Appendix C

Design Hazard Review: DSRP Bench Unit

Design Hazard Review

SLIPSTREAM PILOT TEST UNITS FOR
DIRECT SULFUR RECOVERY PROCESS
AND ADVANCED HOT GAS PROCESS

Design:

Research Triangle Institute
Center for Engineering and Environmental Technology
Process Research Program
3040 Cornwallis Road
Research Triangle Park, NC 27709

Sponsor:

U.S. Department of Energy
National Energy Technology Laboratory
3610 Collins Ferry Road
Morgantown, WV 26505

August 2000

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TABLES AND ATTACHMENTS

APPENDICES

Summary:

A design hazard review (DHR) was conducted at the Research Triangle Institute (RTI), Research Triangle Park, North Carolina, from July 31, 2000 through August 8, 2000.

The review was conducted using piping and instrumentation drawings (P&ID) for two process test units at various stages of modifications. The slipstream test units designed by RTI consist of a direct sulfur recovery process (DSRP) pilot test unit and an advanced hot gas process (AHGP) bench test unit. The process test units were redesigned for field slipstream testing to be integrated with the operation of the Kellogg Brown & Root (KBR) gasification test unit located at the Southern Company Services (SCS) power system development facility (PSDF) in Wilsonville, Alabama.

For reference, an overview of the two hot-gas desulfurization processes is described in Appendix A. The development of these processes are being directed and sponsored by the U.S. Department of Energy (DOE), National Energy Technology Laboratory, Morgantown, West Virginia.

This report summarizes the results of DHR and includes the following reference documents:

- DHR Work Sheets - Appendix I
- Reference P&IDs - Appendix II
- Process Description - Appendix A

Meeting Objectives and Review Documents:

The objectives, assumptions, and constraints for the review sessions are identified in Table I. The P&IDs developed by RTI for the DSRP Pilot test unit and AHGP bench units were the primary review documents. Table II lists the P&IDs subjected to the review. Other reference documents were required in support of review and these are listed in Table III.

TABLE I - MEETING OUTLINE

Meeting Objectives:

- Identify safety and operability hazards during the review of P&IDs and team discussions and develop recommendations for project implementation.
- Develop recommendations for any identified deviations that could significantly affect operability.

Assumptions:

- Design is finalized and necessary design reviews have been completed.

Constraints:

- Review team will refrain from redesign efforts at the meeting and will limit discussions to meet the review meeting objectives.

TABLE II – REVIEW DRAWINGS

Drawing No.	Title	Revision
	DSRP Field Test Pilot Unit	
PID-0010	SIM ROG System	F
PID-0011	Filters and Reactor	H
PID-0012	Sulfur Collection	H
PID-0013	Analytical	H
	AHGP Field Test Bench Unit	
PID-0014	Feed Gases and Preheaters	E
PID-0015	Reactor and Product Recovery	D
PID-0016	Analytical	C
	PSDF Field Test	
PID-0017	SCS-RTI Interface	F
PID-0018	LSO_2 Delivery System	D
PID-0020	Instrument Air	

TABLE III – REFERENCE DRAWINGS

Drawing No.	Title	Revision
Sketch BER 02/11/00	SCS Piping for RTI's DSRP/AHGP Process	02/08/00
E-M-D0002	PSDF General Arrangement Plant Site	O
DSRP RTR 1	Design & Assembly R-101, R-201, and R-211	A
V-188	V-188 Sulfur Canister	A
V-150	Sulfur Separator Pot	G
HX-140	Sulfur Condenser	E
R-130	DSRP Reactor	G
HTR-131	HTR-131 DSRP Reactor Furnace	A
R-130 FLG	R-130 Flange and Cage Detail	-
1	Sorbent Cage	B
HX-090	SIM ROG PHTR Coil	-
V-190	Condenser Head Tank	D
HX-160	Design and Assembly Reheater	B

Methodology:

The procedure selected for this review used an abbreviated guideword approach that incorporated guidewords used in classical HAZOP studies. Using selected guidewords (Table IV), the facilitator directed the discussions to identify operating deviation that was the most likely scenarios for each guideword. The discussions reviewed the failure modes to identify potential hazards or operability problems. Based on the developed scenarios, probability of occurrence and risk consequences were discussed and assessed for the identified hazards or operational problems. Only events and/or issues that resulted in recommendations were recorded on the worksheets. The suggested recommendations are included in Column 7 of the DHR worksheets in Appendix I. The guidelines for the each of the worksheet columns are defined in Table V. The DSRP P&IDs listed in Table II were the subject of the review first. The P&IDs were divided into nodes. The modes generally were separated in two categories, feed streams to the reactors and reactor/product streams. In some cases, the reactors were individually evaluated and product streams divided into functional subsystems. Table VI outlines the review modes used for this study. Two exceptions were the review of PSDF/RTI interfacing and test protocol (study reference E) and analytical P&ID (study reference F).

Study reference number E-1 through E-6 was developed from the plot plan of site shown on drawing E-M-D0002. This review was other than an operating deviation and was reviewed to the following potential interfacing issues.

- Safety and Restriction Zones
- Personnel Access and Egress Routes
- Event Alarms and Personnel Assembly Areas
- Construction/Equipment Access and Egress Routes.

Study reference numbers F-1 through F-3 was conducted on the planned analytical sampling system and required the expertise from RTI's engineer who participated in similar sampling of test units.

TABLE IV – GUIDEWORD CHECKLIST

Guideword	Operating Deviation
Flow	-No -High -Low -Reverse -Misdirected -Plugged
Level	-High -Low -No
Leak	-Oxidation -Corrosion -Seal -Connector
Pressure	-High -Low
Temperature	-High -Low
Contaminants	-Process -Disposal -Handling
Concentrations	-High -Low
Power	-Loss
Instrument Air	-Loss
Operation	-Startup -Shutdown -Emergency/Evacuation Plan -Integrated Test -Sampling
Maintenance	-On-line -Off-line
Exposure	-Fire -Toxic Release -Heat -Explosion

TABLE V – DESIGN HAZARD REVIEW GUIDELINES FOR WORK SHEET COLUMNS

Column 1: Study Reference Number

Identifier that will be located on each of the review P&IDs for easy recall and reference during corrective action and implementation phases.

Column 2: Line Number or Equipment Number or other Identifier

Item identified with subject of deviation and guideword.

Column 3: Guideword and Operating Deviation

Refer to checklist guidewords (Table IV).

Column 4: Possible Causes of Deviation or Problem

Identified failure mode or process upset condition or operability event in reference to Column 3.

Column 5: Consequences and Reasons for Action

Categorize the potential effect of Column 4. "S" for safety, "O" for an operability problem, and include the potential consequences of the event if necessary for added clarification.

Column 6: Existing Precaution

Identify instrumentation and control devices and/or operator action and/or equipment items and/or procedures that prevents or minimize the effect of the event.

Column 7: Recommended Action or Notes/Queries

Review teams recommendations or inquiries with reference to Columns 4, 5, and 6. The recommendations from the team are only suggestions for subsequent evaluation by projects in developing the final corrective action plan. The team's recommendations may be subject to change based on follow-up engineering reviews and/or studies.

Column 8: Action By

To be assigned by project following the review.

Column 9: Further Implications or Follow-up Reviews or Comments

Optional. If applicable, identify other related study reference numbers having similar event conditions or identify specific follow-up review requirements or specific information comments for further clarification.

