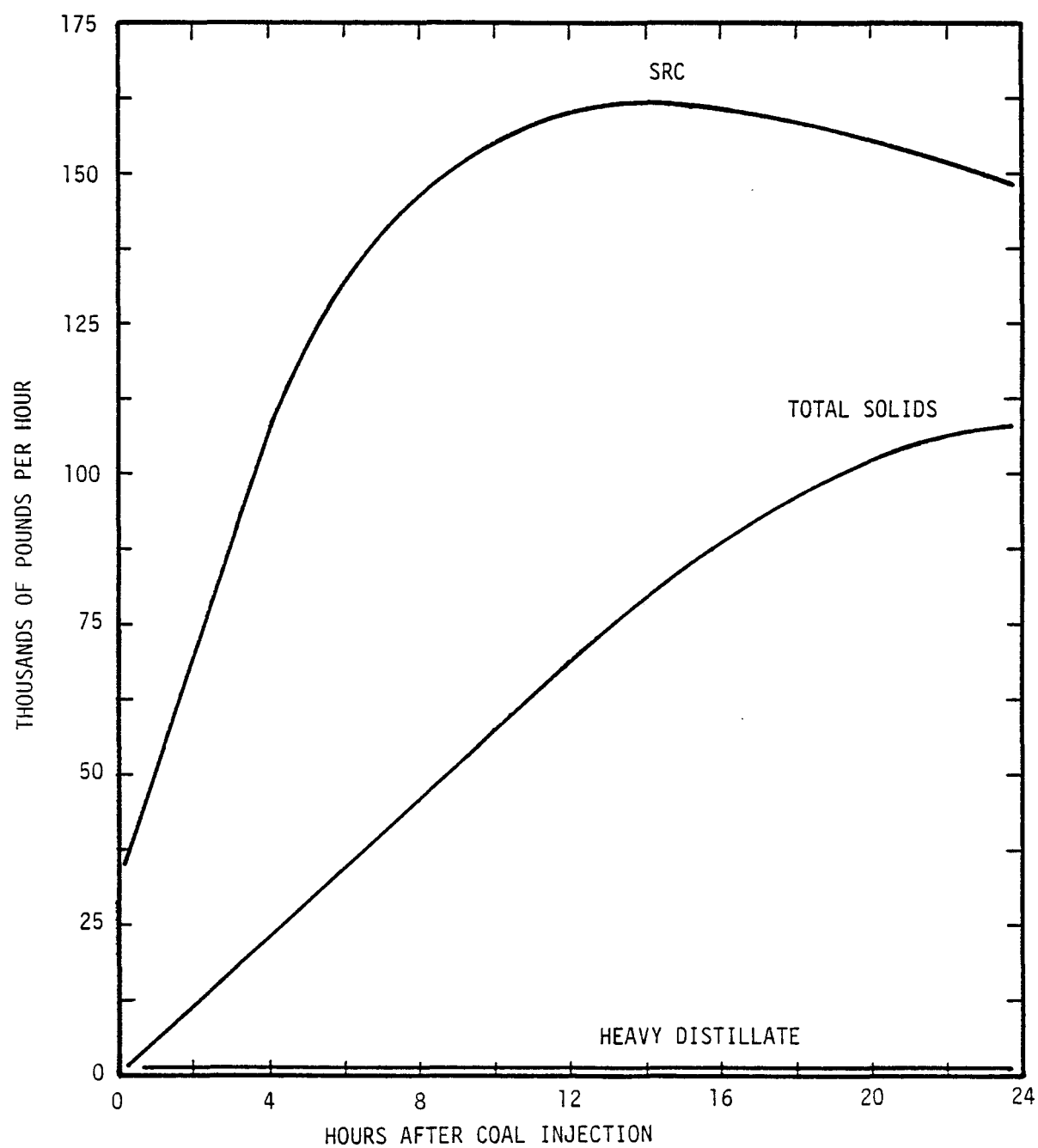


Figure 7D-9. Estimated flowrates SRC-II demonstration plant startup-vacuum flash bottoms

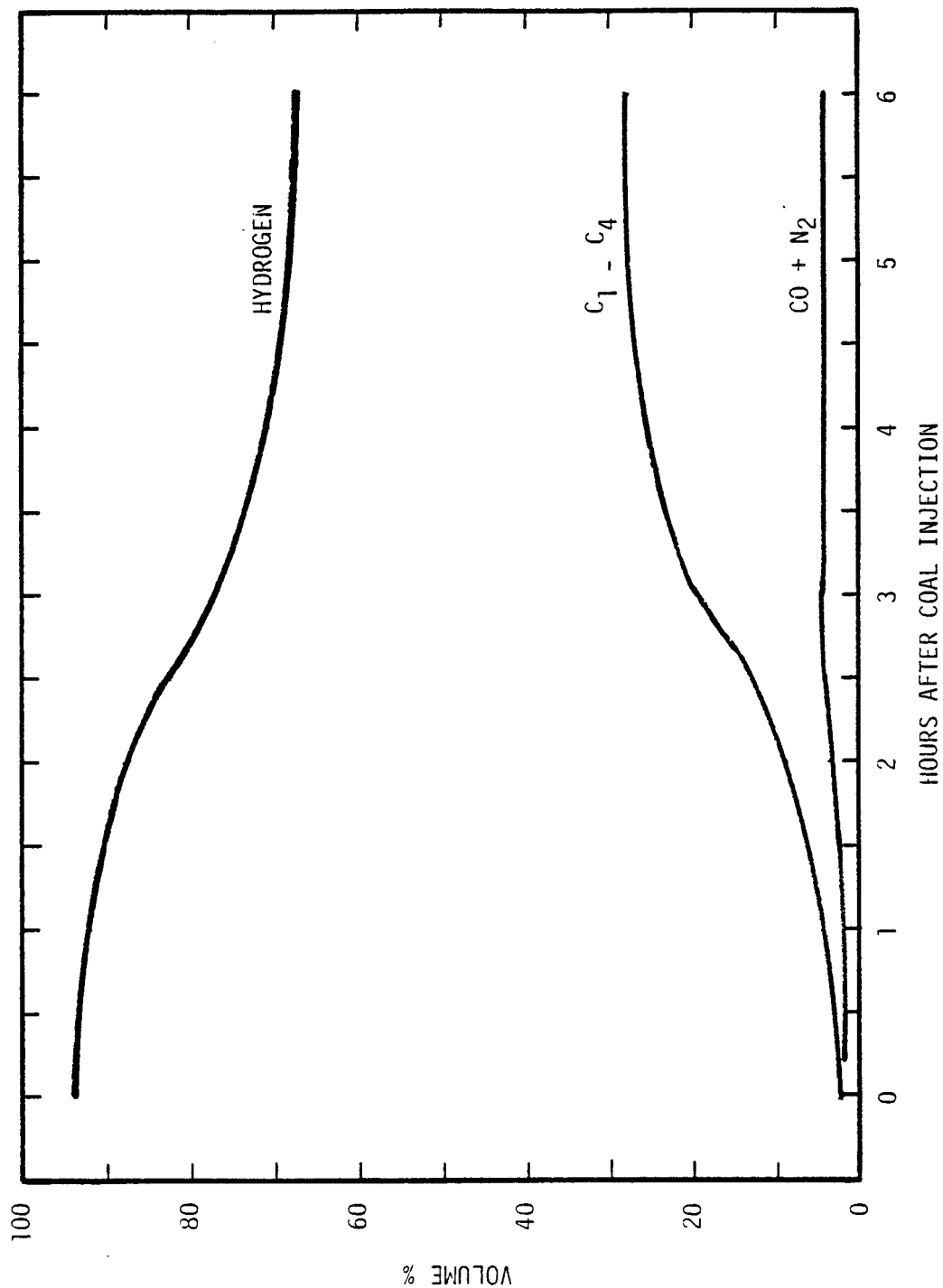


Figure 7D-10. Estimated composition SRC-II demonstration plant startup - feed to high pressure flash gas cryogenic unit

APPENDIX 7E

Effect of Design Coal Range on Vacuum Flash System Operation Through Design Ash Content Range of 9% to 14%

A set of material balance calculations has been completed for three projected cases of product yields for the SRC-II Demonstration Plant. These cases correspond to the range of product yields which would be encountered in the Demonstration Plant as coal ash content varies from minimum, through normal, to maximum. The effects of this range of yields on slurry stream compositions, slurry temperatures, and the vacuum flash system operation were studied. The results indicate that substantial changes in compositions, temperatures, and vacuum bottoms recovery occur as the product yields change, warranting further study to determine their effects on the overall operability of the Demonstration Plant.

The technique used to study each yield distribution involved estimating a dissolver effluent composition, calculating equilibrium flash results at conditions simulating the Demonstration Plant slurry pressure letdown system, and calculating equilibrium flash results for the vacuum flash system. Energy balance calculations were made to estimate slurry temperatures throughout the system.

Curves of estimated vacuum flash feed and drum temperatures are shown in Figure 7E-1.

The variations in the vacuum flash feed composition due to the different yield patterns resulted in significantly different flowrates of the vacuum flash overheads and bottoms streams as shown by Figure 7E-2. The variations in relative flowrate are most pronounced for the overhead stream.

The net effect of the variations in feed composition and drum temperature is a variation in the recovery of organic vacuum bottoms which is the feedstock for the gasifier. The recovered yields of vacuum bottoms are shown in Figure 7E-3.