TABLE VI – PROCESS REVIEW MODES

DSRP Pilot Test Units

Drawing	Node Identifier	Process Nodes
PID-0011	A1	Coal Gas Feed to Reactor
PID-0011	A2	F-120 Blow Back
PID-0011	A3	Nitrogen Feed
PID-0011	A4	F-110 Blow Back
PID-0011	A5	R-130 Reactor
PID-0012	A6	Sulfur Removal System
PID-0012	A7	Reheated Off-gas System

AHGP Bench Test Units

Drawing	Node Identifier	Process Nodes
PID-0014	B1	Coal Gas Feed to Reactor
PID-0014	B2	H_2S/Nitrogen Feed
PID-0014	B3	REGEN SO_2/Nitrogen Feed
PID-0014	B4	REGEN Air/Nitrogen Feed
PID-0015	B5	Reactor/Sulfidation Off-gas
PID-0015	B6	Reactor/ SO_2 REGEN Off-gas
PID-0015	B7	Reactor/Air REGEN Off-gas
PID-0017	C1	Instrument Air
PID-0018	D1	LSO_2 Delivery System
E-M-D0002	E	PSDF/RTI Test Protocol
PID-0013/PID-0016	F1	Analytical Sampling

Review Team:

The review team consisted of several representatives from the Research Triangle Institute at the Center for Engineering and Environmental Technology, Process Research Program, Research Triangle Park, North Carolina and one safety engineer from Southern Company Services at the Power System Development Facility, Wilsonville, Alabama. A hired consultant familiar with conducting hazard review for pilot scale operations facilitated the meeting and directed the team discussions.

Members of the review team are identified in Table VII. Other participants attended part-time and are also listed as attendees on the worksheets.

TABLE VII – DESIGN HAZARD REVIEW TEAM

Jeffrey Portzer	RTI	Process Engineer
Daryl Smith	RTI	Operation/Construction
Brandon Russell*	SCS	Safety/Engineering
Gary Howe	RTI	Analytical Sampling (part-time only)
Peter Cherish**	Consultant	Facilitator

*Scribe for meeting.
**Developed document worksheets based on scribes recorded information and follow-up discussion.

Results:

The results of the Design Hazard Review are documented in Appendix I and Appendix II. Appendix I documents the results of the meeting discussions and tabulates the event scenario, consequence, and existing precautions on the worksheets. Appendix II further identifies a study reference number for the event scenario on each corresponding P&ID. Also included in Appendix I is a column with suggested recommendations for each of the study reference numbers. These suggested recommendations are to be reviewed by the SCS/RTI project team subsequent resolution and implementation.

Follow-up Requirements:

A follow-up action plan for implementation is required to close out the items identified in the review. The following is offered for consideration.

- RTI/SCS project team reviews the event scenarios for each of the study reference numbers and address the validity of each recommendation on a "to-do" or "no-to-do" basis.

- From the results of the above review, develop a corrective action/status list finalizing the recommendations. For reference, a sample of a DHR action item/status form is shown in Attachment I.

  NOTE: Study reference items requiring no follow-up implementation or that are deemed not applicable should be so identified in the status column of the listing.

- It is recommended that prior to startup, the status of each item of the DHR action item list be reviewed by SCS/RTI project/operations team to assess status of completion and operational readiness.

ATTACHMENT I
DHR Action Items

Study Ref. #	Action By	Recommended Action	Status	Estimated Completion Date

APPENDIX I

DHR WORKSHEETS

P&ID: PID-0011 DSRP Filters & Reactor **DATE:** July 31, 2000 **ATTENDEES:** Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A1-1	PID-0011	High flow to DSRP via YV-017	Syngas flow valves YV-016 and YV-017 on cascade control. YV-017 opens and YV-016 closes on demand signal from operator.	• O-Potential damage to F-120 filter elements • Potential high reactor carryover and catalyst elutriation.	Valve CV and line flow restriction may limit flow.	• Confirm maximum allowable pressure drop for pall filter. • If required, consider adding impedance in series with YV017 to limit maximum flow on switchover.	RTI	
A1-2	PID-0011 F-120	Low flow to R-130	F-120 filter element plugging from coal gas tars and/or particulates.	• O-Suboptimum reaction in DSRP. • Pilot unit shutdown	• PDI-112 filter pressure drop increases. • FCV-116 valve opens and FIC output signal increases. • Reactor temperature drops. • Operator intervention.	Provide process upset action plan in operating procedure.	RTI	
A1-3	PID-0011 CKV-173	Reverse flow via CKV-173	KBR transport reactor depressurizes rapidly without notification to DSRP operators.	O-Potential damage to CKV-173 resulting in emergency S/D with forced venting and possible line blowout.	None	Provide computer pressure signal from transport reactor pressure to RTI/DSRP PC for monitoring and trending.	SCS	
A1-4	PID-0011 PDI-0010	Misdirected flow from coal gas line to low pressure nitrogen line via HV-108.	Operator inadvertently leaves or adjusts HV-108 in open position following F-120 filter blowback cycle.	• O-Potential for contaminating low-pressure nitrogen line. • Contaminating SIMROG rotameter FE-097 during purge cycle.	Procedure	Confirm procedure provides precautionary action plan to prevent event occurrence.	RTI	
A1-5	PID-0011 Line 103	Misdirected flow from coal gas line into SIMROG system via HX-180 outlet line.	SCS/RTI operator inadvertently closes isolation valve on LP nitrogen supply to RTI and CKV-171 fails to open.	O-Potential for contaminating SIMROG supply system to R-130.	• Procedure • CKV-171	Consider carseal open manual valve at SCS tie-in connection and provide tagout procedure with RTI	SCS	
A1-6	PID-0011 Drawing pressure/temperature notation for equipment	High pressure From SCS.	• SCS nitrogen supply PCV fails. • KBR transport reactor operation increased to 285 psig test conditions without notification.	S-Potential to over pressure R-130 DSRP reactor.	• Equipment design parameters exceeds operating condition. • PCV-612 • PI measurements • Operator intervention	• Provide proper-drawing notations to clarify noted parameters. • Confirm tubing, piping, and vessel design meets or exceeds API B31.3 petroleum piping requirements.	RTI	

P&ID: PID-0011
DSRP Filters & Reactor

DATE: August 1, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator; Suresh Jain, DOE