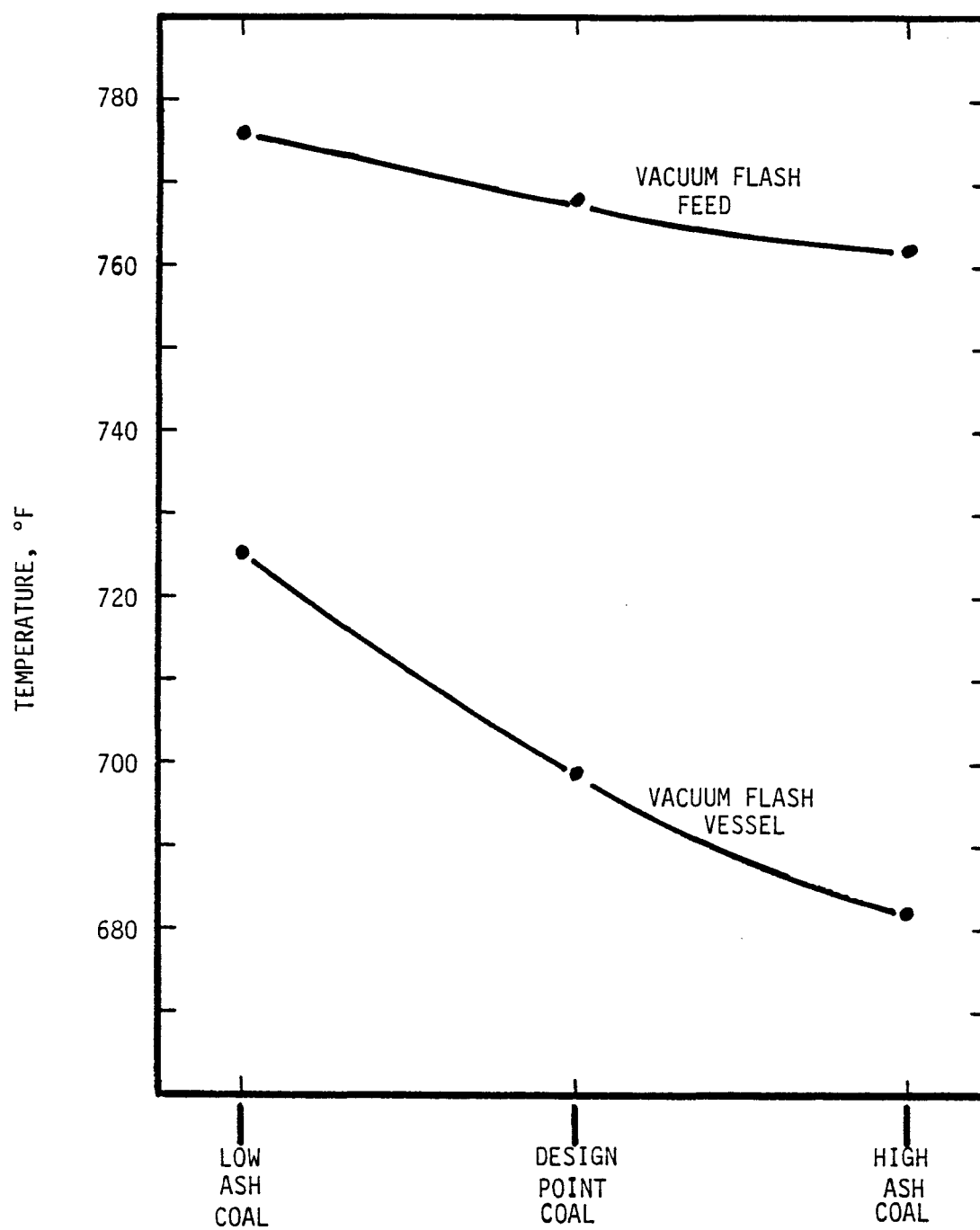


Figure 7E-1. Effect of design range of coal on vacuum flash system temperatures

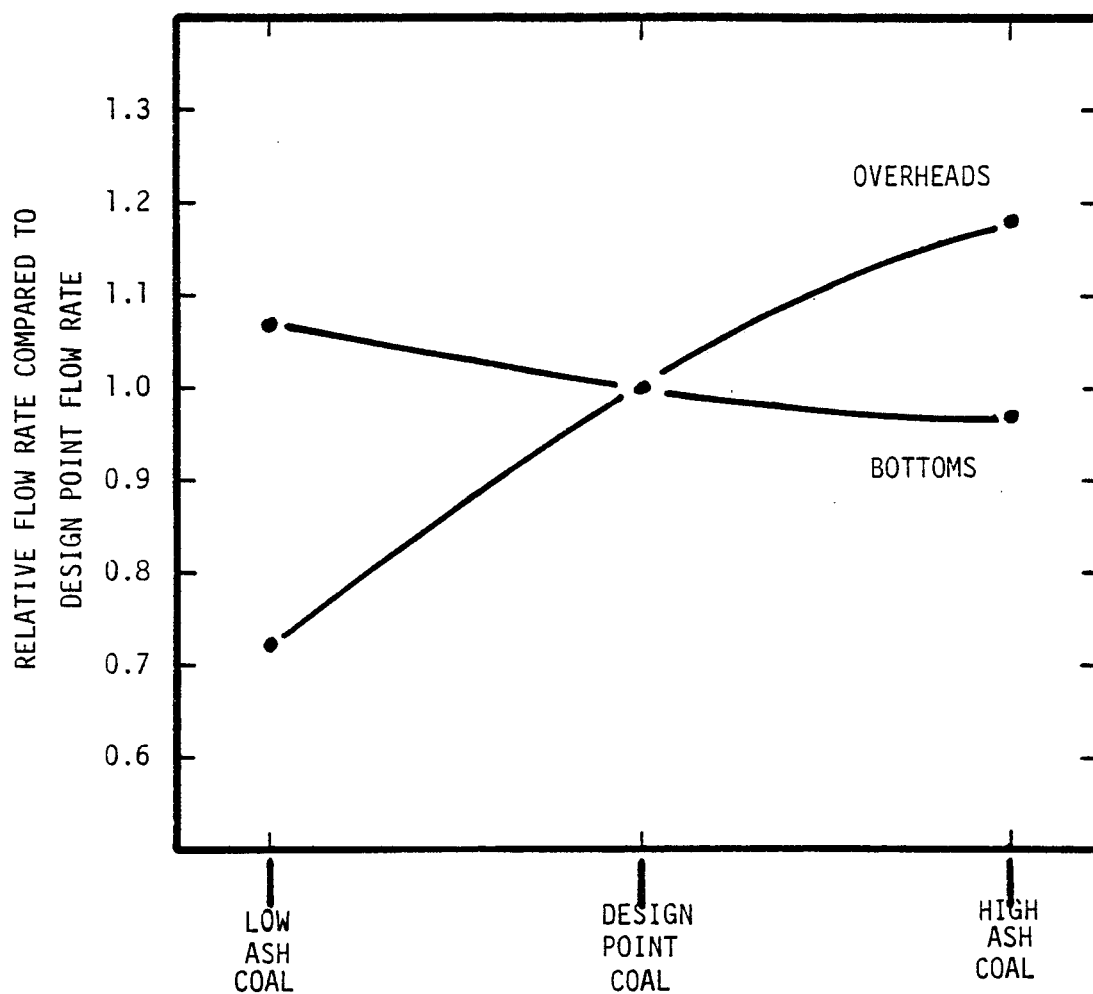
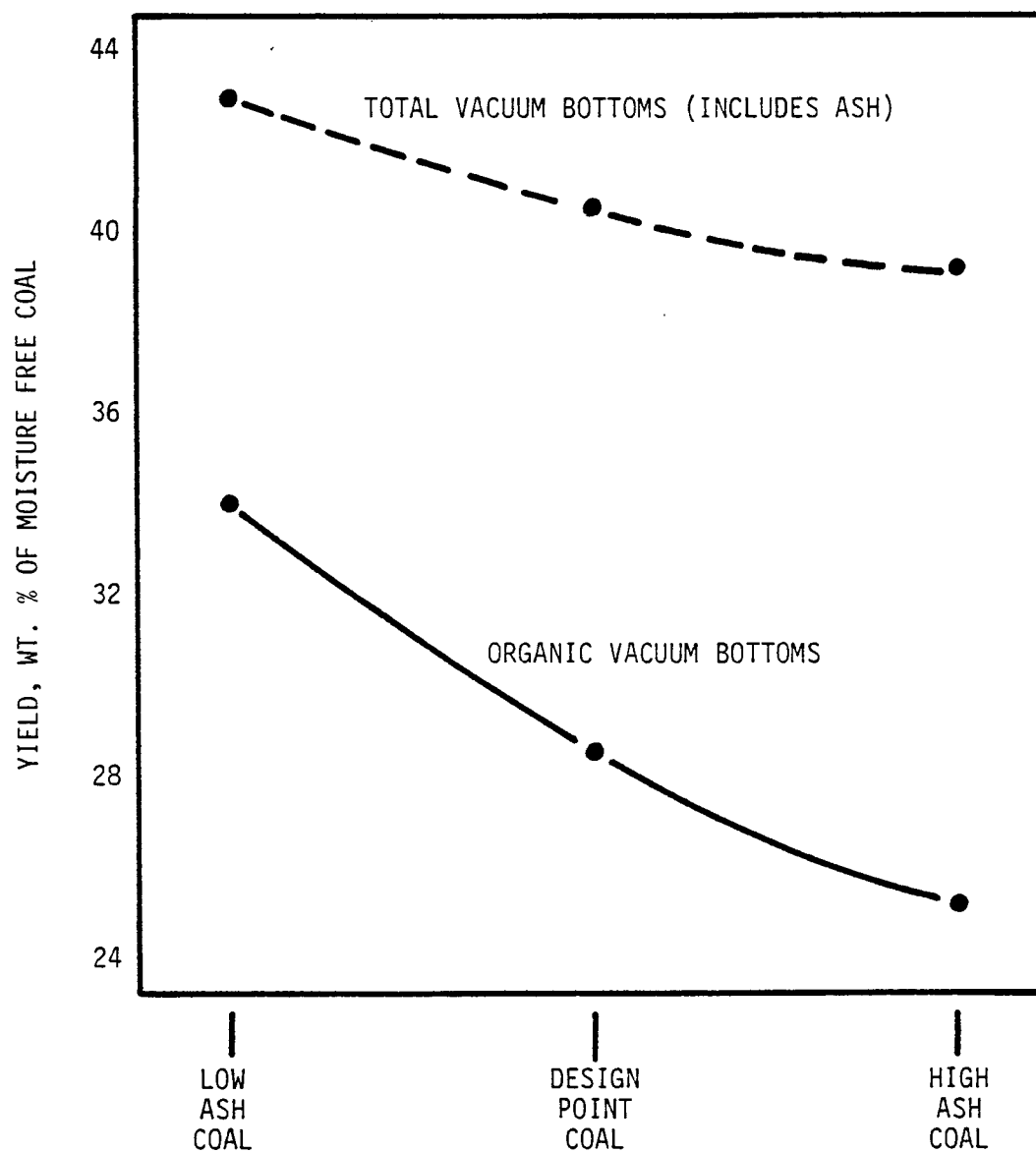


Figure 7E-2. Effect of design range of coal on the flow rates of vacuum flash drum overheads and bottoms streams



NOTE: BASED ON WEST VIRGINIA NORTHWEST PANHANDLE COAL.

Figure 7E-3. Effect of design range of coal on vacuum bottoms yield.

APPENDIX 7F

SRC-II DEMONSTRATION PLANT PRELIMINARY SHUTDOWN SEQUENCE

I. Assumptions

The following basic assumptions were used in the development of this shutdown sequence:

1. The plant process unit configurations were assumed to be those shown in Phase Zero Deliverable No. 1, Demonstration Plant Description. Figure 7-1 of this report is a simplified flowsheet of the plant.
2. All areas were operating.
3. The shutdown was a normal planned one and all areas were to be shut down.
4. All of the process units were to be opened to the atmosphere except the following:
 - The Oxygen Plant cold box - Area 44
 - The Hydrogen Purification Plant cold box - Area 12
 - The refrigeration system in the Product Gas Plant - Area 32
 - The catalyst beds in the Shift and COS Converter - Area 22, and the Methanator - Area 25.

(These items do not usually require repair or replacement and could involve considerable extra work if opened).

II. NORMAL SHUTDOWN PROCEDURE

A. Shutdown of the First Dissolver Train

1. Stop coal feed. Pump level down in coal-slurry mix tank.
2. Direct the slurry recycle to the dissolver charge pump and shut off the flow to these pumps from the mix tank. Flush from pump into mix system with flush oil to clear lines and dilute and cool the slurry in the mix system.
3. Add flush oil to the 1st Low Pressure Flash Drum to maintain recycle to the dissolver charge pump and flow to the

vacuum flash jug. Displace all possible solids in the train by flushing the system with heavy fuel oil to the vacuum flash. Velocities in all solids carrying lines and equipment must be at design rates to ensure thorough flushing.

4. Adjust the temperature on the preheater to maintain a flashing condition of the feed to the vacuum flash jug.
5. Maintain hydrogen flow rates to the preheater and dissolver until the system solids have been flushed out.
6. When the solids have been well flushed out of the dissolver train, direct the flush oil to slop tanks instead of the vacuum jug, reduce the preheater temperature, stop hydrogen flow to the preheater and the dissolver and gradually reduce the system pressure. Switch grades of flush oil as required for proper cleaning.
7. Nitrogen is now used to displace the hydrogen in the train. The gas flow from the train is directed to the flare.
8. Adjust operations in all the other areas to accommodate the shutdown of this train.

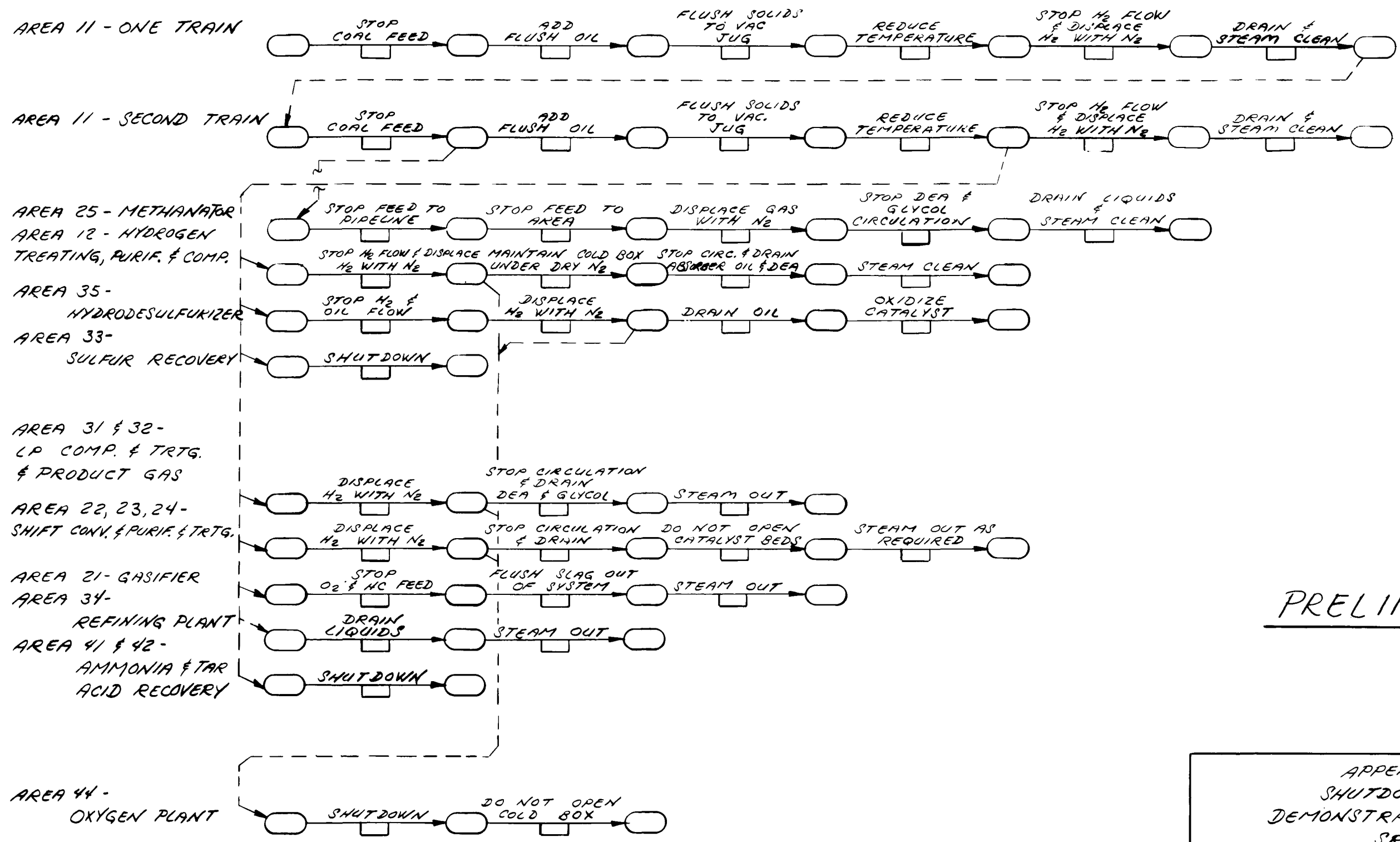
B. Shutdown of the Second Dissolver Train

1. Repeat the same steps 1 through 8 as were followed on the shutdown of the first train.
2. Secure the process lines from the dissolver area to other areas. Drain, steam clean, solvent clean and chemically clean the dissolver area equipment and lines as required for maintenance.

C. Shutdown of Remainder of Plant

1. Stop the flow from the Methanator - Area 25 to the pipeline and put it to the fuel system or flare. Stop the feed gas flows to the methanator after cooling it off. Displace the hydrocarbon gases with nitrogen. Stop the DEA and glycol circulation. Drain the liquids, if required.
2. Shut down the Hydrogen Recycle Gas Treating, Compression and Purification - Area 12. Displace hydrogen with nitrogen. Maintain the cold box under dry nitrogen atmosphere. Drain the absorber oil and DEA solution and steam out the vessels.
3. Shut down the Hydrodesulfurizer - Area 35 by reducing the temperatures and then stopping hydrogen and oil flow. Drain the oil and reduce the pressure. Blanket the unit with nitrogen.

4. Shut down the Sulfur Recovery - Area 33.
5. In LP Gas Compression and Treating - Area 31 and the Product Gas Plant - Area 32, displace the hydrogen with nitrogen. Stop circulation of the DEA and glycol and drain the solutions. Steam out the vessels.
6. In Areas 22, 23 and 24, stop the feed gas flows, reduce the pressure and displace the syngas with nitrogen. Stop the carbonate circulation and drain the solution. Steam out the equipment and lines.
7. Shut down the Gasifier - Area 21. Stop flows of oxygen and mineral residue slurry. Dilute excess slurry to slop tankage. Flush the slag out of the system.
8. Shut down the Refining Plant - Area 34. Drain the liquids to slop tankage. Solvent flush the lines and equipment and then steam clean.
9. Shut down the Oxygen Plant - Area 44.
10. Shut down the Recovery Plants, Ammonia - Area 41 and Tar Acids - Area 42.
11. Shut down the utility plants requiring maintenance and set the others at an idling condition.