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A1-7	PID-0011 TIC Heater Controllers	High temperature tracing on heaters.	Tracing fails and shorts to ground during operation.	S-Potential for overheating tubing and vessels.	TSHH high/high temperature power shutoff protection.	Confirm temperature controller failure mode is fail safe and over current protection is adequate in the configured installation.	RTI	
A1-8	PID-0011 Coal gas feed system	Leaks similar to those experienced from RTI lab test.	• Fusible plug failure on SO_2 tank. • Flange leaks. • Connector leaks. • Valve packing leaks. • Condenser tube failure.	• S-Toxic gas release under pressure. • Personnel exposure hazard	Pressure leak test during assembly and prior to shipment to SCS.	• Develop leak check procedure and leakage rate criteria for acceptability. • Conduct pressure leak test after arrival at PSDF.	RTI	
A1-9	PID-0011 SO_2 feed line to DSRP.	Leaks same as A1-8.	• Connector leaks. • Instrument leaks. • Valve packing leaks.	• S-Potential for high SO_2 gas release. • Operator exposure hazard.	• Pressure leak test prior to operation. • Operator leak check monitoring.	Install SO_2 sensor behind heater control panel and integrating in RTI alarm/monitoring system with audible alarm capabilities.	RTI	
A1-10	PID-0011 Line DSRP-OG-1/2	Leaks same as A1-8.	• Flange leaks. • Connector leaks. • Valve packing leaks.	• S-Potential for high toxic gas (>2000ppm H_2S) release. • Personnel/operator exposure hazard.	• Pressure leak test prior to operation. • Operator leak check monitoring.	Install H_2S sensor located above V-150 sulfur separator pot.	RTI	(refer to B2-2)
A1-11	PID-0011 Vessel and line heaters.	Power loss local failure.	Circuit trips and auto resets.	S-Potential for high temperature equipment damage by overheating.	Design configured for heaters to latch in "off" mode on power failure.	Review and confirm heater latching "off" on power loss meets operating requirements.	RTI	
A1-12	PID-0011 F-110 CKV-171 YV-101	High pressure. Equipment pressure/temperature ratings.	Existing procured equipment incompatible with the new process operating conditions.	S-Potential for equipment overpressure damage and personnel injury.		Review existing equipment for MAWP/temperature ratings and verify compatibility with process operating conditions.	RTI	

P&ID: PID-0011
DSRP Filters & Reactor

DATE: August 1, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator; Suresh Jain, DOE

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A2-1	PID-0011 Filter F-120	Maintenance online cleaning.	Filter plugs.	O-Potential damage to filter element.	PDI-112 filter differential measurements.	• Review filter data and confirm maximum allowable pressure drop across filter element with forward and reverse flow. • Based on data, develop operator procedure and criteria for operation.	RTI	
A2-2	PID-0011 Filter F-120	Maintenance off-line	Filter plugs, unable to be cleaned on-line and unable to vent pressure.	S-Potential for personnel injury due to sudden release of pressure on disassembly.	None.	Develop off-line maintenance procedure for back flushing and cleaning F-120 and F-121.	RTI	
A2-3	PID-0011 F-120 Filter PCV-612	High pressure in F-120 from SCS nitrogen supplies.	PCV-612 and PCV-165 fail.	• O-Potential for filter element damage. • Potential for overpressure equipment vessels.	Low probability of failure for two regulators in series.	• Review and determine pressure conditions in event of PCV-612 and PCV-165 failure. • Determine MAWP for equipment and develop PSV-139 set pressure based on limiting equipment.	RTI	
A2-4	PID-0011 Line 118 nitrogen startup line to coal gas Line 104.	Startup.	Backflow of coal gas into nitrogen purge line up to HV-613.	O-Potential for acid condensation in cold dead leg.	None.	In developing startup procedure, consider opening coal gas supply valve into higher-pressure nitrogen flow before closing HV-163.	RTI	
A2-5	PID-0011 PCV-612 nitrogen supply line.	Low flow during nitrogen startup flow demand.	PCV-612 undersized to flow required capacity.	O-Potential to limit startup pressure and flow requirements.	N/A	• Verify PCV-612 sized to meet requirements for startup demand. • Consider adding upstream pressure indicator for • PCV-612 nitrogen regulator.	RTI	
A2-6	PID-0011 Nitrogen startup and backpulse lines.	Low temperature contaminants.	Uninsulated lines between heated lines and nitrogen block valves.	O-Potential for purge lines to plug with tar and corrode from formed acid condensibles.	None.	Consider adding check valve similar to CKV-173 at branch connection if problem occurs.	RTI	

P&ID: PID-0011
SIMROG System

DATE: August 1, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator; Suresh Jain, DOE

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A3-1	PID-0010 FIC-318-4	High flow of nitrogen in SIMROG.	FIC mass flow controller fails to close due to mechanical damage.	O-Potential for low % SO_2 in SIMROG causing process upset.	• FCV-115 downstream flow control. • Operator action monitoring analysis of SIMROG sampling gas.	None.		
A3-2	PID-0010 F-092	Low flow of nitrogen in SIMROG.	F-092 inline filter plugs.	O-Potential for high % SO_2 in SIMROG causing process upset and high temperature catalyst exposure.	• FIC-318-4 and FIC-115 flow measurements. • SIMROG gas analysis. • Operator action.	For operator procedure, calculate worse case scenario and limits for SO_2 concentration and temperature.	RTI	
A3-3	PID-0018 T-500 PCV-506	Reverse flow of nitrogen to T-500 LSO_2 cylinder.	Low nitrogen pad pressure on T-500.	O-Loss of SIMROG flow (refer to A3-2)	• Operator procedure and monitoring. • Rotameter float may close restricting backflow. • Nitrogen pressure via • PCV-612 available.	Confirm procedure and data logging monitors T-500 tank pad pressure at acceptable frequency.	RTI	
A3-4	PID-0010 HX-090	High temperature from loss of nitrogen flow.	HTR-091 heater fails in shorted condition with TIC-094 selected to control outlet line temperature.	• S-Potential for tube failure and release of toxic gas. • Personnel exposure hazard.	• Operator monitoring and intervention. • TSH-094. • Dual temperature control mode configured.	Review and confirm high temperature shutdown can be accommodated in either control modes to prevent equipment damage.	RTI	
A3-5	PID-0010 FE-097	Reverse flow during online clean out of FE-097 with low pressure N_2.	H-086 3-way valve fails.	O-LSO_2 back flow into low-pressure nitrogen purge line 140.	None.	Consider adding check valve in low-pressure nitrogen line to HV-086.	RTI	

P&ID: PID-0011
DSRP Filters & Reactor

DATE: August 1, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator; Suresh Jain, DOE

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A4-1	PID-0011 Line 103 R-130	High flow SIMROG to R-130.	FIC-115 fails control valve open causing high flow to reactor.	• O-Potential catalyst carryover from R-130. • Major maintenance clean out problem.	• Control valve trim size. • Operator monitoring and intervention.	• Review trim size for valve and determine maximum flow and velocity in R-130 reactor. • Develops limits as required.	RTI	
A4-2	PID-0011 F-110	Reverse flow.	Valve misalignment during filter cleaning.	S-Personnel exposure hazard. Leaks from corrosion in SIMROG line.	Operator procedure for low pressure filter cleaning.	Confirm procedure in place prior to operation.	RTI	
A4-3	PID-0011 F-110 F-111 F-121	Maintenance offline cleaning of filter.	F-110 plugs and requires offline cleaning.	S-Personnel exposure hazard. Sudden pressure release when opening fills to replace filter element.	Operator procedure.	• Consider adding vent, PI, at F-111 and F-121 filters to confirm depressurized condition acceptable for filter element removal. • Consider changing P&IDs to depressurize filters to a low-pressure vent header (see V-188 study reference notes).	RTI	
A4-4	Same as A4-3	Same as A4-3	Same as A4-3	S-Potential handling and disposal hazard.	Unknown.	Confirm storage/disposal requirements of filter media at PSDF.	SCS	
A4-5	PID-0011 F-110 F-120	High temperature shutdown.	Heater element hot spot and/or failures.	S-Equipment overpressure damage at operating temperatures.	High temperature cutout switch TSHH-117.	Confirm temperature S/D conditions and maximum allowable operating temperature of F-110 and F-120 is consistent.	RTI	