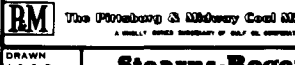


PRELIMINARY

APPENDIX - 7G
SHUTDOWN LOGIC
DEMONSTRATION PLANT
SRC II

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17				
	SYSTEM EVENT	COAL HANDLING	COAL SLURRY AREA	DISSOLVER AND SEPARATORS	RECYCLE GAS	CRYOGENIC H ₂ RECOVERY	TEXACO GASIFIERS	SHIFT CONVERSION	H ₂ PURIFICATION AND COMPR	EXCESS SYNGAS TREATING	METHANATION & GLYCOL TREATING	LOW PRESSURE GAS PREP & TREATING	SWEET GAS RECOVERY	CLAUS PLANT	SUPERSCOT UNIT	ATMOSPHERIC FRACTIONATION	VACUUM FLASH	REFINING AREA SURGE	HDS UNIT	REMARKS	
A-	SYSTEM COMMENTS	INCLUDES COAL UNLOADING, STORAGE, RECLAIM AND CRUSHED COAL HANDLING (AREAS B1, B2, B3)	INCLUDES ALL EQUIPMENT BETWEEN FINE COAL BINS AND THE H.P. SLURRY PUMPS (AREA 11)	INCLUDES ALL AREA 11 EQUIPMENT DOWNSTREAM OF THE H.P. SLURRY PUMPS	AREA 12 WITH THE EXCEPTION OF THE CRYO UNIT	BASED ON 100 RECYCLE GAS FLOW THROUGH THE CRYOGENIC UNIT AREA 12	INCLUDES ALL AREA 21 EQUIPMENT SURGE TANK PROVIDES 30 MIN. SURGE NORMAL RATES	AREA 22	AREA 23	AREA 24 AND DEA TREATING IN AREA 25	AREA 25 EXCEPT DEA TREATING	AREA 31	AREA 32	CLAUS UNIT PORTION OF AREA 33	SUPERSCOT UNIT PORTION OF AREA 33	ATMOSPHERIC COLUMN AND DEBUTANIZER IN AREA 34	(AREA 34) INCLUDES THE VACUUM FLASH TOWER AND ASSOCIATED EQUIP MENT	INCLUDES AREA 34 TANKAGE AND MRS HANDLING	AREA 35 NAPHTHA DISEL TREATER	UNLESS OTHERWISE NOTED EVENTS ARE ASSUMED TO OCCUR WHILE BOTH DISSOLVER LINES ARE RUNNING NORMALLY	
	BOTH DISSOLVER TRAINS COLD	NO NET DEMAND	AREA IS DOWN OR CIRCULATING	AREA IS DOWN OR CIRCULATING	NO FLOW MAY BE AT OPERATING PRESSURE	NO FLOW	HAVE GASIFIERS STABLE BEFORE DISSOLVER START UP	SHIFT UNIT MUST BE LINED OUT PRIOR TO DISSOLVER START-UP	UNIT NEEDS TO BE UP AND STABLE PRIOR TO DISSOLVER START-UP	SYNGAS FLOW TO FUEL SHOULD BE HIGH PRIOR TO DISSOLVER START-UP	SYNGAS IN EXCESS OF FUEL DEMANDS IS METHANATED AND EXPORTED	VAPOR RECOVERY AND GASIFIER LOCK GAS ONLY ACTIVE FLOWS	VERY LOW OR NO FLOW OF FEED GAS	UNIT HOT AND READY FOR FEED	UNIT CIRCULATING AND TREATING CLAUS HEAT-UP TAIL GAS	AREA CIRCULATING OR DOWN COLD	IDLE OR MAY BE RUNNING DILUTED MRS FROM STORAGE TO MAKE AREA 21 FEED	MRS HEATER AND PUMPS WORKING TO KEEP MRS HOT	AREA DOWN OR RUNNING OFF NAPHTHA OR LIGHT FUEL OIL INVENTORY		
B-	FIRST DISSOLVER TRAIN STARTING UP	VARIABLE FINE COAL DEMAND UP TO 140 TPH	TWO CHARGE PUMPS HOT, TWO COLD	ONE LINE HEATING UP, THE OTHER LINE AND FURNACE COLD	H ₂ FLOW AT OR BELOW 50% OF DESIGN	MAY HAVE FROD UNIT TURNDOWN PROBLEMS	MAY HAVE TURNDOWN PROBLEMS TO GET INTO H ₂ BALANCE MRS PRODUCTION RATE VERY HIGH	MAY HAVE EXCESS H ₂ DURING DISSOLVER START-UP	A TIME OF INCREASING FLOW RATES HYDROGEN CONSUMPTION INCREASES VERY RAPIDLY AFTER COAL FEED STARTS	EXCESS SYNGAS DE CREASES AS DISSOLVER H ₂ CONSUMPTION GOES UP	SYNGAS TO METHANA TION DECREASING	ACTIVE FLOW TO C31 102 BEGINS FROM UNITS 10 & 30	LOW NET PRODUCTION OF C ₃ , C ₄ UNIT BASICALLY CIRCULATING	FEED IS RELATIVELY STABLE BECAUSE "UPSET" STREAMS GO TO SUPERSCOT FIRST	VARIABLE ACID GAS RATES FROM UNITS 10 TO 30	UNIT ON TOTAL REFLUX AND CIRCULATING	A TIME OF ERRATIC RATES AND COMPO SITION OF THE HOT SLURRY FEED	DILUTED MRS OR HEAVY FUEL OIL BEING USED TO MAKE SYNGAS	RUNNING OFF IN VENTORY TO MAKE FUEL	THIS IS A LIKELY EVENT TO CAUSE SEVERE AREA UPSETS. MANY AREAS WILL BE OPERATING AT OR NEAR MINIMUM RATES AND WILL BE SENSITIVE TO UPSETS	
	ONE DISSOLVER OPERATING, OTHER DISSOLVER STARTING UP	VARIABLE FINE COAL DEMAND UP TO 260 TPH	TWO CHARGE PUMPS ON SLURRY, TWO ON SOLVENT	ONE LINE HOT AND PRODUCING, ONE FURNACE AND DISSOLVER HEATING UP	H ₂ FLOW AND CONTAMINANTS BE TWEEN 50% AND 100% OF DESIGN	VARIABLE FLOW	BLENDING MRS AND HEAVY OIL FEED	VARYING H ₂ REQUIRE MENTS MAY REQUIRE SHIFT FEED UPSETS	MAKE-UP H ₂ RATES BETWEEN 50% AND 100% OF DESIGN	EXCESS SYNGAS VARIABLE AS ADDITIONAL GASIFIERS START UP	SYNGAS TO METHANA TION LOW AND VARIABLE	C31 102 SHOULD BE ABLE TO OPERATE ON SPEED CONTROL	FEED CHANGES MAY CAUSE OFF-SPEC PRODUCTS. INCREASE REFLUX RATIOS	SULFUR PRODUCTION INCREASING	ACID GASES FROM PROCESS AREAS VARIABLE	REFLUX RATIOS IN CREASED TO HOLD PRODUCT SPECS DURING DISSOLVER START-UP	RUNNING A COMBINA TION OF HOT SLURRY AND REGRUN MRS TO PROVIDE AREA 21 FEED	WORKING OFF ANY EXCESS MRS TO AREA 21 OR 34	RUNNING OFF IN VENTORY	UPSETS DURING THIS EVENT WILL BE MODERATED BY THE STABLE OPERATION OF THE OPERATING DISSOLVER LINE	
C-	BOTH DISSOLVER TRAINS OPERATING	FINE COAL DEMAND UP TO 260 TPH	ALL FOUR CHARGE PUMPS ON SLURRY	BOTH LINES HOT AND FLOWING	H ₂ RATE AND PURITY NEAR DESIGN	SHOULD BE STABLE FLOWS TO UNIT	LINING OUT ON MRS FEED BEING PRODUCED BY DISSOLVERS	LINE UNIT OUT TO COME INTO H ₂ AND FUEL GAS BALANCE	RATES NEAR DESIGN DEPEND ON COAL REACTIVITY	EXCESS SYNGAS RATE DEPENDS ON COAL REACTIVITY AND MRS INVENTORY	SYNGAS TO METHANA TION DEPENDS ON FUEL BALANCE AND COAL REACTIVITY	STABLE OPERATION	SHOULD BE STABLE OPERATION	STABLE OPERATION	STABLE OPERATION	STABLE OPERATION	STEADY OPERATION TO PRODUCE AREA 21 FEED. SMALL FLOWS TO FROM STORAGE	USING HDS TO CONTROL NAPHTHA AND LIGHT FUEL OIL	RUNNING BLOCKED OPERATION ON NAPHTHA LIGHT FUEL OIL TO CONTROL INVENTORY		
	20 CYCLE POWER DIP	ENTIRE UNIT SHUTS DOWN	LOSE LOW PRESSURE SLURRY PUMPS	TRIGGERS AREA SHUTDOWN	N/A EXCEPT FOR DEA STRIPPER REFLUX PUMP	MAY LOSE MECHANICAL REFRIGERATION (ELECTRIC DRIVERS)	MAY LOSE FLUSHING OIL AND BURNER COOLING WATER. LOSE FEED.	IF P22, 101A, B ARE ELECTRIC, THEY WILL HAVE TO BE RESTARTED	WILL LOSE P23, 103 A, B, 9 PLUS AIR COOLERS A23, 101, 102	WILL LOSE LEAN DEA AND DEA REGENERATOR REFLUX PUMPS	WILL LOSE METHANE GAS AIR COOLER, CONDENSATE PUMP, AND GLYCOL CIRCULATION	LOSE VAPOR RECOVERY COMPRESSOR AND AMINE TREATING	TEMPORARY LOSS OF GLYCOL CIRCULATION AND DEPROPANIZER REFLUX	LOSE PRODUCT SULFUR PUMP	LOSE QUENCH SOLU TION AND BRINE CIRCULATION. LOSE IN CINERATOR	LOSE MAIN COLUMN RE BOILER CIRCULATION. BOTH REFLUX PUMPS AIR COOLED OVERHEAD CONDENSER AND PRODUCT PUMPS	LOSE PRODUCT PUMPS AND HOTWELL PUMPS AREA IS SHUTDOWN	LOSE VAPOR RECOVERY COMPRESSOR, MRS PUMPS, AND MOST OTHER PUMPS	LOSE ALL PUMPS AND RECYCLE COMPRESSOR	PROVIDING STEAM DRIVEN SPARE PUMPS COULD GREATLY REDUCE THE IMPACT OF POWER DIPS IN MANY AREAS	
D-	POWER FAILURE	ENTIRE UNIT SHUTS DOWN	LOSE LOW PRESSURE SLURRY PUMPS	TRIGGERS AREA SHUTDOWN	N/A EXCEPT FOR DEA STRIPPER REFLUX PUMP	WILL LOSE MECHANICAL REFRIGERATION WITH OUT STEAM DRIVERS GENERATOR POWER TO AUXILIARY DRIVERS	NEED STEAM DRIVERS ON PUMPS AND BACKUP POWER FOR INSTRU MENTS TO AVOID SHUTDOWN	POSSIBLE LOSS OF SHIFT CONDENSATE RETURN TO AREA 21 IF PUMPS ARE ELECTRIC	WILL LOSE PUMPS P23, 103, A, B, 9 PLUS AIR COOLERS A23, 101, 102	WILL LOSE LEAN DEA AND DEA REGENERATOR REFLUX PUMPS	WILL LOSE METHANE GAS AIR COOLER, CONDENSATE PUMP, AND GLYCOL CIRCULATION	LOSE VAPOR RECOVERY COMPRESSOR AND AMINE TREATING	LONG TERM LOSS OF GLYCOL CIRCULATION AND DEPROPANIZER FLARING	LOSE PRODUCT SULFUR PUMP	LOSE QUENCH SOLU TION AND BRINE CIRCULATION. LOSE IN CINERATOR	LOSE MAIN COLUMN RE BOILER CIRCULATION. REFLUX PUMPS ON BOTH COLUMNS & AIR COOLED OVERHEAD CONDENSER AND PRODUCT PUMPS	LOSS OF PRODUCT PUMP CAUSES FLASH TOWER TO FILL WITH SLURRY	LOSE VAPOR RECOVERY COMPRESSOR, MRS PUMPS, AND MOST OTHER PUMPS	LOSE ALL PUMPS AND RECYCLE COMPRESSOR	PROVIDING STEAM DRIVEN SPARE PUMPS COULD GREATLY REDUCE THE IMPACT OF POWER FAILURE IN MANY AREAS	
	LOSS OF EMERGENCY GENERATOR DURING POWER FAILURE	N/A	N/A	N/A	LOSS OF COMPRESSOR CONTROLS WILL TRIGGER SHUTDOWN	WILL LOSE MECHANICAL REFRIGERATION	UNIT SHUTDOWN UNLESS INSTRUMENTS ARE BATTERY BACKUP	UNIT SHUTDOWN UNLESS INSTRUMENTS ARE BATTERY BACKUP	LOSS OF ELECTRONIC INSTRUMENTS	LOSS OF ELECTRONIC INSTRUMENTS	LOSS OF ELECTRONIC INSTRUMENTS	LOSS OF ELECTRONIC INSTRUMENTS	LOSS OF ELECTRONIC INSTRUMENTS AND COMPRESSOR	LOSS OF INSTRUMENTS WILL DROP OUT REACTION FURNACE	N/A	LOSS OF INSTRUMENTS WILL DROP OUT FIRED REBILDER	LOSE ELECTRONIC INSTRUMENTS	ELECTRONIC INSTRU MENT FAILURE	INSTRUMENT FAILURE	ASSUMES ELECTRONIC INSTRUMENTS ARE NOT ON BATTERY POWER SUPPLY	
E-	POWER BOILER FAILURE	N/A	HIGH PRESSURE SLURRY PUMPS INOPERATIVE	LOSS OF BFW CIRCULATION CAUSES OVER HEAT IN SEPARATORS AND SHUTDOWN. LOSE CIRCULATION THROUGH CHARGE HEATER	LOSE H ₂ CIRCULATION AND OFF-GAS COMPRESSION	STOPS MOL SIEVE REGENERATION AND WILL STOP MECHANICAL REFRIGERATION IF IT IS STEAM DRIVEN	FORCES UNIT SHUTDOWN	LOSE CONTROL OF HEAT REMOVAL	UNIT SHUTDOWN	LOSE DEA REGENERATION	LOSE GLYCOL REGENERATION	LOSS OF L.P. GAS COMPRESSION SOUR GAS TO FLARE	LOSE COMPRESSORS AND REFRIGERATION UNIT RESULTS IN LIGHT ENDS TO FLARE	LOSE AIR TO REACTION FURNACE AREA SHUTS DOWN	LOSE AIR TO INLINE BURNER. LOSE STRIPPER REBOILER AREA SHUTS DOWN	LOSS OF STRIPPING AND REBIL STEAM CAUSES PRODUCTS TO GO OFF SPEC	LOSE VACUUM	LOSE MRS JET MIX PUMP	LOSE STEAM TO EFFLUENT COOLING TRAIN	THIS EVENT IS MORE LIKELY THAN MIGHT BE EXPECTED BECAUSE THE CURRENT DESIGN BASIS INCLUDES ONLY ONE BOILER	
	COOLING WATER SYSTEM FAILURE (LOSS OF CIRCULATION)	N/A	MAY AFFECT COOLING ON SLURRY CHARGE PUMPS GEAR BOXES	SEPARATORS BEYOND VII 118 HEAT UP	LOSE DEA TREATING AND METHANE OFF GAS COMPRESSION	LOSE CONDENSERS ON MECHANICAL REFRIGERATION AND REGENERATION COOLER	LOSE BURNER COOLING	N/A	LOSE ABSORBER FEED COOLER AND OVERHEAD CONDENSER PLUS COMPRESSOR INTER-COOLING	LOSE LEAN CARBONATE AND DEA COOLERS AND CARBONATE ABSORBER OVERHEAD COOLER	LOSE METHANATED PRODUCT GAS FINAL COOLER AND LEAN GLYCOL COOLER	LOSE COMPRESSOR AFTERCOOLERS AND AMINE COOLERS AREA SHUTS DOWN	FORCES AREA SHUTDOWN	N/A	MULTIPLE EXCHANGERS AND REFRIGERATION UNIT FAILURE CAUSES SHUTDOWN	LOSE DEBUTANIZER OVERHEAD CONDENSER, PRODUCT COOLERS, AND MAIN COLUMN OVERHEAD TRIM COOLER	LOSE VACUUM AND OVERHEAD COOLER	N/A	LOSE RX EFFLUENT STRIPPER OVERHEAD AND PRODUCT COOLERS	CURRENT PUMPING SCHEME INCLUDES: PROCESS COOLING TOWER: 1 TURBINE DRIVEN AND 2 MOTOR DRIVEN PUMPS OPERATING: 1 MOTOR DRIVEN SPARE UTILITY COOLING TOWER: 3 TURBINE DRIVEN AND 1 MOTOR DRIVEN PUMPS OPERATING: 1 MOTOR DRIVEN SPARE	
F-	CONDENSATE CONTAMINATED	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	CONTAMINATED CONDENSATE GOES TO THE RAINWATER BASIN. DEMINERALIZED WATER SYSTEM CAN MAKE UP FOR THIS LOSS FOR 16 HOURS IF DEMINERALIZERS ARE OPERATING	
	RAW WATER FAILURE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	MOST AREAS ARE NOT AFFECTED BECAUSE OF THE STORAGE CAPACITY OF THE CLEAR WATER STORAGE TANK (7.5 MRS AT DESIGN RATES)	
	DEMINERALIZER FAILURE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	DEMINERALIZED WATER TANK HOLDS 780,000 GALLONS WHICH IS 24 HOURS DEMAND AT DESIGN RATES	
G-	LOSS OF INSTRUMENT AIR	AFFECTS DUST COLLECTION FILTER AND CAN THAWING	NO CONTROL OF LEVELS AND PRESSURES IN THE AREA	LACK OF CONTROL CAUSES SHUTDOWN	LOSS OF CONTROL VALVES WILL CAUSE SHUTDOWN	WILL LOSE REFRIGERATION UNITS	CAUSES UNIT SHUTDOWN	LOSE CONTROL VALVES	LOSE CONTROL VALVES	LOSE CONTROL VALVES	LOSE CONTROL VALVES	LOSE CONTROL VALVES	CAUSES AREA SHUTDOWN	AREA 33 CONTROL VALVES FAIL	AREA 33 CONTROL VALVES FAIL	UNIT WILL SHUTDOWN	LOSE CONTROL VALVE ACTION	LOSE MRS HEATER AND SOLVENT DILUENT CONTROL	LOSE RECYCLE COMPRESSOR AND PRESSURE CONTROL	NORMALLY NITROGEN IS USED AS BACK-UP FOR INSTRUMENT AIR. N ₂ BACK-UP WAS IGNORED FOR THIS EVENT	
	LOSS OF NITROGEN	LOSE N ₂ BLANKET ON FINE COAL BINS	N/A	N/A	LOSE DEA SURGE TANK BLANKET	N/A	LOSE N ₂ BLANKET ON ASH AND WATER SYSTEMS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	LOSE PRESSURE CONTROL ON VACUUM TOWER	LOSE N ₂ BLANKET ON MRS STORAGE AND DILUTE MRS HOLD TANKS	N/A	THE OXYGEN PLANT START-UP CAN TAKE A PERIOD OF DAYS TO WEEKS TO PRODUCE SPECIFICATION OXYGEN
	LOSS OF OXYGEN PLANT	N/A	N/A	N/A	N/A	N/A	VAPORIZE LOX TO SUPPLY GASIFIER (24 HR SUPPLY)	N/A	N/A	N/A	N/A	N/A	N/A	BACK-UP AIR SUPPLY NOT AVAILABLE	BACK-UP AIR SUPPLY NOT AVAILABLE	N/A	N/A	N/A	N/A		
I-																					

NOTES:
1 "N/A" NOT AFFECTED
"LOX" LIQUID OXYGEN

THIS DOCUMENT IS THE EXCLUSIVE PROPERTY OF STEARNS-ROGER INCORPORATED. IT HAS NOT BEEN PUBLISHED AND IS CONFIDENTIAL IN CONSIDERATION OF THE LOAN HEREOF. RECIPIENT PROMISES NOT TO COPY, REPRODUCE, EXHIBIT, LOAN OR OTHERWISE PUBLISH, DISPOSE OF, NOR TO USE THIS DOCUMENT FOR ANY PURPOSE OTHER THAN THAT FOR WHICH IT IS SPECIFICALLY FURNISHED WITHOUT THE WRITTEN PERMISSION OF STEARNS-ROGER NOR TO USE THE SAME IN ANY WAY DETRIMENTAL TO STEARNS-ROGER.	NO.	REVISIONS				DATE	BY	CHKD	APPRD	PRINT RECORD				ENGINEERING REVIEW		AUTHORIZED FOR RELEASE		CUSTOMER APPROVAL		DRAWING STATUS		APPENDIX-7 H SYSTEM EVENT MATRIX (SHEET #1) SRC II DEMONSTRATION PLANT  The Stearns & Rogers Coal Mining Co. A WHOLLY OWNED SUBSIDIARY OF B.F. GOODRICH Stearns-Roger INCORPORATED ORDER NO. C-23000 REV. 	DWG. NO. 22811 SHEET NO. 71E06 -106 REV. 

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SYSTEM EVENT	COAL HANDLING	COAL SLURRY AREA	DISSOLVER AND SEPARATORS	RECYCLE GAS	CRYOGENIC H ₂ RECOVERY	TEXACO GASIFIERS	SHIFT CONVERSION	H ₂ PURIFICATION AND COMPR	EXCESS SYNGAS TREATING	METHANATION & GLYCOL TREATING	LOW PRESSURE GAS PREP & TREATING	SWEET GAS PLANT	CLAUS PLANT	SUPERSCOT UNIT	ATMOSPHERIC FRACTIONATION	VACUUM FLASH	REFINING AREA SURGE	HDS UNIT	REMARKS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
SYSTEM COMMENTS	INCLUDES COAL UNLOADING, STORAGE, RECLAIM AND CRUSHED COAL HANDLING (AREAS 61 62 63)	INCLUDES ALL EQUIPMENT BETWEEN FINE COAL BINS AND THE H. P. SLURRY PUMPS (AREA 11)	INCLUDES ALL AREA 11 EQUIPMENT DOWNSTREAM OF THE H. P. SLURRY PUMPS	AREA 12 WITH THE EXCEPTION OF THE CRYO UNIT	BASED ON 100% RECYCLE GAS FLOW THROUGH THE CRYO UNIT AREA 12	INCLUDES ALL AREA 21 EQUIPMENT COMMENTS ARE BASED ON HAVING 3 50 GASIFIERS	AREA 22	AREA 23	AREA 24 AND DEA TREATING IN AREA 25	AREA 25 EXCEPT DEA TREATING	AREA 31	AREA 32	AREA 33 CLAUS UNIT	AREA 33 SUPERSCOT UNIT	ATMOSPHERIC COLUMN AND DEBUTANIZER IN AREA 34	(AREA 34) INCLUDES VACUUM FLASH TOWER AND ASSOCIATED EQUIP- MENT	INCLUDES AREA 34 TANKAGE AND MRS HANDLING	AREA 35 NAPHTHA DIESEL TREATER	UNLESS OTHERWISE NOTED, EVENTS ARE ASSUMED TO OCCUR WHILE BOTH DISSOLVER LINES ARE RUNNING NORMALLY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSS OF OXYGEN COMPRESSOR	N/A	N/A	N/A	N/A	N/A	SHUTS DOWN GASIFIERS	RESULTS IN LOSS OF FEED FROM GASIFIERS	UNIT 20 SHUTDOWN	UNIT 20 SHUTDOWN	UNIT 20 SHUTDOWN	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	THIS EVENT WILL SHUTDOWN THE ENTIRE PLANT UNLESS THE COMPRESSOR CAN BE RESTARTED IMMEDIATELY																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSE FUEL GAS SUPPLY	CAN THAWING NOT AVAILABLE	N/A	N/A	LOSE LEAN OIL SURGE TANK BLANKET	N/A	N/A	N/A	N/A	THIS AREA SUPPLIES FUEL GAS	N/A	N/A	DEPROPANIZER OFF GAS VENTED TO FLARE	PRECLUDES START-UP OR AUXILIARY HEATING	LOSE PURNER AND INCINERATOR UNIT SHUTS DOWN OR CIRCULATES	N/A	N/A	LOSE MRS HEATER	LOSE BLANKET ON FEED SURGE DRUM	THIS IS A TOTAL FUEL GAS SYSTEM FAILURE. NOT LOSS OF ANY SINGLE FUEL GAS STREAM																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSE FUEL OIL SUPPLY	N/A	N/A	HEATERS SHUTDOWN	N/A	N/A	PRECLUDES GASIFIER HEAT-UP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	INCINERATOR SHUTDOWN	FIRE REBOILER SHUTS DOWN	N/A	N/A	LOSE FEED HEATER AND STRIPPER REBOILER																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
LOSE COAL FEED	FINE COAL BINS PROVIDE 2-4 HOURS SURGE FOR UNIT 10	LONG OUTAGES WILL UPSET SLURRY CON- CENTRATION	N/A IF OUTAGE IS SHORT. IF OUTAGE IS LONG, SLURRY CONCENTRATION DROPS	H ₂ CONSUMPTION DROPS OFF AS SLURRY CONCENTRATION DROPS	N/A	IF OUTAGE IS LONG, MRS RATE FROM AREA 34 DROPS OFF AS DOES H ₂ REQUIREMENTS	N/A	RATES FALL AS CONVERSION IN DISSOLVERS DROPS OFF	RATES RISE AS H ₂ MAKE-UP TO DIS- SOLVERS DROPS OFF	IF OUTAGE IS LONG, IT MAY RESULT IN SYNGAS METHANATION	N/A	N/A	N/A	N/A	N/A	IF OUTAGE IS LONG, WILL NEED TO REPRO- CESS DILUTED MRS TO MAKE AREA 21 FEED	N/A	N/A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
DEPRESSURE ONE DISSOLVER	VERY RAPID DE- CREASE IN COAL DEMAND	BLOCK IN AND FLUSH FROM H. P. PUMPS TO DISSOLVER	UPSETS 1500 PSIG STEAM GENERATION AND SEPARATORS DROPS OUT CHARGE HEATER	DEPRESSURING DIS- SOLVER ISOLATED FROM RECYCLE LOOP	FLOW DROPS BY 50	POSSIBLE TURNDOWN PROBLEMS	AS H ₂ DEMAND DROPS, SHIFT FEED GAS RATE DROPS	STEP CHANGE IN H ₂ DEMAND	STEP CHANGE IN SYNGAS TO FUEL	MAY REQUIRE AD- DITIONAL SYNGAS METHANATION TO GET IN H ₂ BALANCE	FEED ERRATIC	FEED ERRATIC	N/A	TEMPORARY INCREASE FOLLOWED BY LARGE DECREASE IN FEED RATE	FEED UPSETS ARE CAUSED BY LARGE FLOW INCREASES	FEED INCREASE UPSET SLURRY PRO- DUCT INCREASE	INCREASED VACUUM BOTTOMS RUNDOWN RATE	N/A	SYSTEM RESPONSES TO THIS EVENT ARE BASED ON DEPRESSURING THE DISSOLVER THROUGH THE LETDOWN VALVES AND SEPARATORS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSE HYDROGEN PRODUCTION	N/A	DROP OUT FRESH COAL FEED TO CUT H ₂ CONSUMPTION	H ₂ PARTIAL PRESSURE AND DISSOLVER TOTAL PRESSURE DECA CONTINUE TO CIRCUL- ATE	CAUSES PRESSURE DECAY AND LOSS OF H ₂ PURITY	PRESSURE DECAY AND HEAVIER FEED	THIS EVENT CAUSED BY LOSS OF GASIFI- FIERS	NO FLOW THROUGH SHIFT	UNIT SHUTDOWN	IF PROBLEM IS IN AREAS 22 23, STEP INCREASE IN FEED RATE TO AREA 24	IF PROBLEM IS IN AREAS 22 23, MORE SYNGAS WILL NEED TO BE METHANATED	LOSE ONLY STEADY FEED TO VAPOR RECOVERY COMPRESSOR (LOCK GAS)	N/A	N/A	LOSS OF REDUCING HYDROGEN	N/A	SWITCH VAC. BOTTOMS TO RUNDOWN TANKAGE	N/A	FORCES AREA SHUTDOWN	AREA 21 COMMENTS ARE BASED ON 3 50 GASIFIERS. SURGE TANK PROVIDES 30 MIN. SURGE. NORMAL RATES AND 50% LEVEL.																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
AREA 12 CRYO UNIT SHUTDOWN	N/A	N/A	INCREASE MAKE-UP H ₂ RATE TO KEEP H ₂ PARTIAL PRESSURE UP AND OR CUT OR DROP COAL FEED	RECYCLE GAS TO FLARE WITH IN- CREASED MAKE-UP H ₂	UNIT SHUTDOWN	INCREASED FEED RATE TO KEEP H ₂ PARTIAL PRESSURE UP IN THE DISSOLVERS	INCREASED FEED RATE TO MAKE MORE H ₂ FOR DISSOLVERS	INCREASED H ₂ MAKE- UP RATE	EXCESS SYNGAS IS REDUCED DUE TO HIGHER H ₂ REQUIRE- MENTS IN UNIT 10	NO SYNGAS AVAILABLE FOR METHANATION	N/A	LOSE SIDE STREAM FEED TO DEETHANIZER FEED COMPRESSOR	N/A	N/A	N/A	N/A	N/A	HIGHER UNIT 10 NEEDS FOR H ₂ JEOPARDIZES H ₂ SUPPLY TO HDS	AFTER A SHUTDOWN, THE CRYO UNIT CAN TAKE A PERIOD OF DAYS TO WEEKS TO MAKE SPECIFICATION PRODUCTS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSE GAS TREATING	N/A	MIX TANK VAPOR TO FLARE	ROUTE L. P. FLASH VAPOR TO FLARE	ROUTE L. P. GAS STREAMS TO FLARE	FLARE ETHANE RICH GAS	FLARE LOCK GAS	VENT FLASH GAS TO FLARE	FLARE FLASH GAS	FLARE FLASH GAS	LOSE DEETHANIZER OFF GAS FEED TO METHANATOR	AREA SHUTDOWN	UNIT CIRCULATES OR SHUTS DOWN	N/A	LOWER ACID GAS RATE	VENT OFF GASES TO FLARE	N/A	VAPOR RECOVERY VAPORS WOULD BE SENT TO FLARE	VENT SOUR GASES TO FLARE																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
LOSE ATMOSPHERIC REFINING	N/A	SUBSTITUTE FUEL OIL FOR FRAC. RECYCLE AND SEND H. C. CONDENSATE TO SLOPS	RUN H. C. FEEDS TO HEAVY SLOPS	LOSS OF LEAN OIL CAUSES HEAVIES TO GET INTO 2FA AND SIEVES	FLARE H. C. CONDENSATE THAT NORMALLY GOES TO THE DEBUTANIZER	N/A	N/A	N/A	N/A	N/A	LOSE ABOUT 1/2 THE L. P. GAS COMPRESSOR FEED	H. C. CONDENSATE MUST GO TO FLARE	N/A	N/A	AREA 34 IS DOWN	MUST DIVERT VACUUM FLASH OVERHEAD TO RUNDOWN TANK	LOSE NAPHTHA, LIGHT FUEL OIL, AND HEAVY OIL RUNDOWNS	N/A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
LOSE VACUUM FLASH	N/A	N/A	RUN L. P. HOT SLURRY TO MRS TANKAGE	N/A	N/A	BRING IN DILUTED MRS OR HEAVY FUEL OIL FEED FROM TANKAGE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	LOSE HEAVY HOT FEED FROM VACUUM FLASH OVERHEAD	UNIT DOWN	LOSE VACUUM BOTTOMS RUNDOWN OR MRS RE-UP CAPABILITY	N/A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
LOSE SULFUR PLANTS	N/A	N/A	N/A	VENT ACID GAS TO FLARE	N/A	N/A	N/A	FLARE ACID GAS	FLARE ACID GAS	N/A	FLARE SOUR GAS	N/A	AREA 33 IS DOWN	AREA 33 IS DOWN	N/A	N/A	N/A	N/A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
LOSE HDS UNIT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	MINOR FEED UPSET	N/A	N/A	N/A	N/A	N/A	INVENTORIES OF UNTREATED NAPHTHA LIGHT FUEL OIL RISE	UNIT DOWN	ASSUMES ADEQUATE UNTREATED NAPHTHA AND LIGHT FUEL OIL TANKAGE FOR SURGE DURING HDS OUTAGE																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSE AMMONIA/TAR ACID RECOVERY	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	FEED RATE DROPS	N/A	N/A	N/A	N/A	N/A	ASSUMES SHORT SHUTDOWN. SHUTDOWN OF MORE THAN 4-6 HOURS WILL FILL THE SOUR WATER SURGE TANK AND CAUSE PLANT SHUTDOWN																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSE WATER RECLAMATION	DUST CONTROL WATER COMES FROM STORAGE TANK	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
NATURAL GAS CURTAILMENT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	PLANT CANNOT START UP WITHOUT IMPORTED NATURAL GAS																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
LOSE SLAG HANDLING	N/A	N/A	N/A	N/A	N/A	DUMP SLAG WATER SLURRY TO EMERGENCY POND	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ASSUMES SLAG WATER CAN BE DUMPED TO EMERGENCY SLAG POND DURING SLAG HANDLING SHUTDOWN																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
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SYSTEM EVENT	AMMONIA RECOVERY	TAR ACID RECOVERY	WASTE WATER RECLAIMING	WASTE WATER EVAPORATION	OXYGEN PLANT	STEAM SYSTEMS	RAW WATER	DEMINERALIZERS	COOLING WATER SYSTEM	PRODUCT STORAGE AND SHIPPING	FUEL SYSTEMS	FLARE SYSTEM	FIRE WATER SYSTEM	SEWER SYSTEMS	PLANT AND INSTRUMENT AIR	NITROGEN SYSTEM	SLAG HANDLING	REMARKS
A- SYSTEM COMMENTS	AREA 41	AREA 42 THIS AREA TAKES FEED FROM AND IS CLOSELY TIED TO AREA 41	AREA 43 EXCEPT EVAPORATORS AND ASSOCIATED EQUIPMENT	AREA 43 WASTE WATER EVAPORATORS PLUS RECLAIMED WATER TANK AND PUMPS	AREA 44	AREA 51	ALL OF AREA 52 EXCEPT THE DEMIN- ERALIZER EQUIPMENT	AREA 52 DEMINERALIZER AND RELATED EQUIPMENT	AREA 53 PROCESS COOLING TOWER: 80,730 GPM UTILITY COOLING TOWER: 32,430 GPM	AREA 54 LIQUID PRODUCT STORAGE AND SHIPPING INCLUDING HEAVY FUEL OIL	AREA 54 FUEL GAS AND FUEL OIL SYSTEMS	AREA 54 FLARE SYSTEMS	AREA 54 FIRE WATER SYSTEMS	AREA 54 SEWERS	AREA 54 INCLUDES COMPRES- SORS AND DISTRI- BUTION SYSTEM	AREA 54 INCLUDES NORMAL GAS SUPPLY AND BACKUP LIQUID SUPPLY SYSTEMS	AREA 64	UNLESS OTHERWISE NOTED, EVENTS ARE ASSUMED TO OCCUR WHILE BOTH DISSOLVER LINES ARE RUNNING NORMALLY.
BOTH DISSOLVER TRAINS COLD	AREA DOWN OR RUNNING OFF FEED INVENTORY	AREA DOWN OR RUNNING DEPENDING ON AREA 41 STATUS	FEED TANKAGE PROVIDES 1.5 TO 2.5 HOURS SURGE AT DESIGN RATES AT 50% FULL	FEED TANKAGE PROVIDES 1.5 HOURS SURGE AT DESIGN RATE AND 50% LEVEL	EARLY START-UP REQUIRED TO HAVE HIGH PURITY O ₂ READY FOR AREA 21	FULL STEAM CAPACITY NEEDED FOR PROCESS AREA START-UP	WATER SYSTEMS NEED TO BE IN STABLE OPERATION	DEMINERALIZER NEEDS TO BE OPERATING AND DEIONIZER FULL	BOTH SYSTEMS CIR- CULATING WITH LOW EVAPORATION AND MAKE-UP RATES	NET REVERSE FLOW FROM STORAGE TO PROCESS AREA TO PRODUCE FUEL	MINIMUM FUEL RE- QUIREMENTS OF ABOUT 600 MMBTU HR PRO- VIDED FROM STORED & PURCHASED FUELS	N/A	N/A	N/A	DEMAND NEAR NORMAL DESIGN	PURGING REQUIRE- MENTS MAY BE HIGH		
FIRST DISSOLVER TRAIN STARTING UP	POTENTIAL FEED COMPOSITION UPSSETS CAN BE SMOOTHED BY TANKAGE	FEED UPSET, SMOOTHED OUT BY AREA 41	AREA FEED RATE MUST CLOSELY FOLLOW WASTE WATER RATES FROM PLANT	EVAPORATOR FEED RATE WILL HAVE TO FOLLOW WATER MAKE RATE	EXCESS O ₂ VENTED TO ATMOSPHERE	STEAM DEMAND DROPS AS WASTE HEAT GENERATION BEGINS	RATES RISE COOLING TOWER EVAPORATION AND OTHER LOSSES RISE	WATER NEEDS MAY VARY AS LEVELS ARE ESTABLISHED IN WASTE HEAT EQUIP- MENT	AS EXCHANGER DUTIES RISE, SO DO EVAPO- RATION AND MAKE-UP WATER RATES	LITTLE OR NO NET PRODUCTION OF PRODUCTS	NET FUEL USAGE IS HIGH UNTIL SYNGAS AND NAPHTHA PRO- DUCTS ARE GOING TO FUEL	N/A	N/A	N/A	N/A	N/A		THIS EVENT IS LIKELY TO CAUSE SEVERE AREA UPSSETS. MANY AREAS WILL BE OPERATING AT OR NEAR MINIMUM RATES, AND WILL BE SENSITIVE TO UPSSETS.
ONE DISSOLVER OPERATING, OTHER DISSOLVER STARTING UP	WATER FEED RATE FOLLOWS AVERAGE SOUP WATER PRO- DUCTION RATE	AREA FOLLOWS AREA 41 PRODUCT WATER RATE	A TIME OF IN- CREASING FEED RATES	A TIME OF IN- CREASING FEED RATES	EXCESS O ₂ VENTED TO ATMOSPHERE	STEAM DEMAND DROPS AGAIN AS MORE WASTE HEAT IS RECOVERED	THROUGHPUT CONTI- NUES TO RISE AS HEAT REJECTION TO COOLING WATER RISES	DEMINERALIZER WATER DEMAND MAY VARY AS PROCESS STEAM GENERATORS COME ONSTREAM	PROCESS COOLING TOWER DUTY BETWEEN 50-75% UTILITY COOLING TOWER NEAR DESIGN	PRODUCT RATES SOMEWHAT BELOW 50% OF DESIGN	NEED GOOD NAPHTHA INVENTORY TO PRO- VIDE START-UP FUEL	N/A	N/A	N/A	N/A	N/A		UPSSETS DURING THIS EVENT WILL BE MODERATED BY THE STABLE OPERATION OF THE OPERATING DISSOLVER LINE.
BOTH DISSOLVER TRAINS OPERATING	FEED TANK PROVIDES 5 HRS. FILLING EMPTYING SURGE WHEN 50% FULL (DESIGN RATES)	UNIT NEAR DESIGN FEED RATE OF 284 GPM	RATES DEPEND MOSTLY ON COOLING TOWER BLOWDOWN	RATES DEPEND MOSTLY ON GASIFIER ASH HANDLING AND CLARIFIER RATE	STABLE OPERATION	DEMAND STABLE AT ABOUT 590,000 LBS. HRS.	RATES STEADY AND FOLLOWING CLEAR WATER TANK LEVEL	STEADY DEMAND FOR DEMINERALIZED WATER	BOTH COOLING WATER SYSTEMS NEAR DESIGN DUTIES DEPENDING ON WEATHER	TOTAL CAPACITY OF PRODUCT TANKS AVERAGES 18 DAYS PRODUCTION, VARIES FROM 3-24 DAYS	VACUUM BOTTOMS RATE IS ADJUSTED TO COME INTO FUEL BALANCE	N/A	N/A	N/A	N/A	N/A		
20 CYCLE POWER DIP	LOSE AREA FEED AND SOLUTION CIRCULA- TION	LOSE FEED AND ALL PUMPS	LOSE ALL PUMPS AND INCINERATORS	LOSE PUMPS INCLUD- ING RECLAIMED WATER PUMP	LOSE LIQUID O ₂ , LIQUID N ₂ , AND CONDENSER PUMPS	LOSE BOILER UNLESS DESIGNED TO RIDE THROUGH A POWER DIP	LOSE ALL PUMPS AND CLARIFIER DRIVE	LOSE DEGASSER FLOWER AND ALL PUMPS EXCEPT SPARE DEMINERALIZER WATER PUMP	LOSE ALL COOLING TOWER FANS AND 25-50% OF PUMPS	LOSE ALL LOADING PUMPS AND HEAVY FUEL OIL CIRCULA- TION	LOSE FUEL OIL CIRCULATING PUMPS	LOSE LIQUIDS TRANS- FER AND RECIRCULA- TION PUMPS	LOSE JOCKEY PUMP AND DIESEL PUMP WILL START	LOSE SANITARY LIFT STATION AND TREAT- MENT UNIT	LOSE ONE INSTRU- MENT AIR COMPRESSOR	AREA UNABLE TO SUPPLY N ₂ AT NORMAL PRESSURE		
POWER FAILURE	LOSE AREA FEED AND SOLUTION CIRCULA- TION	LOSE FEED AND ALL PUMPS	LOSE ALL PUMPS AND INCINERATORS	LOSE PUMPS INCLUD- ING RECLAIMED WATER PUMP	LOSE LIQUID O ₂ , LIQUID N ₂ , AND CONDENSER PUMPS	LOSE BOILER UNLESS INSTRUMENTS ARE ON UNINTERRUPTIBLE POWER	LOSE ALL PUMPS AND CLARIFIER DRIVE	LOSE DEGASSER FLOWER AND ALL PUMPS EXCEPT SPARE DEMINERALIZER WATER PUMP	LOSE ALL COOLING TOWER FANS AND 25-50% OF PUMPS	LOSE ALL LOADING PUMPS AND HEAVY FUEL OIL CIRCULA- TION	LOSE FUEL OIL CIRCULATING PUMPS	LOSE LIQUIDS TRANS- FER AND RECIRCULA- TION PUMPS	LOSE ELECTRIC PUMPS AND DIESEL DRIVEN PROCESS FIREWATER PUMP WILL START	LOSE SANITARY LIFT STATION AND TREAT- MENT UNIT	LOSE ONE INSTRU- MENT AIR COMPRESSOR	AREA UNABLE TO SUPPLY N ₂ AT NORMAL PRESSURE		
LOSS OF EMERGENCY GENERATOR DURING POWER FAILURE	N/A	N/A	N/A	N/A	N/A	LOSE BOILER IF WHEN BATTERY BACK- UP DISCHARGES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		ASSUMES ELECTRONIC INSTRUMENTS ARE NOT ON BATTERY POWER SUPPLY.
POWER BOILER FAILURE	LOSE ALL THREE TOWER REBOILERS	LOSE REBOILER, STRIPPING, AND EJECTOR STEAM	BRINE CONCENTRATOR AND INCINERATORS SHUTDOWN	LOSE EVAPORATORS	LOSE AIR COMPRES- SORS AND OXYGEN COMPRESSOR	AREA IS DOWN	LOSE SPARE CLEAR WATER PUMP	LOSE SPARE DEMINERALIZED WATER PUMP	LOSE 40-75% OF COOLING WATER PUMPS DEPENDING ON WATCH PUMPS ARE IN USE	N/A	LARGE REDUCTION IN FUEL USAGE	LOSE SMOKE SUP- PRESSION AND K.O. DRUM HEATING STEAM	N/A	N/A	LOSE SPARE AIR COMPRESSOR	LOSE N ₂ VAPORIZER		THIS EVENT IS MORE LIKELY THAN MIGHT BE EXPECTED BECAUSE THE CURRENT DESIGN BASIS INCLUDES ONLY ONE BOILER.
COOLING WATER SYSTEM FAILURE (LOSS OF CIRCULATION)	LOSE OVERHEAD CONDENSERS AND PUMP AROUND COOLER	LOSE ALL THREE OVERHEAD CONDENSERS	LOSE BRINE CONCENTRATOR	LOSE VACUUM ON EVAPORATORS	LOSE O ₂ COMPRESSOR TURBINE CONDENSERS AND GENERATOR COOLING	4" HG CONDENSATE NOT RETURNED, BFW DEMAND UP BY 1000+ GPM	N/A	N/A	AREA DOWN	N/A	N/A	PROBABLE LARGE LOAD TO BOTH FLARES	MAY INHIBIT DIESEL DRIVEN PUMPS AUTO STARTING	N/A	LOSE AIR COOLER	LOSE COMPRESSED NITROGEN COOLER		CURRENT PUMPING SCHEME INCLUDES: PROCESS COOLING TOWER: 3 TURBINE DRIVEN 5.2 MOTOR DRIVEN 1 MWPS OPERATING - 1 MOTOR DRIVEN SPARE UTILITY COOLING TOWER: 3 TURBINE DRIVEN & 1 MOTOR DRIVEN PUMPS OPERATING - 1 MOTOR DRIVEN SPARE
CONDENSATE CONTAMINATED	N/A	N/A	RAINWATER BEGIN BEGIN FILLING MAY NECESSITATE HIGHER FLOW TO PROCESS WATER SUMP	N/A	N/A	CONDENSATE DUMPED TO SEWER AND BFW RATE INCREASES	N/A	DEMINERALIZER WATER SYSTEM DE- SIGN TO SUPPLY AN EXTRA 1000 GPM FOR UP TO 16 HRS	N/A	N/A	INCREASED BOILER DUTY CAUSES STEP CHANGE IN FUEL RATE	N/A	N/A	LARGE (1000 GPM) FLOW IN CLEAN WATER SEWER TO STORM WATER RETENTION BASIN	N/A	N/A		CONTAMINATED CONDENSATE GOES TO THE RAINWATER BASIN. THE DEMINERALIZED WATER SYSTEM CAN MAKE-UP FOR THIS LOSS FOR 16 HOURS IF THE DEMINERALIZERS ARE OPERATING.
RAW WATER FAILURE	N/A	N/A	ADJUST WATER BLOW- DOWN RATES TO AREA 43 TO LOWER RAW WATER DEMAND	LOWER EVAPORATOR FEED RATES AND HIGHER RECLAIMED WATER DEMAND	N/A	N/A	AREA DOWN	DEMINERALIZER IS SUPPLIED FROM CLEAR WATER SURGE TANK WITH ABOUT 2 HR. STORAGE	N/A UNTIL CLEAR WATER STORAGE TANK IS DRAIN DOWN (2 HR. MIN), THEN LOSE MAKE-UP WATER	N/A	N/A	N/A	LOSE MAKE-UP TO PROCESS FIRE WATER TANK. TANK HAS 2.1 MILLION GALLONS CAPACITY	N/A	N/A	N/A		MOST AREAS ARE NOT AFFECTED BECAUSE OF THE STORAGE CAPACITY OF THE CLEAR WATER STORAGE TANK (2.5 HOURS AT DESIGN RATES).
DEMINERALIZER FAILURE	N/A	N/A	WILL CREATE EXTRA REGENERANTS ON DE- MINERALIZER RESTART	N/A	N/A	STEAM SYSTEM SUP- PLIED FROM DEMINERALIZER WATER TANK (24 HR CAPACITY)	NET CLEAR WATER DEMAND DROPS BY 560 GPM	DEMINERALIZED WATER STORAGE TANK CAN SUPPLY 80 LBS FOR UP TO 24 HRS.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		DEMINERALIZED WATER TANK HOLDS 780,000 GALLONS, WHICH IS 24 HRS. DEMAND AT DESIGN RATES
LOSS OF INSTRUMENT AIR	LOSE CONTROL VALVES	LOSE CONTROL VALVES	LOSE pH CONTROL ON PROCESS WATER	N/A	LOSE PRESSURE CONTROL ON AIR COMPRESSOR K.O. DRUMS	BOILER SHUTDOWN BECAUSE OF LOSS OF CONTROL VALVE ACTION	N/A	LOSE REGENERATION VALVE CONTROL	N/A	N/A	N/A	LOSE LEVEL CONTROL ON HEAVY H.C. FLARE DRUM	N/A	N/A	N/A	N/A		NORMALLY NITROGEN IS USED AS A BACK-UP FOR INSTRUMENT AIR. N ₂ BACK-UP WAS IGNORED FOR THIS EVENT.
LOSS OF NITROGEN	N/A	N/A	N/A	N/A	THIS AREA CAUSES LOSS OF NITROGEN	N/A	N/A	N/A	N/A	LOSE N ₂ BLANKET ON TANKS AND LOSE TANK CAR UNLOADING	LOSE BLANKET GAS TO FUEL OIL TANK	N/A	N/A	N/A	NO N ₂ AVAILABLE AS INSTRUMENT AIR BACK-UP	AREA DOWN		
LOSS OF OXYGEN PLANT	N/A	N/A	N/A	N/A	UNIT IS DOWN	AIR COMPRESSORS COME OFF LINE REDUCING 1500+ STEAM DEMAND BY UP TO 110,000+ HR.	N/A	N/A	PROCESS COOLING TOWER N/A IMMEDI- ATELY. UTILITY COOL- ING TOWER DUTY DROPS OFF IMMEDIATELY	N/A	N/A	N/A	N/A	N/A	N/A	LOSE GASEOUS N ₂ MUST VAPORIZE LIQUID N ₂ FROM INVENTORY?		THE OXYGEN PLANT START-UP CAN TAKE A PERIOD OF DAYS TO WEEKS TO PRODUCE SPECIFICATION OXYGEN.