P&ID: PID-0011 DSRP Filters & Reactor **DATE:** August 2, 2000 **ATTENDEES:** Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A5-1	PID-0011 R-130	High temperature. Over heating reactor vessel.	• Indirect temperature control of vessel by TIC-314 and TIC-135 through radiation heating. • Local overheating due to hot spots. • Reaction exothermal heating along with external vessel heating could exceed allowable design temperature	• S-Potential equipment damage. • Personnel exposure hazard. • Personnel injury potential.	• R-130 design pressure 350 psig at 675°C. • TSHH 134 and TSHH 135 set at 675°C.	• Consider moving TSHH 134 and TSHH 135 temperature sensor to measure wall temperature directly. • Consider alarm for TI-129 (R-130 freeboard). • Estimate the effect of reaction heating in conjunction with control scheme. • Develop procedure to mitigate reaction exotherm by flow adjustment or addition of inerts. • Calculate maximum possible outlet temperature of bed given configured CV for FC-115 and FC-116. • Based on results of calculation develop operating control philosophy and procedures. • Determine TI failure mode-high or low signal output to controllers.	RTI	
A5-2	PID-0011 R-130	Low temperature in feed and off-gas lines.	• Loss of heating. • High heat loss.	• O-Unable to initiate reaction (below 500°C). • O-Potential to condense sulfur (approximately 200°C). Sulfur solidifies at 130°C. • O-Potential for S/D corrosion products to condense.	• Heaters capable to preheat mixed feed and off-gas line to 999°F (537°C). • Reactor vessel and process lines insulated. • Feed and off-gas lines alonized.	Review requirements and status for alonizing feed and off-gas lines for R-130.	RTI	
A5-3	PID-0011 R-130	High-pressure. R-130 vessel overpressure.	• Relief line plugs and PSV-139 fails to open. • Relief line hot insulated.	• S-Potential equipment damage. • Potential for personnel injury.	PSV-139 set at 392 psig (MAWP of vessel 350 psig).	• Confirm release pressure of PSV-139 and readjust as required. • Consider moving overpressure protection to upstream location. Move PSV-139 or install new PSV downstream of PCV-612 in nitrogen supply to process.	RTI	

P&ID: PID-0011 DSRP Filters & Reactor **DATE:** August 2, 2000 **ATTENDEES:** Daryl Smith, RTI; Jeff Portzer, RTI; Brandon Russell, SCS; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A5-4	PID-0011 R-130	Leaks in feed and off-gas line connectors to vessel.	• Thermal cycling. • Misaligned ferrules. • Compression fittings close coupled to bottom of vessel.	• S-Potential toxic gas release. • Personnel exposure hazard.	Monitoring and leak checking.	• Consider moving compression fittings for ¾ inch inlet line and for TI-125 outside of insulation. • Review best position for locating H_2S sensor (refer to A1-10). • Consider installing Conax fittings on R-130 TI's 126-129.	RTI	
A5-5	PID-0011 R-130	Low pressure. Startup, process upset, or off-design pressure operation.	• Low pressure process operation. • Shutdown sequence. • Startup	• O-Potential for high-pressure velocity and catalyst carryover. • Potential for catalyst to plug downstream orifice in V-150.		Develop operating velocity and pressure limit to prevent catalyst carryover.	RTI	

P&ID: PID-0012 Sulfur Collection **DATE:** August 2, 2000 **ATTENDEES:** Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A6-1	PID-0012 HX-140 V150 V-190	High flow. PCV-164 backpressure control valve fails to open.	• Loss of instrument air. • Loss of local power.	O-Potential for R-130 catalyst to elutriate over into HX-140 and plugs orifice in V-150 feed line.	None.	• Consider adding filter in R-130 outlet. • Review fail position of PCV-164.	RTI	
A6-2	PID-0012 V-150	Low flow.	Orifice in V-150 partially plugged.	O-Shutdown and maintenance required for orifice clean out.	Procedure not developed at this time.	Confirm shutdown and clean out procedure in place.	RTI	
A6-3	PID-0012 PSV-143	High pressure in HX-140.	HX-140 sulfur condenser tube failure.	• O-Potential to overpressure HX-140 pressure vessel. • S-Toxic gas release. • Hot liquid spray burn hazard.	• PSV-143 relief valve on vessel. • Steam/gas vent discharge to pad.	Consider venting PSV-143/PSV-191 into a KO pot to knockout hot water and vent gas to a safe location.	RTI	
A6-4	PID-0012 HX-140 Condenser coil	Maintenance hazard.	Removal of coil following failure.	S-Personnel hazard. Operator must climb skid for access to HX-140/V-190.	None.	Develop fall protection plan.	RTI	
A6-5	PID-0012 DSRP	Maintenance hazard DSRP under vent header pressure.	RTI operator opens DSRP process containment equipment while KBR is running.	S-Personnel hazard and potential for operator injury.		• Consider providing double block and bleeds for syngas, nitrogen, and tail gas at RTI skid for maintenance. • Consider providing additional bleed off to relieve system pressure to L.P. vent header/K.O. POT (refer to A6-3).	RTI	

P&ID: PID-0012 Sulfur Collection **DATE:** August 2, 2000 **ATTENDEES:** Daryl Smith, RTI; Jeff Portzer, RTI; Brandon Russell, SCS; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A6-6	PID-0012 V-150 (refer to A6-1)	Low pressure. PCV-164 fails to open.	• Loss of instrument air. • Loss of power. • Rapid depressurization.	• O-Potential for choke flow across V-150 orifice resulting in high velocity jet penetration. • Jet impacts vessel sidewall and erodes.		Estimate jet velocity and penetration length and confirm acceptability.	RTI	
A6-7	PID-0012 V-188	Maintenance under pressure.	• On-line removal of sulfur from V-188. • V-188 depressured to vent header pressure.	• S-Personnel exposure hazard. • V-188 not depressured when flange bolts are loosened. • (PI-196 plugs).	PI-196 indicates pressure in V-188.	Develop procedure to inspect PI-196 tap and clean as needed when opened for sulfur removal.	RTI	
A6-8	PID-0012 V-188	Maintenance under pressure.	On-line removal of sulfur from V-188.	S-Personnel exposure hazard to toxic gas vented from V-188. V-188 depressured to vent header.		• Provide high point atmospheric vent for V-188 to safe location. • Develop a design for on-line venting and discharge.	RTI RTI/SCS	Review design when complete.
A6-9	PID-0012 V-188	Maintenance under pressure.	On-line removal of sulfur V-188.	S-Personnel exposure to residual gas remaining in V-188.		• Review requirement and provide procedure for wearing respirator during V-188 disassembly and disconnect for sulfur removal. • Consider personnel monitor.	RTI/SCS	
A6-10	PID-0012 HX-140 V-190	No flow. Loss of cooling water.	Supply valve inadvertently closed.	S-Potential for steam generated overpressure in V-190/HX-140.	PSV-143/PSV-191 relief valves.	Verify criteria sizing PSVs and flow rates and discharge capacities.	RTI	