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SYSTEM EVENT		AMMONIA RECOVERY	TAR ACID RECOVERY	WASTE WATER RECLAIMING	WASTE WATER EVAPORATION	OXYGEN PLANT	STEAM SYSTEMS	RAW WATER	DEMINERALIZERS	COOLING WATER SYSTEMS	PRODUCT STORAGE AND SHIPPING	FUEL SYSTEMS	FLARE SYSTEMS	FIRE WATER SYSTEM	SEWER SYSTEMS	PLANT AND INSTRUMENT AIR	NITROGEN SYSTEM	SLAG HANDLING	REMARKS				
A-	SYSTEM COMMENTS	AREA 41	AREA 42	AREA 43 EXCEPT EVAPORATORS AND ASSOCIATED EQUIPMENT	AREA 43 WASTE WATER EVAPORATORS PLUS RECLAIMED WATER TANK AND PUMPS	AREA 44	AREA 51	ALL OF AREA 52 EXCEPT FOR THE DEMINERALIZER EQUIPMENT	THE AREA 52 DEMINERALIZER AND RELATED EQUIP- MENT	AREA 53 PROCESS COOLING TOWER: 80,730 GPM UTILITY COOLING TOWER: 33,430 GPM	AREA 54 LIQUID PRODUCT STORAGE AND SHIPPING INCLUDING HEAVY FUEL OIL	AREA 54 FUEL GAS AND FUEL OIL SYSTEMS	AREA 54 FLARE SYSTEMS	AREA 54 FIRE WATER SYSTEMS	AREA 54 SEWERS	AREA 54 INCLUDES COMPRES- SORS AND DISTRI- BUTION SYSTEM	AREA 54 INCLUDES NORMAL GAS SUPPLY AND BACK-UP LIQUID SUPPLY SYSTEMS	AREA 54	UNLESS OTHERWISE NOTED, EVENTS ARE ASSUMED TO OCCUR WHILE BOTH DISSOLVER LINES ARE RUNNING NORMALLY.				
	LOSS OF OXYGEN COMPRESSOR	N/A	N/A	N/A	N/A	N ₂ AND O ₂ VENTED TO ATMOSPHERE	1500+ STEAM DEMAND DROPS BY 170,000+ HR.	N/A	N/A	PROCESS COOLING TOWER: N/A IMMEDI- ATELY. UTILITY COOLING TOWER DROPS BY ABOUT 50.	N/A	N/A	N/A	N/A	N/A	N/A	N/A		THIS EVENT WILL SHUTDOWN THE ENTIRE PLANT UNLESS THE COMPRESSOR CAN BE RESTARTED IMMEDIATELY.				
B-	LOSE FUEL GAS SUPPLY	N/A	N/A	N/A	N/A	LOSE SYNGAS HEATER UPSTREAM OF POWER RECOVERY TURBINE ON AIR COMPRESSOR	COULD CAUSE BOILER PRESSURE SWING IF BOILER WAS FIRING. MAINLY GAS. LOSE 800+ SUPERHEATER	N/A	N/A	N/A	N/A	FUEL GAS SYSTEM DOWN - STEP IN- CREASE IN FUEL OIL USAGE	LOSE PILOTS	N/A	SHUTS DOWN INCINERATOR	N/A	N/A		THIS IS A TOTAL SYSTEM FAILURE. NOT LOSS OF ANY PARTICULAR FUEL GAS STREAM				
	LOSE FUEL OIL SUPPLY	N/A	N/A	LOSE INCINERATORS	N/A	N/A	COULD CAUSE BOILER PRESSURE SWING IF BOILER WAS FIRING MAINLY FUEL OIL	N/A	N/A	N/A	LOSE HEAVY FUEL OIL HEATER	FUEL OIL SYSTEM DOWN - STEP IN CREASE IN FUEL GAS USAGE	N/A	N/A	N/A	N/A	N/A						
C-	LOSE COAL FEED	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A						
	DEPRESSURE ONE DISSOLVER	N/A	N/A	FEED RATES AND RECLAIMED WATER DEMAND DROP OFF SLOWLY	FEED WATER RATE DROPS OFF SLOWLY	N/A	NET STEAM DEMAND DROPS OFF SOMEWHAT (ABOUT 25.)	N/A	N/A	EXPECT A TEMPORARY INCREASE IN COOLING WATER RETURN TEM- PERATURE FOR PRO- CESS COOLING TOWER	N/A	N/A	PROBABLE LARGE LOADS TO FLARES	N/A	N/A	N/A	N/A		SYSTEM RESPONSES TO THIS EVENT ARE BASED ON DEPRESSURING THE DISSOLVER THROUGH THE LETDOWN VALVES AND SEPARATORS				
D-	LOSE HYDROGEN PRODUCTION	N/A	N/A	LOSE A MAJOR PRO- CESS WATER FEED FROM GASIFIERS	N/A	O ₂ VENTED UNTIL UNIT 21 COMES BACK ON LINE	STEAM DEMAND AT ALL PRESSURE LEVELS DECREASES AS UNITS SHUTDOWN	N/A	N/A	PROCESS COOLING TOWER LOAD DROPS BY 10-15	N/A	SYNGAS NOT AVAIL- ABLE FOR FUEL GAS- MUST IMPORT GAS MAIN PLANT AREAS ARE DOWN	N/A	N/A	N/A	N/A	N/A		AREA 21 COMMENTS ARE BASED ON HAVING 3-50 GASIFIERS. FEED SURGE TANK PROVIDES 30 MIN. SURGE. NORMAL RATES AND 50% LEVEL				
	AREA 12 CRYO UNIT SHUTDOWN	N/A	N/A	N/A	N/A	WILL NEED LIQUID N ₂ TO GET RESTARTED	LOSS OF METHANE OFF GAS COMPRESSOR INCREASES LETDOWN OF H.P. STEAM TO LOWER LEVELS	N/A	N/A	N/A	N/A	N/A	RECYCLE GAS FLARED DURING AREA 12 UPSET	N/A	N/A	N/A	N/A						
E-	LOSE GAS TREATING	N/A	N/A	N/A	N/A	N/A	LOSE 9300 HP WORTH OF STEAM DRIVERS PLUS SEVERAL REBOILERS	N/A	N/A	SMALL LOAD DROP FOR PROCESS COOL- ING TOWER	N/A	N/A	LOW PRESSURE GASES FLARED DURING UPSET	N/A	N/A	N/A	N/A						
	LOSE ATMOSPHERIC REFINING	N/A	N/A	N/A	N/A	N/A	MINOR LOAD CHANGES UNLESS DISSOLVERS SHUTDOWN	N/A	N/A	N/A	LOSE PRODUCT RUNDOWN TO TANKAGE	FUEL OIL USAGE DROPS AS REBOILER SHUTS DOWN	N/A	N/A	N/A	N/A	N/A						
F-	LOSE VACUUM FLASH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A						
	LOSE SULFUR PLANTS	MUST VENT ACID GAS TO FLARE OR SHUT- DOWN	N/A	N/A	N/A	N/A	LOSE 50,000+ HR STEAM MAKE FROM WASTE HEAT BOILERS	N/A	N/A	UP TO 10% DUTY REDUCTION FOR PROCESS COOLING TOWER	N/A	SMALL REDUCTION IN FUEL DEMAND	TEMPORARY FLARING OF ACID GASES	N/A	N/A	N/A	N/A						
G-	LOSE HDS UNIT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	LOSE TREATED LIGHT FUEL OIL RUNDOWN IF HDS IS RUNNING LIGHT FUEL OIL	SMALL REDUCTION IN FUEL OIL DEMAND	N/A	N/A	N/A	N/A	N/A		ASSUMES ADEQUATE UNTREATED NAPHTHA AND LIGHT FUEL OIL STORAGE FOR SURGE DURING HDS OUTAGE.				
	LOSE AMMONIA/TAR ACID RECOVERY	UNIT DOWN	UNIT DOWN	LOSE A MAJOR PRO- CESS WATER FEED (TAR ACID EJECTOR CONDENSATE)	N/A	N/A	LOSE 800+ 250+ AND 75+ USERS	N/A	N/A	N/A	LOSE AMMONIA AND TAR ACID RUNDOWNS	N/A	N/A	N/A	N/A	N/A	N/A		ASSUMES SHORT SHUTDOWN. SHUTDOWN OF MORE THAN 4-6 HOURS WILL FILL THE SOUR WATER SURGE TANK AND CAUSE A PLANT SHUTDOWN.				
H-	LOSE WATER RECLAMATION	N/A	MUST DIVERT PRODUCT WATER ELSEWHERE	UNIT DOWN	UNIT DOWN	N/A	N/A	RAW WATER DEMANDS INCREASE IF OUTAGE IS LONG	N/A	APPROX. 10% DUTY REDUCTION FOR PROCESS COOLING TOWER	N/A	SMALL REDUCTION IN FUEL OIL DEMAND	N/A	N/A	N/A	N/A	N/A						
	NATURAL GAS CURTAILMENT	N/A	N/A	N/A	N/A	N/A	MAY AFFECT PILOTS DEPENDENT ON SOURCE OF PILOT GAS	N/A	N/A	N/A	N/A	PILOT GAS NOT AVAILABLE AND PIPE LINE GAS NOT AVAIL- ABLE AS FUEL GAS BACK-UP	LOSE PILOTS IF THEY ARE NATURAL GAS	N/A	N/A	N/A	N/A		PLANT CANNOT START-UP WITHOUT IMPORTED NATURAL GAS				
I-	LOSE SLAG HANDLING	N/A	N/A	LOSE 70 GPM VACUUM FILTRATE WATER FROM AREA 54	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A		ASSUMES SLAG WATER CAN BE DUMPED TO EMERGENCY SLAG POND DURING SLAG HANDLING SHUTDOWN				
NOTES 1 "N/A" NOT AFFECTED																							
J-																							
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SECTION 8 DATA BASE

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SECTION 8 DATA BASE

8.1 INTRODUCTION

This section describes the data base for the Phase Zero SRC-II Demonstration Plant Design (Deliverable No. 1) and the revisions which have been incorporated into the current Bridging Work. Because several changes and improvements have been made to the original Phase Zero design basis the majority of this section will be used to present the current SRC-II data base.

8.2 BACKGROUND

In 1977, Gulf initiated design work for a site specific 6700 TPSD SRC-II plant. Following selection of a plant site in April 1977, near Morgantown, West Virginia, the design coal and process yields were specified. At this time, however, process yield data on coals in the immediate vicinity of the proposed plant site were limited, since most of the experimental SRC-II work had been made with Kentucky and Illinois coals.

Under these circumstances, a Blacksville Mine Coal was selected as the most likely coal for the Demonstration Plant design because of the proximity of this coal to the plant site. Since then, several Pittsburgh Seam coals have been tested, producing a considerable amount of additional experimental data. Results from these tests demonstrated that Blacksville and other coals in the Morgantown area were less desirable feed stocks than coals from the Panhandle area of West Virginia. These coals were more reactive and produced significantly better yields. As a consequence of this testing, recent design work has been based on the more reactive Panhandle coals.

8.3 COAL DESIGN BASIS

The Phase Zero Conceptual Design was based on a Blacksville mine coal analysis. This analysis is shown in Table 8-1 and in Section 3 of the Demonstration Plant Description (Deliverable No. 1).

Having successfully identified coals with acceptable reactivity through pilot plant testing, definitive engineering work was initiated in the Bridging task effort using a revised coal analysis. The coal selected for Phase I design is representative of the West Virginia Panhandle area and has been based on analyses of several coals which have been tested at the SRC pilot plants. Thus, the revised design coal composition is based on a pool of data and pilot plant experience rather than a single coal analysis.

The current Panhandle coal compositions are shown in Table 8-2 for three coal reactivities. The design composition and high and low reactivity compositions have been selected to represent different reactivities as a result of variations in the coal feed composition.

The high and low reactivity coal compositions correspond to a high ash (14%), high iron content coal and low ash (9%), low iron content coal, respectively. These ash concentrations were selected because a minimum ash level (iron content) is required to produce good oil yields from the SRC-II process and a minimum ash level was specified to limit the solids concentration in the gasifier feed slurry to less than 50 percent. Although variations in the coal ash concentration are unavoidable, the coal washing plant and coal storage blending facilities will be used to minimize this effect.

TABLE 8-1

BLACKSVILLE FEED COAL COMPOSITION (PHASE ZERO BASIS)

<u>COMPONENT</u>	<u>Wt.% (MF BASIS)</u>
Carbon	73.2
Hydrogen	5.2
Nitrogen	1.4
Oxygen	7.2
Sulfur	
Pyrites + Sulfate	1.6
Organic	<u>1.0</u>
Total	2.6
Ash	10.4
(Iron Content)	<u>(1.4)</u>
TOTAL	100.0

TABLE 8-2

PANHANDLE FEED COAL COMPOSITION

(BRIDGING TASK BASIS)

<u>Coal Description</u>	<u>Low Reactivity</u>	<u>Design Reactivity</u>	<u>High Reactivity</u>
Coal Composition, Wt % (MF Basis)			
Carbon	73.93	70.49	67.50
Hydrogen	5.11	4.88	4.69
Nitrogen	1.22	1.12	1.32
Oxygen	7.54	7.87	8.27
Sulfur			
Pyrites	1.8	2.0	2.2
Organic	1.3	1.54	1.9
Sulfate	<u>0.07</u>	<u>0.05</u>	<u>0.05</u>
Total	3.17	3.59	4.15
Chlorine	0.03	0.05	0.07
Ash	9.0	12.0	14.0
(Iron Content)	(1.58)	(1.75)	(1.93)
 TOTAL	 <u>100.00</u>	 <u>100.00</u>	 <u>100.00</u>

8.4 DESIGN BASIS YIELDS

The Demonstration Plant is being designed for a range of process yields in order to provide sufficient flexibility for operation with coals of varying reactivity. Two yield cases, in addition to the design case, have been specified to account for changes in coal reactivity. The additional product yields include a low severity case (low hydrogen consumption) and high severity case (high hydrogen consumption). The Demonstration Plant will be designed with the capability to process variations in product yields resulting from variations in coal reactivity. These bridging task design yield distributions (low, design, and high reactivity cases) are shown in Table 8-3 and the Phase Zero design process yield distribution, a point design, is shown in Table 8-4.

A comparison of the Blacksville Coal design yield (Phase Zero) and the Panhandle Coal design yield shown in Tables 8-3 and 8-4, demonstrates the increased reactivity of the Panhandle coal. It is particularly significant to note the total oil yield increased from 33.6 percent (moisture free coal basis) to 36.0 percent (mfc basis) and the 900°F+ fraction and unconverted coal yield decreased from 33.9 percent (mfc basis) to 28.6 percent (mfc basis). Because the Panhandle coal is more reactive the hydrogen consumption also increased from approximately 4.0 percent (mfc basis) to 4.4 percent (mfc basis).

The yields shown in Table 8-3 were developed from the coal compositions presented in Table 8-2. The catalytic effect of the ash causes these yield ranges; thus, low ash coal produced relatively low oil yields and high ash coal produced relatively high oil yields. These low and high reactivity cases were developed as generalized yield distributions for low and high reactivity coals, as characterized in Table 8-2. Experimental results from the pilot plants were used to specify these yields which are representative of changes in coal reactivity over a considerable range. These yields were elementally balanced using typical product analyses to verify consistency.

TABLE 8-3

PANHANDLE COAL SRC-II YIELDS
(BRIDGING TASKS BASIS)

<u>Case Description</u>	<u>Process Yields Wt.% of MF Coal</u>		
	<u>Low Reactivity</u>	<u>Design Basis</u>	<u>High Reactivity</u>
Coal	Low Ash	Design Ash	High Ash
Hydrogen Consumption	4.0	4.4	4.7
C ₁	5.5	5.8	6.2
C ₂	3.9	4.4	4.7
C ₃	3.7	4.1	4.4
C ₄	<u>2.0</u>	<u>2.2</u>	<u>2.4</u>
Total	15.1	16.5	17.7
C ₅ - 350 F	7.3	7.9	8.2
350-550 F	16.1	17.1	17.1
550-900 F	<u>11.8</u>	<u>11.0</u>	<u>10.5</u>
Total	35.2	36.0	35.8
SRC	29.0	24.0	20.6
IOM(1)	<u>5.1</u>	<u>4.62</u>	<u>4.63</u>
Total	34.1	28.62	25.23
H ₂ O	5.8	6.2	6.6
H ₂ S	2.1	2.45	2.8
NH ₃	0.4	0.45	0.5
CO	0.2	0.08	0.05
CO ₂	1.1	1.0	0.8
Cl	0.01	0.02	0.03
Ash(2)	9.0	12.0	14.0
Residual S+Cl(2)	<u>0.99</u>	<u>1.08</u>	<u>1.19</u>
Total	10.0	13.1	15.2
TOTAL	100.0	100.0	100.0

(1) IOM - Insoluble Organic Matter

(2) Ash refers to the conventional combustion analysis rather than the mineral matter content. However, due to loss of mass during the ashing technique and chemical changes to the coal mineral matter during hydrogenation, the residual sulfur and chlorine must be included for material balance purposes.

TABLE 8-4

BLACKSVILLE COAL PROCESS YIELDS
(PHASE ZERO BASIS)

	<u>Process Yields Wt.% of MF Coal</u>
Hydrogen Consumption	4.0
C ₁	6.6
C ₂	4.2
C ₃	3.4
C ₄	<u>1.9</u>
Total	16.1
C ₅ - 350 F	6.6
350-600 F	17.6
600-900 F	<u>10.0</u>
Total	33.6
SRC	26.9
IOM(1)	<u>7.0</u>
Total	33.9
H ₂ O	5.2
H ₂ S	1.6
NH ₃	0.5
CO	0.3
CO ₂	0.9
Ash(2)	<u>12.0</u>
TOTAL	100.0

(1) IOM - Insoluble Organic Matter

(2) Ash refers to hydrogenated mineral matter.

8.5 PROCESS VARIABLES AND CONDITIONS

There are five primary independent variables which affect the yields from the SRC-II process. Those variables are:

- Dissolver Temperature
- Dissolver Slurry Space Velocity
- Dissolver Outlet Hydrogen Partial Pressure
- Coal Concentration
- Coal Slurry Ash Concentration

For a particular coal, the values of these variables determine the product yields.

These design conditions have been determined by pilot plant experimentation and design analysis to produce acceptable conversion levels for the design Panhandle coals shown in Table 8-2 and are conditions at which commercial size vessels and equipment can be designed and operated. The design temperature and pressure specified for the dissolver for the above operation conditions are 900°F and 2200 psia, respectively.

8.6 PRODUCT SPECIFICATIONS

Product specifications have not yet been finalized. Product specifications when set must recognize the limitations and differences in the Demonstration Plant when compared to the inspections of product produced in the pilot facilities. In addition, product specifications must be as broad as the end-use and handling will permit to maximize the operating and design flexibility in the coal liquefaction plant to produce saleable product.