P&ID: PID-0012 Sulfur Collection **DATE:** August 4, 2000 **ATTENDEES:** Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
A7-1	PID-0012 HX-160	Leak from damaged reheater tube.	• Local corrosion hole in HX-160 tube wall. • Heater overheating reheater tube wall.	S-Personnel exposure hazard. Toxic release of high temperature tailgas under system pressure (>2000ppm H_2S).	Tube material of construction.	Provide local toxic gas sensor over skid (refer to A1 leaks.) (refer to A1-10).	RTI	Investigate vendor sources for better corrosion resistant material at operating conditions.
A7-2	PID-0012 PCV-164	Low pressure. Plugged PT-164 pressure tap resulting in false control pressure to PC-164.	Sulfur carryover from V-150 and condensing in unheated pressure sensing line.	O-Operability upset. Loss of reactor pressure at normal flow rates resulting in high velocity carryover of catalyst.	Off-gas filter F-195.	• Consider alternate location for relocating PI-164. • If tap plugging becomes an unmanageable operability problem relocate tap.	RTI	
A7-3	PID-0012 Line 136/137 DSRP OG	High pressure. Plugged line/filter.	Local heater failure and/or cold spot.	• O-Operability upset. • Unable to control back pressure. • Potential for overpressuring equipment. • Unable to depressure.	System/equipment PSVs.	• Identify required bleed points for final depressuring prior to breaking into pressure containment equipment (refer to A6-5). • Review need to vent tailgas at thermal oxidizer for plugged line.	RTI SCS	

P&ID: PID-0014
Feed Gases & Preheaters
DATE: August 4, 2000
ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
B1-1	PID-0014 R-330	High pressure. PSV-334 relief line plugged from off-gas condensibles.	PCV-602 fails. Potential for AHGP to pressurize to nitrogen supply pressure (425-450 psig).	• S-Equipment damage. • Potential to overpressure R-330 reactor.	PSV-334	• Consider overpresssure protection on upstream feed system. • Consider setting PSV-602 at MAWP of R-330.	RTI	
B1-2	PID-0014 YV-05 YV-016	Reverse flow. Nitrogen backflows into DSRP coal gas feed.	Startup switchover from nitrogen startup mode to coal gas processing with YV-05 and YV-016 are first opened.	O-Startup upset.	Procedure calls for AHGP operating pressure less coal gas supply pressure.	Flag startup upset potential in procedure.	RTI	
B1-3	PID-0014 PCV-303 PCV-306	High pressure. 1800 psig H_2S and air cylinders feed AHGP.	PCV-303 or PCV-306 fails.	• S-System overpressure. • Potential equipment damage. • Potential personnel hazard.	PCV regulators show built-in overpressure relief valves.	• Confirm that a relief valve is integrated into regulator and can protect downstream equipment. • Review (TBD) vent design to safe location (refer to A6-3).	RTI	

P&ID: PID-0014
Feed Gases & Preheaters

DATE: August 4, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
B2-1	PID-0014 CYL-302	Leaks. Location unknown (TBD).	Hookup connectors, valve, or regulator leak H_2S into trailer.	S-Toxic gas release.	Gas monitoring alarms.	Suggest outside location in safe location and off loading convenience.	RTI/SCS	
B2-2	PID-0014 (Same as B2-1)	Leaks. Outside location (refer to B2-1).	(Same as B2-1)	S-Toxic gas release.	Not defined.	Locate H_2S sensor head for outside cylinder rack (refer to A1-10).	RTI/SCS	

P&ID: PID-0014
Feed Gases & Preheaters
DATE: August 4, 2000
ATTENDEES: Daryl Smith, RTI; Jeff Portzer, RTI; Brandon Russell, SCS; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
B3-1	PID-0014 HX-325 SO_2 REGEN PHTR coil	Leaks.	Over temperature tube rupture.	S-Personnel exposure hazard. Toxic gas release in trailer under pressure.	• SO_2 toxic gas alarm. • Close YV-9 SO_2 isolation valve. • Close manual HV-513 outside trailer.	Develop failure mode action plan for operating procedure.	RTI	
B3-2	PID-0014 FCV-309 Line 1007- SO_2 REGEN gas	Reverse flow.	Blocked flow in Line 1007 and LSO_2 pressure greater than nitrogen pressure in 1005.	S-Equipment failure. Potential to backflow LSO_2 into nitrogen supply.	Procedure PCV pressure settings.	• Confirm procedure. • Consider check valve in line 1005.	RTI	

P&ID: PID-0014 AHGP Feed Gases & Preheaters **DATE:** August 7, 2000 **ATTENDEES:** Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
B4-1	PID-0014 Air REGEN feed CYL-301	High pressure. Process air from high-pressure cylinder (1800 psi).	• PCV-306 failure with system blocked. • MAWP of V-320 and F-335 unknown.	S-Potential for equipment overpressure V-320 air REGEN PHTR and R-330 designed for lower pressure service.	• MFC/FCV-309 pressure rating 3000 psig at ambient temperature. • R-330 MAWP 365 psig @ 1250°F.	• Confirm MAWP/temp for V-320 and F-335 and other equipment upstream of PCV-366 in air REGEN path. • Consider overpressure of process air feed with downstream PSV set at limiting MAWP of equipment.	RTI	
B4-2	PID-0014 Air REGEN feed R-330	Leak. Air leak into process during sulfidation mode of operation.	HV-311 cylinder isolation valve open and YV-1 isolation valve unable to close completely.	• S-Equipment and personnel hazard. • Potential to introduce air into fuel gas at elevated pressure and temperature.	• Procedure • HV-311 and air cylinder valve closed by procedure and checklist.	• Consider adding bleed valve inside trailer to vent line between cylinder valve and HV-311 and confirm procedural checklist in place. • Determine flammability range of fuel gas inside reactor and potential combustion rate and pressure rise.	RTI	Review the existing precautions in light of results of the flammability analysis.
B4-3	PID-0014 Air REGEN feed MFC/FCV-309 MFC/FCV-313	Reverse flow. LSO_2 backflows into process nitrogen line tie in at HX-325 SO_2 REGEN PHTR coil.	Product line at/or downstream of R-330 plugs.	O-MFC fails and leaks.	MAWP/temp of MFC.	• Consider adding check valve process N2 line 1005. • Consider adding check valve in process air line 1004.	RTI	
B4-4	PID-0014 YV-03 Emergency nitrogen purge flow.	High flow. High velocity through R-330.	Emergency S/D valve sequence.	O-Potential for sorbent carryover and distributor damage.		• Determine maximum velocity and nitrogen flow rate. • Consider installing RO downstream of YV-03 to limit emergency nitrogen purge flow.	RTI	
B4-5	PID-0014 R-330	Process air feed continues after sorbent regeneration is complete.	Operator error.	O-Potential intrusion into thermal oxidizer syngas inlet.	• Procedure. • TE-338 reactor temperature. • Off-gas analyzer monitoring.	Determine maximum flow through FCV-313 required for sorbent regeneration.	RTI	