The following table shows typical properties for naphtha (C₅- 350 F) and fuel oil distillate produced at the Ft. Lewis Pilot Plant.

	<u>Naphtha</u>	<u>Fuel Oil</u>
Gravity, Sp. Gr.	0.84	.992
Viscosity, CST @ 100 F	0.929	4.05
Flash Point, F	<50.0	173.0
Pour Point, F	--	-55.0
Ash, wt. %	--	0.04
Sulfur, wt. %	0.18	0.24
Nitrogen, wt. %	0.66	0.97
Oxygen (by difference), wt. %	2.28	4.10
Hydrogen, wt. %	12.42	8.74
Carbon, wt. %	84.46	85.91

The raw naphtha can be hydrodesulfurized and reformed into high octane gasoline as discussed in Deliverable 9, Volumes 1 and 8.

Bridging task design efforts are directed toward producing products which meet Petroleum, Gas Processors and Chemical Industry Requirements, as appropriate. Product specifications for these industries are outlined in Table 8-5.

8.7 EXPERIMENTAL DATA

Three test facilities have been used to develop data for the SRC process. These facilities include the 25 lb/day bench scale unit at Gulf's research facilities in Merriam, Kansas where initial investigations were begun in 1962; the developmental plant at Ft. Lewis near Tacoma, Washington which was designed for 50 ton/day SRC-I, started SRC-I operation in 1974, modified for SRC-II operation at 30 ton/day in 1977, and since then has operated about 62 percent of the time in the SRC-II mode and 38 percent in the SRC-I mode; one-half ton per day pilot unit located at Gulf Research and Development Company, which was designed in accordance with the SRC-II Demonstration Plant conceptual design as then conceived, was started in 1977. It is this plant which has confirmed the design basis summarized in Tables 8-2 and 8-3 and provides the primary source of material balance data.

Four Pittsburgh Seam Coals have been tested during the design confirmation pilot plant runs. Three of these coals were from the Panhandle region of West Virginia (and Ohio) and one from an area located between the Panhandle region and the plant site. All of the coals from the Panhandle region produced good yields at the design conditions; the fourth coal produced marginally satisfactory yields. Future work is planned to include tests using blends of coals from the Panhandle region and plant site area.

Approximately 500 SRC-I and SRC-II pilot runs have been made at the three pilot plants. Over 200 of these test runs have been completed in SRC-II operation and approximately 100 test runs have been completed using Pittsburgh Seam Coal. This substantial data base is indicative of the effort which has been made to develop the SRC-II process.

The following ranges of process conditions have been investigated at the pilot plants.

Dissolver Temperature (°F)	830-900
Dissolver Pressure (psia)	1000-2500
Coal Concentration (% of feed)	20-45
Dissolver Space Velocity (hr ⁻¹)	.7-30
Recycle Ash Concentration (% of dissolver feed)	0-12

TABLE 8-5

PETROLEUM, GAS PROCESSORS, AND CHEMICAL INDUSTRY SPECIFICATIONS

No. 6 FUEL OIL ⁽¹⁾		
Water & Sedimentation, ASTM D-95	2%	
Solids, ASTM D-473	0.5%	
Viscosity @122 F, Furol Sec.	300 Max. ⁽²⁾	
Flash Point, F	150 Min.	
	COMMERCIAL PROPANE ⁽³⁾	COMMERCIAL BUTANE ⁽⁴⁾
Vapor Press. @100 F, psig	208 Max.	70 Max.
Volatile Residue 95% Evap., F, ASTM D-1837	-37 Max. 2.5% C ₄₊ Max.	36 Max. 2% C ₅₋ Max.
Residual Matter ASTM D-2158	0.05 ml Max. Pass	- -
Corrosion, Cu Strip, ASTM D-1838	1 Max.	1 Max.
Volatile Sulfur, grs/100 cf, ASTM D-2784	15 Max.	15 Max.
Moisture Content, ASTM D-2713	Pass	- -
Free Water	- -	None
	SULFUR ⁽⁴⁾	ANHYDROUS AMMONIA ⁽⁴⁾
Purity %	99.90 Min.	99.5 Min
Moisture %	0.10 Max	0.5 Max
Organic Impurities %	0.02 Max.	10 ppm Max.
Ash %	0.01 Max.	- -

(1) ASTM - 396 (Industry Standard for No. 6 Fuel Oil).

(2) Viscosity will be less than minimum No. 6 Fuel Oil Specification.

(3) Gas Processors Association.

(4) Conforms to Chemical Industry Standards.

By analyzing the yield results over these ranges of conditions the design conditions shown in Section 8.5 were chosen. The selection criteria included consideration of many factors such as product yield distribution, product physical properties and compositions, process thermal efficiency, operability, environmental impacts, and potential product markets. The primary consideration, however, was to maximize oil yields subject to mechanical, process, and economic constraints.

A majority of the recent experimental tests have been made at conditions relatively close to the design conditions. This has been done for the following reasons: 1) yield data for small changes in process conditions around the design point has been stressed; 2) several Pittsburgh Seam Coals have been evaluated to study the effect of potential feedstocks; 3) testing at conditions outside of current feasibility for the Demonstration Plant due to process and mechanical considerations was discouraged; and 4) limitations of existing pilot plants or commitments of pilot plant facilities were made to develop other data. Even though much of the recent experimental work has been made over a fairly limited range of conditions, these conditions are close to the maximum feasible severity because of process requirements, mechanical limitations, or practical considerations. A discussion of these process variable limitations follows:

Dissolver Temperature (design basis: 860°F)

The dissolver temperature is near the practical limit for vessel design. Increases in this temperature would result in a significant drop in the allowable stress for the base metal. This would require a reduction of either the internal pressure or vessel diameter in order to keep the required thickness below 12 inches, which is the maximum available material thickness. Higher reactor temperatures would also increase the possibility of coking in the dissolver. Temperatures more than 20 or 30 degrees below the design point have been shown experimentally to significantly decrease the reaction rate, thus interest in lower temperature has been minimal.

Reactor Pressure (design basis: 2000 psia)

The dissolver operating pressure is currently constrained at approximately 2000 psia for two reasons. Pressures above 2000 psia would exceed the dissolver allowable operating limits for hydrogen partial pressure because of hydrogen embrittlement (Nelson curves) unless the dissolver temperature is decreased and secondly the present dissolver diameter is limited because of available thickness (max. of 12 inches) and allowable stresses. Designs for pressures above 2000 psia would require smaller vessel diameters and, hence, more dissolvers or higher allowable stresses.

Increasing the pressure, without other compensations, would be expected to adversely affect the capital and operating costs, mechanical reliability, and thermal efficiency. Consequently, pressures above 2500 psi have not been explored. Lower pressure has been found experimentally to produce poorer yields.

Coal Concentration (design basis: 30%)

The maximum coal concentration is constrained by the total solids content of the feed slurry and the viscosity of the feed slurry. Yields can be improved by lowering the coal concentration and increasing the solids content of the coal slurry; however, the low coal concentrations are economically unattractive and recirculating more solids through the dissolver high pressure system increases corrosion-erosion. Even if the coal throughput was increased so that the same "size" plant could be used at lower coal concentrations, the thermal efficiency would be reduced and slurry erosion would be increased to undesirable levels.

As the coal concentration is increased above 30 percent, the slurry becomes more difficult to blend and pump and at some limit the recycle slurry (and hence recycle ash) must be reduced to be replaced with additional solvent. Depending upon the feed slurry and solvent ratio and dissolver conditions the maximum solids concentrations are limited to approximately 40 percent to 50 percent.

Coal Slurry Ash Concentration

The concentration of recycle solids (mineral matter) in the coal feed slurry is determined by the amount of ash in the feed coal, conversion severity, and recycle slurry flow rates. Increasing the recycle ash concentration improves the conversion due to catalytic species in the coal mineral matter. As the solids level is increased, however, the feed slurry becomes more difficult to mix and pump because of increasing solids concentrations and increasing concentrations of high boiling fraction material (SRC) resulting in high slurry viscosities. Finally, high recycle slurry rates increase corrosion-erosion, particularly for the slurry letdown valves.

Current pilot plant experience has been limited to a maximum concentration of approximately 10-12 percent recycle ash in the coal feed slurry.

Dissolver Space Velocity

The process yield distribution and dissolver vessel size considerations are the primary factors determining the design space velocity. The SRC process has been operated over a relatively large range of space velocities. At high space velocities, above approximately 1.5 hr^{-1} , the conversion to oil is poor. At low space velocities the conversion to oil increases but the gas yields become very large. Because of metallurgical constraints, the number of reactors must be increased if space velocity is lowered for the Demonstration Plant.

8.8 PROCESS YIELD MODELS

As described in previous sections, a substantial amount of yield data has been produced at the pilot plants in developing the SRC process. Several coals and a wide range of conditions have been evaluated at these facilities. Because many of these tests were made by changing more than one primary process variable at a time, an explanation of the results is not always obvious. By application of a regression analysis technique these data can be more effectively evaluated.

A computer algorithm was utilized to perform a linear regression of a data set of 78 experiments using the five primary independent process variables. Results from this model showed that as much as 94 percent of the data variance could be explained by the model.

The following Table 8-6 summarizes the model predicted effect of changes in five operating conditions for four product yields. The changes shown are changes about the design point.

Another model incorporating second order effects has recently been completed. Work is now in progress to combine data bases from different coals in order to formulate a general operating variable-yield prediction model. Results from these models are being used to develop a hydrodynamic-kinetic model for predicting reactor behavior and scale-up and are discussed below.

TABLE 8-6
EFFECT OF CHANGES IN PRIMARY PROCESS VARIABLES ON YIELDS*

PROCESS VARIABLE CHANGE					
Product	Hydrogen Partial Pressure	Temperature	Residence Time	Coal Conc.	Ash Conc.
Yield	+	+	+	+	+
Hydrogen Consumption		+	+		+
Hydrocarb. Gas (C ₁ -C ₄)		+	+	-	+
Total Oil (C ₅ -850 F)	+	+	+	-	+
SRC + Un- Converted					
Coal	-	-	-	+	-

*An increase in the process variable or yield response is shown as + and decrease is shown as -.

8.9 DISSOLVER MODELING AND SCALE-UP

Data from the existing SRC-II pilot plants, dissolver modeling and simulation studies, and experience from refining processes have been developed to establish a reasonable basis for scaling the SRC-II dissolver. The risk associated with scale-ups greater than 10 to 100 are usually considerable; however, complete elimination of all process uncertainties is not possible and each scale-up is unique and largely a matter of judgment based on the previous scale-ups.

Neglecting mechanical problems, which are discussed elsewhere, the primary process concerns associated with the dissolver scale-up involve the liquefaction chemistry and fluid dynamics. These kinetic and hydrodynamic system interactions determine the reactor effluent compositions and process stability. In order to scale the dissolver system, an assurance must be established that the dissolver yields are predictable, the liquefaction processes are controllable, and the unit can be operated for long periods of time.

SRC-II process experimentation is being conducted at three pilot facilities: the Merriam laboratory pilot unit, the GS&TC's process development unit, P-99, and the Ft. Lewis pilot plant. The nominal coal charge rates for these pilot plants are: .01 ton/day, 1/2 ton/day, and 30 ton/day, respectively. The corresponding dissolver volumes vary from approximately 0.037 ft³ to 1.8 ft³ to 92 ft³. These represent scale-up factors of 49 and 51, respectively, with an overall scaling factor of approximately 2500. The successful scale-up and operation of the pilot units has indicated that the SRC-II dissolver yields are predictable and controllable. The Demonstration Plant dissolver volume is over 200 times as large as the Ft. Lewis Pilot Plant dissolver.

Statistical analysis of the process yield data from the pilot plants has not conclusively shown an effect of scale. Inspection of the data from the three pilot plants has shown that the yields of gas, total oil, and SRC are approximately equal at similar operating conditions. So far, it has not been

possible to separate the normally small differences in the pilot unit yields from the differences in operating conditions and coal compositions; as more data is collected, it is expected a better determination of the effect, if any, of scale-up will be possible.

Pilot plant operating experience has demonstrated that the SRC-II liquefaction process is stable and controllable. No incidents of runaway reactions have been recorded at any of the pilot plants, including periods of power outages, start-ups and shut-downs, and erratic operation caused by poor inlet feed temperature control or system pressure, during the operating history of those plants.

In order to develop a fundamental approach to the problem of dissolver scale-up, GMRC initiated a project to provide a comprehensive mathematical model of the SRC-II dissolver system. The model includes an extensive kinetic treatment consistent with the available data and is coupled with the hydrodynamic effects of a three-phase upflow fluidized bed dissolver. As a result of computer simulations, the model has the capability of providing important impacts on (1) the scale-up to commercial-sized reactors, (2) the development of reactor performance information, (3) the understanding of the coal liquefaction process, and (4) the optimization of the operating conditions for the reactor system.

The comprehensive reactor model has been used to consider the effects of variations in holdups of the three phases as a function of reactor length, differences in backmixing of the three phases, and complex reaction mechanisms for the liquefaction process. This model provides a reasonable simulation method by which actual data can be extended to represent the behavior of larger reactors and predict the dissolver performance outside and within the data base. In addition to incorporating the primary reaction variables, the model also includes scale-up variables such as gas and slurry velocities and reactor dimensions.

Results from the simulation model do not indicate any significant yield differences are expected with the demonstration plant dissolvers. Preliminary results show that the gas hold up volume may increase approximately 10 percent. Backmixing behavior of the gas and slurry phases are not expected to change as a result of scale-up. As a means of testing the model predictions, additional pilot plant tests are planned to study the effect of different dissolver configurations. The model indicates the dissolver will perform as a stirred tank reactor. As the dissolver is scaled-up, the importance of L over D ratio may increase and the stirred tank concept may be reduced for large diameters; if so, internal distributors could be required.

It has been assumed almost without exception that upflow is the desired mode for dissolver operation. As a result of Bridging task design efforts distinct benefits for operation of large dissolvers in a down flow configuration have been identified, particularly for startup and emergency situations. These benefits include: (1) elimination of solids build-up in the bottom of the dissolver, (2) improved separation of high temperature vapor and slurry, (3) simplification and reduction of the dissolver outlet piping size and expansion loops, (4) methods for operating the dissolver with variable slurry retention times by varying the liquid level; this could be important for startup and shutdown situations, (5) a more reliable method for blowdown of the reactor contents under emergency situations, and (6) changes in the inlet and outlet piping configurations to reduce the possibility of slug flow. Based on previous bench scale tests and recent modeling efforts, downflow operations should be evaluated at the P-99 pilot unit.

8.10 SRC-II PHYSICAL PROPERTIES DATA BOOK

One of the functions of the SRC pilot plants has been to develop physical and thermodynamic data for coal derived liquids in order to provide a sound data base for the demonstration plant process design. Each of the SRC pilot facilities has been utilized in this effort to measure and correlate properties of coal derived liquids. Data from the pilot plants has been integrated and the research coordinated so that results are available to each of the pilot plants and the process design team.

As a result of the pilot plant experimental programs, a fairly extensive data base has been generated and compiled. To date, correlations have been established for such properties as: density, heat capacity, thermal conductivity, surface tension, and viscosity. These and other data have been assembled in an SRC-II Properties Data Book and used in the design of the demonstration plant. The Properties Data Book has recently been updated and re-issued.

Concurrent with the development of laboratory data, a general process design computer program at Gulf Research and Development Company has been used for predicting thermodynamic properties and calculating vapor-liquid equilibrium flashes. This program, which was originally used for petroleum fractions, was modified for coal liquids using pilot plant data. Results from these complex equations of state have been used to make material balance and heat balance calculations for the demonstration plant design and will be used to establish a firm design specification for the SRC-II process. Gaps in the physical thermodynamic properties data base have been identified and programs are in progress to provide the additional needed process data. Additional details concerning future work to improve the data base are discussed below.

8.11 DATA REQUIREMENTS

As the demonstration plant process design work progresses, more physical, thermodynamic, and process data are needed for each plant area and stream. Most of the current data base has been developed in the pilot plant operations, primarily in the dissolver area of the process. Due to differences between the demonstration plant and pilot plant configurations and the presence of several supporting processes in the demonstration plant which do not exist in the pilot plants, additional data are required. Because of these data needs, we are now unable to provide Stearns-Roger the final firm design basis that they require to prepare a definitive schedule for mechanical completion of the SRC-II Demonstration Plant in 1983.