P&ID: PID-0015
AHGP Reactor & Product Recovery

DATE: August 7, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
B5-1	PID-0015 R-330 Fluid bed reactor	High pressure.	Plugged reactor outlet and plugged relief line to PSV-334.	S-Vessel overpressure.	PSV-334 relief valve for R-330.	• (Refer to B1, B2, B3, and B4) • Consider overpressure of system via feed stream PSVs.	RTI	
B5-2	PID-0015 V-375 Condensate pot	Leaks.	HV-376 liquid discharge valve leaks under system pressure.	S-Potential toxic gas release inside trailer.		Consider adding second valve downstream at end of gooseneck discharge line.	RTI	
B5-3	PID-0015 Line 1002 H_2S feed to reactor.	High concentration.	• Loss of instrument air. Isolation valve fail position. • No isolation of H_2S supply.	• S-Potential high H_2S concentration in tail gas with nitrogen by-pass flow via YV-3. • Possible high velocity in R-330 causing carryover of bed material.	None.	Identify closing H_2S cylinder valve in the procedure failure action plan for loss of instrument air and if emergency shutdown is initiated.	RTI	
B5-4	PID-0015 Cooling water FE-352A Rotameter	High pressure. FE-352A installed for lower pressure service.	CW supply to RTI from KBR closed loop cooling at 140 psig.	S-FE-352A fails due to over pressure.		Provide rotameter for the higher-pressure service.	RTI	
B5-5	PID-0015 Cooling water	Leak. Process leak into cooling water.	Corrosion failure of HX-370 condenser tube.	S-Potential for over pressure failure of rotameters in CW supply line.		Consider adding check valve in CW supply lines.	RTI	
B5-6	PID-0015 R-330	Contaminants. Oxygen in coal gas.	KBR upset, startup, or S/D.	O-Potential for high reactor outlet temperature.		• Provide typical oxygen concentrations in KBR syngas. • Review concentrations and assess process effects and define action plan, if required.	SCS RTI	

P&ID: PID-0014
AHGP Reactor & Product Recovery

DATE: August 8, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
B6-1	PID-0017 PCV-602	High pressure. Supply nitrogen pressure delivered to process.	PCV-602 failure.	O-Potential for equipment over pressure.	• PSV setting for high-pressure protection of nitrogen supply to line 1005. • MAWP/temp of equipment.	Confirm PSV setting and MAWP/temp.		
B6-2	PID-0015 HX-340/V-350	High pressure.	Tube rupture failure in HX-340.	S-Potential for equipment over pressure.	PSV-345 set at 50 psig for over pressure protection.	• Verify sizing flow capacity for PSV-345 based on steam generation with a ruptured tube. • Confirm MAWP/temp of equipment.		
B6-3	PID-0015 R-330	High flow/high velocity through R-330.	Rapid process depressurization.	O-Potential for sorbent carryover and distributor damage.	Filter F-335 provided as barrier and collector.	None.		
B6-4	PID-0015 V-350	Material of construction.	Tube coil may be fabricated from copper.	O-Material selection not per design requirement.		• Confirm MOC for tube coil. • If coil is copper, replace with stainless steel.		

P&ID: PID-0015
AHGP Reactor & Product Recovery

DATE: August 8, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
B7-1	PID-0015 Line 1012	Reverse flow. Integrated operation startup.	AHGP online and operating with DSRP off-line for maintenance and YV-010 leaks through.	S-Potential for toxic gas from AHGP off-gas line 1012 to by-pass leakage to DSRP with concentrated SO_2 in off-gas.	YV-010 positive tight shutoff.	• Review operating modes for line 1012 AHGP REGEN off-gas to DSRP. • Consider adding positive isolation of line 1012 when not in use.	RTI	
B7-2	PID-0015 AHGP Process Unit.	Shutdown containment pressure.	System riding on 15-17 psig vent header pressure.	O-Potential of venting process gas to trailer and discharging toxic gas.	Procedure (TBD).	Provide vent lines to vent AHGP process gas to vent blower.	RTI	
B7-3	PID-0015	Shutdown sorbent damage.	• Normal shutdown sequence in stopping feed flows. • Operator error.	O-Potential for catalyst damage by SO_2 flow.	Procedure for S/D.	Verify procedure identifies that SO_2 flow is shutdown first.	RTI	

P&ID: PID-0020
Instrument Air

DATE: August 3, 2000

ATTENDEES: Daryl Smith, RTI; Jeff Portzer, RTI; Brandon Russell, SCS; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
C1-1	PID-0017 DSRP instrument air skid. Line 1027-IA	Low pressure supply to DSRP.	Valve upstream of instrument air supply filter F-630 inadvertently closed to isolate air supply to trailer.	• Loss of air supply to DSRP. • DSRP instrument air failure.		Consider adding isolation valve on 1027-IA HDR-1/2" T-SS.	RTI	

P&ID: PID-0018
LSO_2 Delivery System

DATE: August 3, 2000

ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

STUDY REF	• LINE NO • EQUIPMENT NO • OTHER	• OPERATING DEVIATION • POSSIBLE CONDITION • GUIDE WORD	• POSSIBLE CAUSES OF DEVIATION • PROBLEM	CONSEQUENCES & REASONS FOR ACTION O-OPERABILITY S-SAFETY HAZARD	EXISTING PRECAUTION	• RECOMMENDED ACTION REQUIRED • NOTES/QUERIES	ACTION BY	• FURTHER IMPLICATIONS • FOLLOW-UP REVIEW • COMMENTS
D1-1	PID-0018 Line 1052-LSO_2	Leak.	• Routing path of 1/8" LSO_2-tubed. • LSO_2 line accidentally breaks.	S-Toxic gas release under pad pressure.	• Unknown • Design TBD	• Provide safe routing path to mitigate tubing damage. • Consider providing tube shielding for damage protection.	RTI	
D1-2	PID-0018 Line 1052-LSO_2	High-pressure. Thermal liquid expansion.	Liquid SO_2 trapped between closed valves (HV-51, HV-512, and HV-513) at pad gas pressure.	S-Potential for high pressure tube rupture and toxic gas vented.	None.	• Develop procedure for long down periods to allow LSO_2 boil off prior to closing line block valves. • Consider adding expansion pot and venting under ambient vapor pressure to safe location.	RTI	
D1-3	PID-0018 T-500	High-pressure.	PCV-506 nitrogen pad regulator fails and PSV-508 undersized.	• S-Potential for fuse plug blowout. • High volume toxic gas release.	• PSV-508 (sizing unknown) • T-500 fuse plug.	• Confirm sizing capacity of PSV-508. • Get written guidance from air products for overpressure relief venting on T-500 padded cylinder.	RTI	
D1-4	PID-0018	Low flow. High-pressure drop through tubing.	1/8" LSO_2 supply tubing undersized for length of run.	O-SO_2 feed limited to DSRP.	Unknown.	Review routing requirements (refer to D1-1) and check pressure drop at maximum feed rate.	RTI	

P&ID: E-M-D0002
PSDF/RTI Test Protocol
DATE: August 4, 2000
ATTENDEES: Daryl Smith, RTI; Brandon Russell, SCS; Jeff Portzer, RTI; Pete Cherish, Facilitator

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E-1	E-M-D0002 SCS Structure	Leaks detected.	Shaft seal or valve packing leak.	• S-Emergency response. • Gas monitor alarms activated in SCS structure.	TBD	• Develop SCS/RTI emergency response plan. • Provide a wall placard in the RTI trailer identifying alarms and emergency action sequence.	SCS/RTI	Review gas monitor alarms, trailer personnel assembly plan, control room notification plan, shutdown, and evacuation plan.
E-2	E-M-D0002 Propane vaporizer/tanks.	Leaks identified.	Venting or equipment wear/damage.	S-Potential fire/explosion hazard.	TBD	Develop RTI shutdown and evacuation plan.	RTI/SCS	Suggest SCS on-site safety review with RTI, et al.
E-3	E-M-D0002 Assembly building.	Operation emergency. Severe weather.	• Thunder storms. • Tornadoes. • Hurricanes.	S-Potential operator/personnel injury.	• Radio/TV weather warning alerts. • Evacuate to safe shelter.	Finalize RTI shutdown and evacuation plan.	RTI/SCS	Suggest SCS on-site safety review with RTI, et al.
E-4	E-M-D0002 Proposed pilot units and SO_2 cylinder.	Leaks. SO_2 cylinder/skid.	• Thermal cycling mechanical tube connectors. • RTI equipment damage. • SO_2 cylinder/valve/line damage.	• S-Toxic gas release. • Personnel hazard.	TBD. Gas detector alarms.	• Develop RTI/SCS operation and emergency response plan. • Provide orange strobe light at skid for SO_2 sensor alarm to alert RTI for closing supply valve and need to evacuate.	RTI/SCS SCS	Suggest SCS on-site safety review with RTI, et al.
E-5	E-M-D0002 DSRP, AHGP, trailer.	Leaks. Hot and cold pressure leaks.	Equipment, tubing pressure/temperature cycling.	• S-Toxic/flammable gas leaks. • Personnel and fire hazard.	Gas detector alarms.	• SCS to specify and install LEL and oxygen sensors inside trailer and at skid. • RTI to provide contact closure to SCS for gas monitor high/high alarm. • RTI to evaluate feasibility of locating all gas cylinders outside, as required to insure adequate atmosphere inside trailer.	SCS/RTI RTI/SCS RTI/SCS	
E-6	E-M-D0002 SO_2 cylinder	Storage inventory.	Excess inventory supplied by vendor (greater 1000 pounds).	S-PSDF/site reportable inventory storage violation.	TBD	Develop inventory control procedure for receiving, delivery, and installation of cylinders.	SCS/RTI	

P&ID: PID-0013/PID-0016 Analytical **DATE:** August 4, 2000 **ATTENDEES:** Daryl Smith, RTI; Jeff Portzer, RTI; Gary Howe, RTI; Brandon Russell, SCS; Pete Cherish, Facilitator

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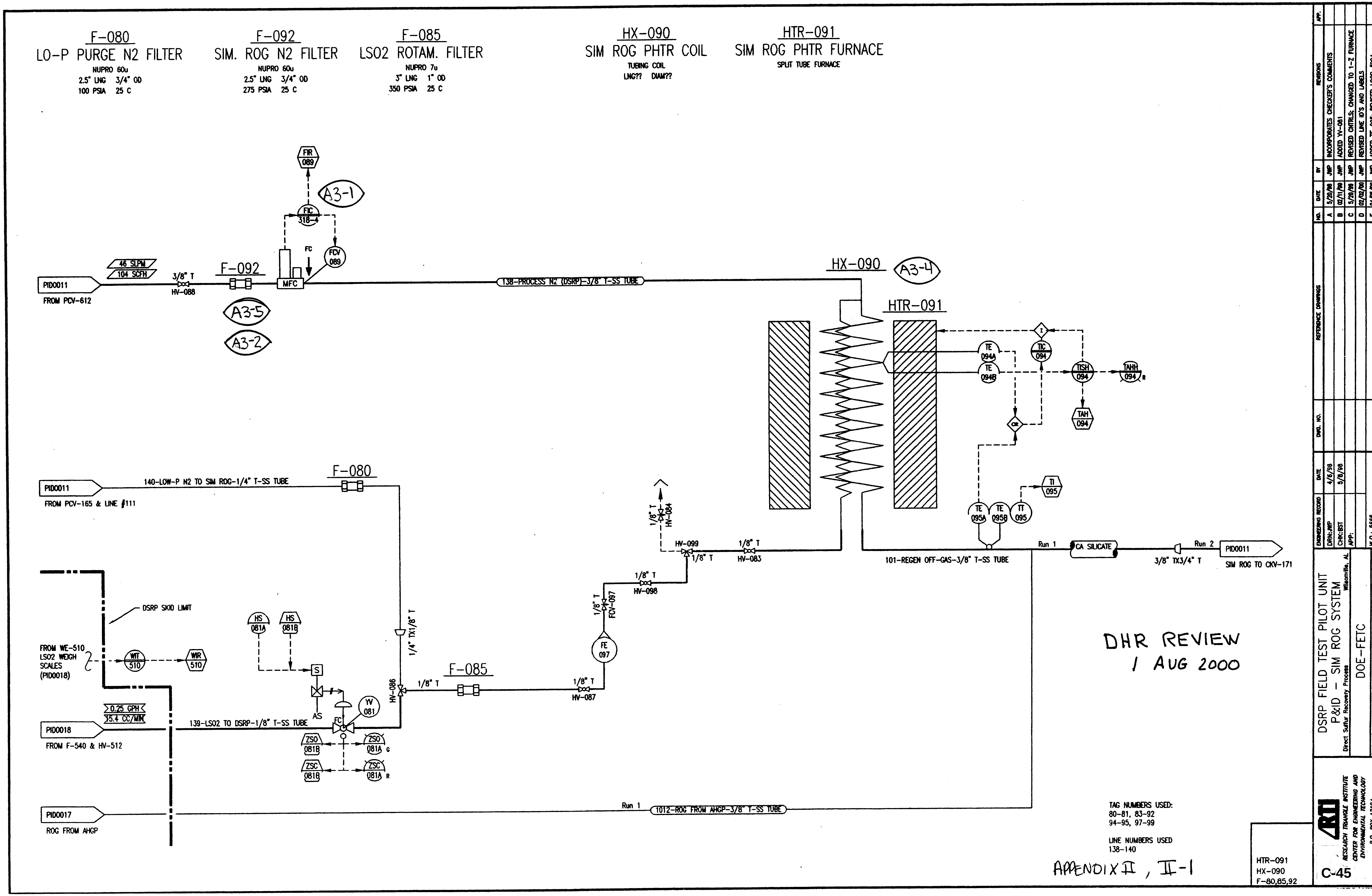
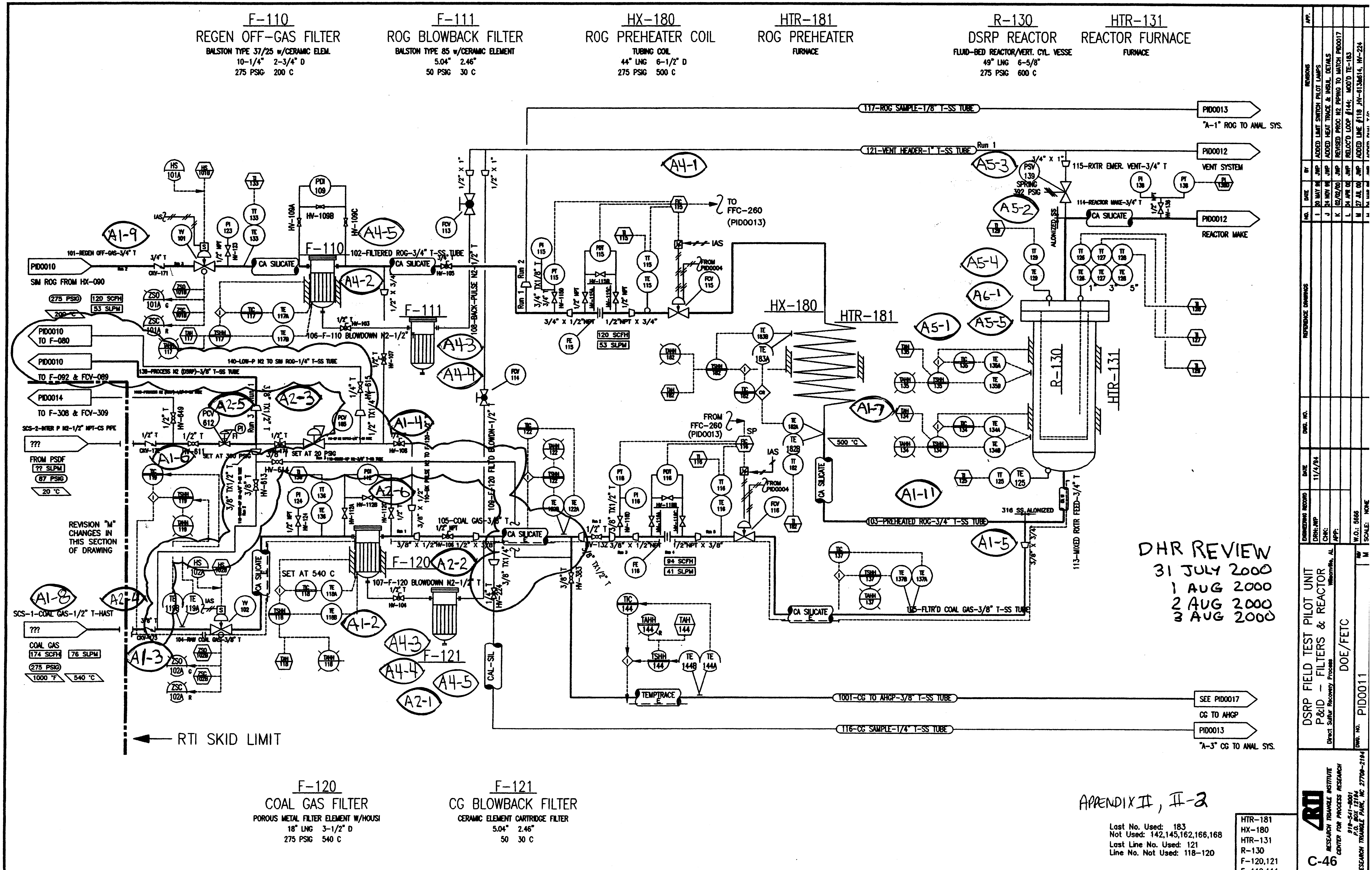
F1-1	PID-0013 HX-210 A-1 Sample Coil. Line 117-ROG sample.	Leak/tube rupture.	Corrosion.	O-S/D DSRP to replace coil and perform maintenance.		Consider installing high temperature valve at tail gas sample line tie-in to perform replacement/maintenance of coil.	RTI	
F1-2	PID-0013 HX-225 Sample Cooler.	High pressure.	PCV-223 regulator failure while blocked in.	O-Potential for over pressure and damage to HX-225.		• Determine MAWP/temp of HX-225. • Consider PSV for over pressure protection.	RTI	
F1-3	PID-0013/PID-0016 Support gas cylinders.	Leak. H_2/N_2 cylinders.	Fusible plug failure from service age/pressure creep.	S-Potential for flammable mixture or low oxygen trailer atmosphere.	HVAC system designed for 4-6-volume change per hour.	• Confirm/test volume change rates. • Leave HVAC on when trailer not occupied and cylinders are in trailer. Include in procedure checklist.	RTI	