8.11.1 Scale-Up and Process Verification

A common industry practice is to precede the first commercial application of a new process with successful operation of one pilot plant production above bench scale size and at least one more reproduction on a larger scale unit of all important processing operations. This approach has not been fully utilized in developing the SRC-II pilot plant program. Although the SRC-II process has been operated at the 25 lb/day Merriam Bench Scale Unit, the 1/2 ton/day Gulf Science and Technology P-99 Unit and the 30 ton/day Ft. Lewis Pilot Plant, some of the SRC-II process area steps have not been tested at all of the pilot facilities.

Successful operation and verification of process yields from the three pilot facilities has substantiated the dissolver design. However, some other process operations that are present in the Demonstration Plant have not been demonstrated at Ft. Lewis, including energy efficient slurry blending, severe preheater operation, high temperature heat recovery, specific conditions of high pressure gas-liquid separation, high temperature slurry pressure let-down, vacuum flashing without feed preheat, vacuum bottoms pumping to high pressure, and integrated vacuum bottoms gasification. These process operations have not been tested because the Ft. Lewis plant was originally

designed and operated as a 50 ton/day SRC-I plant and was later modified at minimum cost for the 30 ton/day SRC-II operation. Equipment necessary for SRC-II reaction area studies was included in the modification, but little emphasis was placed on energy efficient downstream equipment that is needed in a Demonstration Plant.

If Ft. Lewis is to continue as an effective tool in the development and improvement of the SRC-II technology, modifications are necessary so that critical SRC-II processing steps will be verified prior to operation of the Demonstration Plant. Progress has been made to confirm the design of some critical processes at the Ft. Lewis Pilot Plant, e.g., a new preheater has been designed and installed and will be operated in the near future, and a vacuum bottoms pumping test loop is now being designed. Other process operations should also be verified prior to fabrication of the Demonstration Plant equipment. The following critical process steps should be tested at the Ft. Lewis Pilot Plant.

- (1) Install and operate a coal slurry mix system similar to the Demonstration Plant design.
- (2) Install and operate a high pressure and low pressure separation system and a slurry pressure let-down system similar to the Demonstration Plant design.
- (3) Install and operate a vacuum separation system similar to the Demonstration Plant design.

These three steps cannot be accomplished prior to specification of the final design basis for the Demonstration Plant; however, information should be obtained in sufficient time to confirm equipment selection or to allow incorporation of more efficient processing steps prior to completion of Demonstration Plant construction.

In order to ensure that the data for these three items are collected in a timely and efficient manner and coordinated effectively with the design and construction of the Demonstration Plant, schedules employing critical path technique will be developed and utilized.

8.11.2 SRC-II Specific Data Requirements

In order to complete the definitive design of the Demonstration Plant and to provide a safe, reliable process, the following data needs to be expanded or developed.

- (1) Viscosity relations for dissolver feed slurry.
- (2) Characterization of foaming tendencies in the slurry mixing system.
- (3) Viscosity relationships and heat transfer data for the dissolver preheater.
- (4) Identification of coking conditions in the slurry preheater dissolver, and vapor-liquid separation system.
- (5) Data to support model simulation of solid and gas holdups in the dissolver.
- (6) Verification of liquefaction heats of reaction.
- (7) Determination of process yields as a function of operating conditions and stream compositions during startup.
- (8) Viscosity of dissolver separator vapor.
- (9) Estimation of dissolver separator entrainment.
- (10) Erosion rate of dissolver effluent piping as a function of velocity.
- (11) Additional erosion-corrosion data for all high temperature streams, sour waters, and slurries.
- (12) Recycle slurry viscosity.
- (13) Film side heat transfer coefficients for dissolver separator vapor.
- (14) Identification of conditions which cause salt deposition.
- (15) High pressure acid gas-water equilibrium data.
- (16) Specification of types and amounts of coal chemicals.
- (17) Identification of certain trace components in the recycle hydrogen stream.
- (18) Determination of sour water pH, concentrations of polar molecules, phenols, coal chemicals, and certain trace impurities.
- (19) Thermal conductivity data for recycle slurry.

- (20) Surface tension of fractionation products.
- (21) Particle size and settling characteristics of recycle slurry.
- (22) Vacuum flash vapor-liquid equilibrium data.
- (23) Viscosity of vacuum bottoms.
- (24) Chemical and physical properties of gasifier slag.
- (25) Gasifier slag leaching data.
- (26) Gasifier water analyses.

Considerable technical support work is currently underway to develop the above data. Plans call for completion of the work in time to meet the Demonstration plant design schedule requirements for all important information.

1.11.3 SRC-II Design Basis

Gulf Science and Technology Company is developing a complete process design specification for the reaction area of the SRC-II process utilizing a general process computer program, which was originally developed for Petroleum Desulfurization and Hydrocracking Processes, and has been modified for application to the SRC-II process. This design specification will include all of the process information and design bases necessary for completing a definitive engineering design of a 6700 TPSD SRC-II process including: coal specifications, yield specifications, product properties, process configuration and operating conditions (including a PFD), material and heat balances, thermodynamic and physical property data, critical equipment and vessel specifications, and materials specifications. This design specification should be available for the Phase I design activities and will incorporate design work finished during the Bridging task efforts. As a result, this specification will finalize the Phase I design criteria.

SECTION 9

TRADE OFF STUDIES

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SECTION 9

TRADE-OFF STUDIES

This section provides a summary discussion of major process trade-off and technical uncertainty studies performed since the start of the original Demonstration Plant conceptual design in early 1975. (Refer to Deliverable No. 1, Demonstration Plant Description - Section 1.3 Background Information.)

These major trade-off studies cover four specific periods of time as follows:

- (1) Major trade-off studies utilized in setting the original conceptual design process configuration.
- (2) Major trade-off studies performed from early 1976 to April 1977 to improve the original conceptual design.
- (3) Major trade-off studies made from July 1978 to February 1979 during Phase Zero and until the start of bridging in February 1979.
- (4) Major trade-off bridging studies made since February 1979.

Each of the four categories is broken down and studies performed are briefly discussed as follows:

9.1 MAJOR TRADE-OFF STUDIES UTILIZED IN SETTING THE ORIGINAL CONCEPTUAL DESIGN PROCESS CONFIGURATION

9.1.1 Hydrogen Production

For syngas hydrogen production (gasification system), an extensive analysis was made by Stearns-Roger in early 1975. Alternates studied include:

- (a) Koppers-Totzek low pressure gasification: using vacuum bottoms slurry as feed.

- (b) Steam-Hydrocarbon catalytic reformers: using both naphtha and light hydrocarbon as feed water vacuum bottoms slurry was burned in a power plant boiler for production of electricity.
- (c) Babcock and Wilcox gasifiers, both low and high pressure types: using vacuum bottoms slurry as feed.
- (d) Texaco partial oxidation gasifier: using vacuum bottoms slurry as feed.

Partial oxidation of the heavy residual hydrocarbon containing ash, called vacuum bottoms slurry, was adopted as a simpler and ultimately more operable alternative. Furthermore, partial oxidation of this difficult stream was more acceptable from an environmental standpoint. After detailed review, Gulf selected the Texaco process for further study. It is considered the more desirable from the standpoint of efficiency and proven experience at the desired operating pressure.

9.1.2 Recycle Hydrogen Purification

It was desirable to operate the SRC-II Process at a pressure as low as economically feasible and still maintain a reasonable dissolver hydrogen partial pressure (a key process variable). The process produces a large quantity of light hydrocarbons (methane and heavier) which dilute the dissolver effluent gas stream. After considering absorption and pressure-swing-adsorption, it was decided that cryogenic separation was the only reasonable process step for removal and recovery of the main diluents. This cryogenic step could produce a recycle hydrogen stream of high purity which permitted an acceptable hydrogen partial pressure at reasonable system total pressure.

The cryogenic system is prototype from the standpoint of different feed gas and higher system pressure than previously used. However, at present it is the only reasonable approach to this specific process requirement.

9.1.3 Sulfur Resistant Shift Conversion

For Syngas Shift Conversion, the BASF facility at Ludwigshafen, Germany was considered to be similar enough to the original design requirement to provide a background of successful operation. The Texaco gasifier at Ludwigshafen used a heavy oil feed to produce syngas at high pressure. For the original conceptual design, preliminary process information was obtained from BASF, using their catalyst, which is suitable for high pressure operation in the presence of sulfur. Other catalysts considered at the time did not have this capability. The feed gas to the water-gas shift conversion is adjusted to the required steam content in the syngas production system.

Reaction of steam with CO to make hydrogen reduces CO to about 2 percent, a feasible concentration in dry purified syngas.

High system pressure for shift-conversion allows economical heat recovery within the process by generating steam in waste heat boilers.

Further investigations determined that Haldor-Topsoe, in partnership with Exxon Research and Engineering, had developed a shift catalyst suitable for high pressure operation in the presence of sulfur compounds. For the 1977 Demonstration Plant Conceptual Design more detailed process design information was prepared by Haldor-Topsoe. The processing method and conditions are generally similar to the original design.

9.2 MAJOR TRADE-OFF STUDIES PERFORMED FROM EARLY 1976 TO APRIL 1977 TO IMPROVE THE ORIGINAL CONCEPTUAL DESIGN

9.2.1 Oxygen Compression Study

The basis for this study was the 1700 T/D oxygen requirement for the original Demonstration Plant Conceptual Design.

Three manufacturers of large compression equipment were contacted to determine availability of equipment for this service. The combination of capacity and final discharge pressure in the oxygen service was found to be prototype. Machines with the volume handling capacity had been designed to a pressure level of 950 PSI, and two of the manufacturers had designed machines for oxygen service that would meet about two thirds of the required capacity. The other had a design to meet the capacity but a prototype third stage was required to reach design discharge pressure of 1600 PSI. One vendor proposed a combination of a two stage centrifugal machine and two 50 percent reciprocating machines to do the service without using prototype equipment. Enough information is now available for preparation of firm design specifications and solicit firm quotations for the compressor service.

9.2.2 High Pressure Steam Generation

This system was designed to recover high temperature waste heat from the dissolver separator vapor stream and contains three heat exchangers in series. The steam generator is placed first in the series because a variable amount of heat can be removed without causing a large change in process-side outlet temperature. Recycle hydrogen is heated in the two subsequent exchangers.

Because of liquid carryover in the separator vapor stream and because this liquid contains solids, the system is a "first of a kind". The concept for the process-side flow interconnects the exchangers so the flow is continuous, single pass downflow. Heat transfer and mechanical considerations were studied in detail. Design studies have continued and improvements will continue to be pursued.

9.2.3 Treating of Hydrogen Makeup Stream

The purpose of this study was to prepare a design and cost estimate for alternate methods to purify the hydrogen makeup stream and systems for recovery of product sulfur from the H_2S gas from the gas purification steps.

The original Demonstration Plant Conceptual Design used the Selexol Process to selectively extract hydrogen sulfide and carbon dioxide from the makeup hydrogen stream. Hydrogen sulfide was converted to sulfur in a Claus Unit. A SCOT Tail Gas Unit was designated to reduce sulfur content of the incinerator effluent to an environmentally acceptable level.

This study and the present Demonstration Plant Conceptual Design are based on using the Benfield Process to remove total acid gas from the makeup hydrogen stream. This acid gas stream is treated in a selective SCOT/ADIP Process followed by a Claus Unit to convert the hydrogen sulfide portion to sulfur.

The economics developed using Illinois coal indicated that the Benfield, SCOT/ADIP, Claus Train should be used.

Further studies during bridging on both process and utility systems for overall plant indicate the Selexol Process may be more favorable for the present design.

9.3 MAJOR TRADE-OFF STUDIES MADE FROM JULY, 1978 TO FEBRUARY, 1979
DURING PHASE O AND UNTIL THE START OF BRIDGING IN FEBRUARY, 1979

9.3.1 Vacuum Bottoms Slurry Boiler Study

This study addressed an alternate to the Texaco Partial Oxidation Process for disposing of vacuum bottoms slurry produced in the vacuum tower. It proposes that a power boiler be fired with vacuum bottoms slurry to produce steam and drive an electrical generator. Approximately 250 megawatts of power would be generated. The boiler would of course be equipped with Flue Gas Desulfurization which is much better developed now than in 1975 when considered previously.

Hydrogen for the dissolver would be produced by steam reforming of the light hydrocarbon streams produced in the plant.

Results of the study indicate that the investment cost would probably be 15 to 20 percent higher, and the thermal efficiency would be approximately equal to the present Demonstration Plant Conceptual Design, Deliverable No. 1.

9.3.2 Low-Pressure Gasification

This study compares the economics of a low pressure commercial gasification process with the elevated pressure Texaco Gasification Process. The main points of comparison were thermal efficiency, capital costs, and operating reliability.

Results of the study indicate that the low-pressure process would result in an overall plant thermal efficiency loss of about 3 percent when compared to the present conceptual design. Overall plant investment cost is indicated

to be about 10 percent higher than the present conceptual design. Although operating reliability should be better for the low-pressure process, the poorer thermal efficiency is undesirable.

9.4 MAJOR TRADE-OFF BRIDGING STUDIES MADE AFTER FEBRUARY, 1979

9.4.1 Lower Pressure Gasifier (600 to 800 psi)

Because the Department of Energy indicated a separate study of this change in pressure was in progress, this study was not made.

9.4.2 Naphtha Production

This study was based on the need to remove excess syngas as feed to the methanation process. The basic purpose of this change is to reduce complexity of methanation. To accomplish this change, it was necessary to alter priority of plant fuel from that shown in the present Demonstration Plant Design. The present design is based on using desulfurized naphtha and syngas as plant fuel components. This naphtha study is based on using syngas and butane as fuel with desulfurized naphtha as a balancing fuel component. This means upgrading as well as desulfurizing the naphtha. Thus the naphtha hydrodesulfurizer severity will be increased so as to permit sale of the product to gasoline producers for use in motor fuel.

9.4.3 Production of Clean Fuel Oil

Continuing studies and improvements to the fractionation system have resolved the need for this trade-off study. (Refer to Deliverable No. 1 Demonstration Plant Description - Section 6.5.)

9.4.4 Alternate Scheme for Purifying Makeup Hydrogen

After considering the high energy consumption for the present Demonstration Plant Design, an extensive study was made to compare the Selexol Process and the Benfield-Super SCOT system. This study indicates a considerable advantage for Selexol, particularly in energy savings.

9.4.5 Alternate System for Producing Hydrogen

In early 1977, preliminary studies were initiated to determine an alternate process scheme to produce plant hydrogen requirements. This study was terminated at an early date because the conceptual design for Blacksville coal

was given top priority. The basis for this alternate scheme was to replace shift-conversion with a combination of hydrogen-carbon monoxide separation and reforming of light hydrocarbons. Approximately 60 percent of H_2 requirements would be made from separation of H_2 in the syngas with the remainder made from reforming light hydrocarbons.

This study was based on continuing the earlier work. In this case, a preliminary heat balance was made and no significant improvement in overall thermal efficiency was found. Also, waste heat recovery from the gasifier is a major requirement for the alternate scheme and discussions with gasifier licensors indicated this heat recovery could not be accomplished with present technology and with project schedule time period. Because of these negative facts, the study was not pursued.

In addition to the above major trade-off bridging studies, additional studies are in progress and as detail design is developed, others will be added. For definition of some of these general type studies, reference is made to Deliverable No. 1, Demonstration Plant Description, Section 1.4 - Bridging.

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SECTION 10

CONFIDENCE ANALYSIS

10.1 PLANT OPERATING AND CAPITAL COSTS

The Capital Cost estimate accuracy and reliability are presented in Section 2.7 of Deliverable No. 2, Demonstration Plant Capital and Operating Costs; also the economic evaluation in Volume 3, Deliverable No. 12, Appendix B - Project Baseline Plans, contains sensitivity analyses as regards capital and operating costs.

Appendix A of Deliverable No. 2 is a study, made by Bechtel Incorporated, to provide a third party confirmation of the preliminary capital cost estimate by Stearns-Roger for the design and construction of the Demonstration Plant. As indicated by Deliverable No. 2 cost estimates, Bechtel confirmed Stearns-Roger's cost estimate.

10.2 PLANT OPERABILITY AND TECHNICAL RISK

P & M is having separate risk analyses made for Plant Operability and for Technical Risk. These will be provided to DOE as soon as possible.