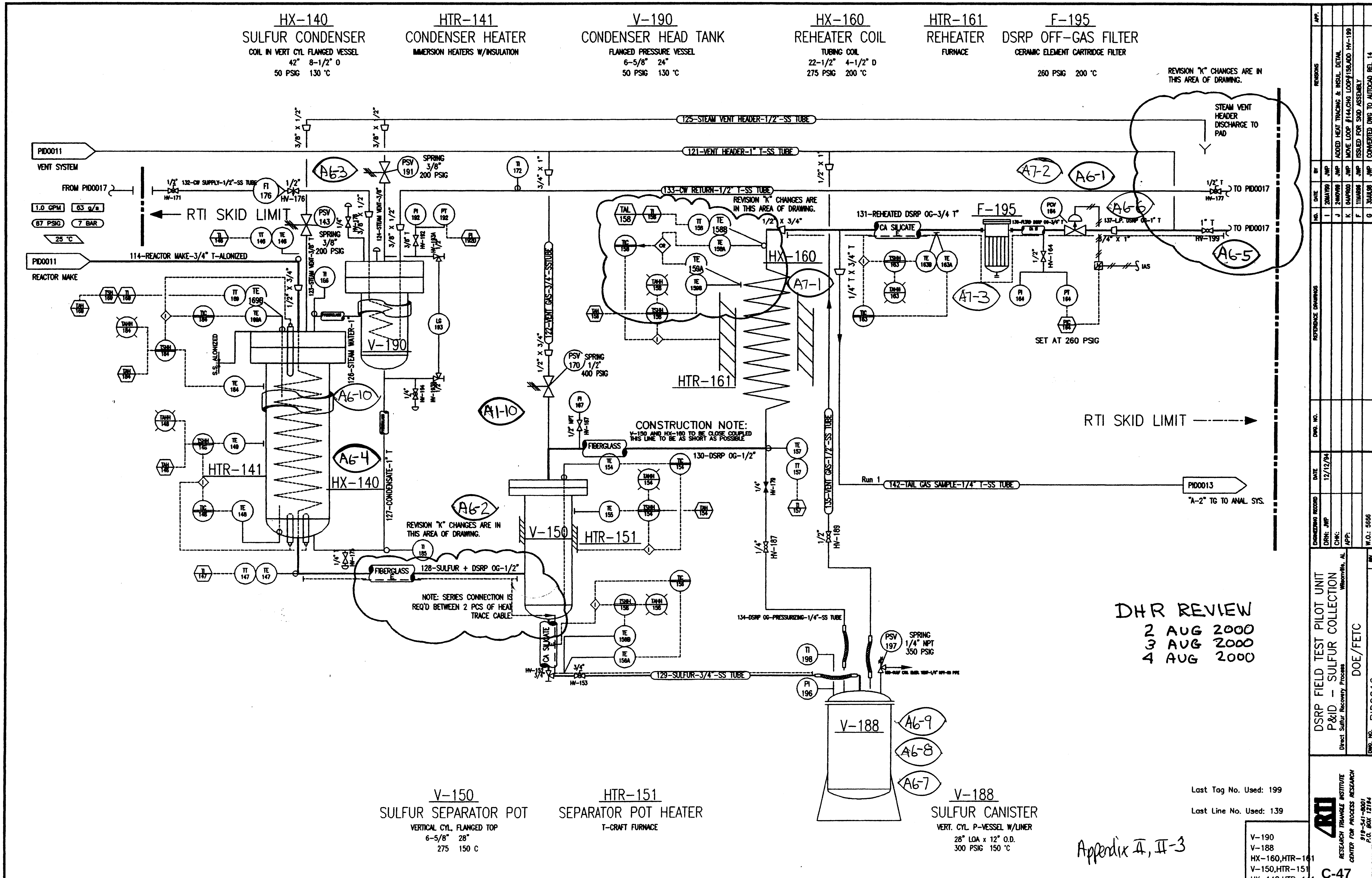
APPENDIX II

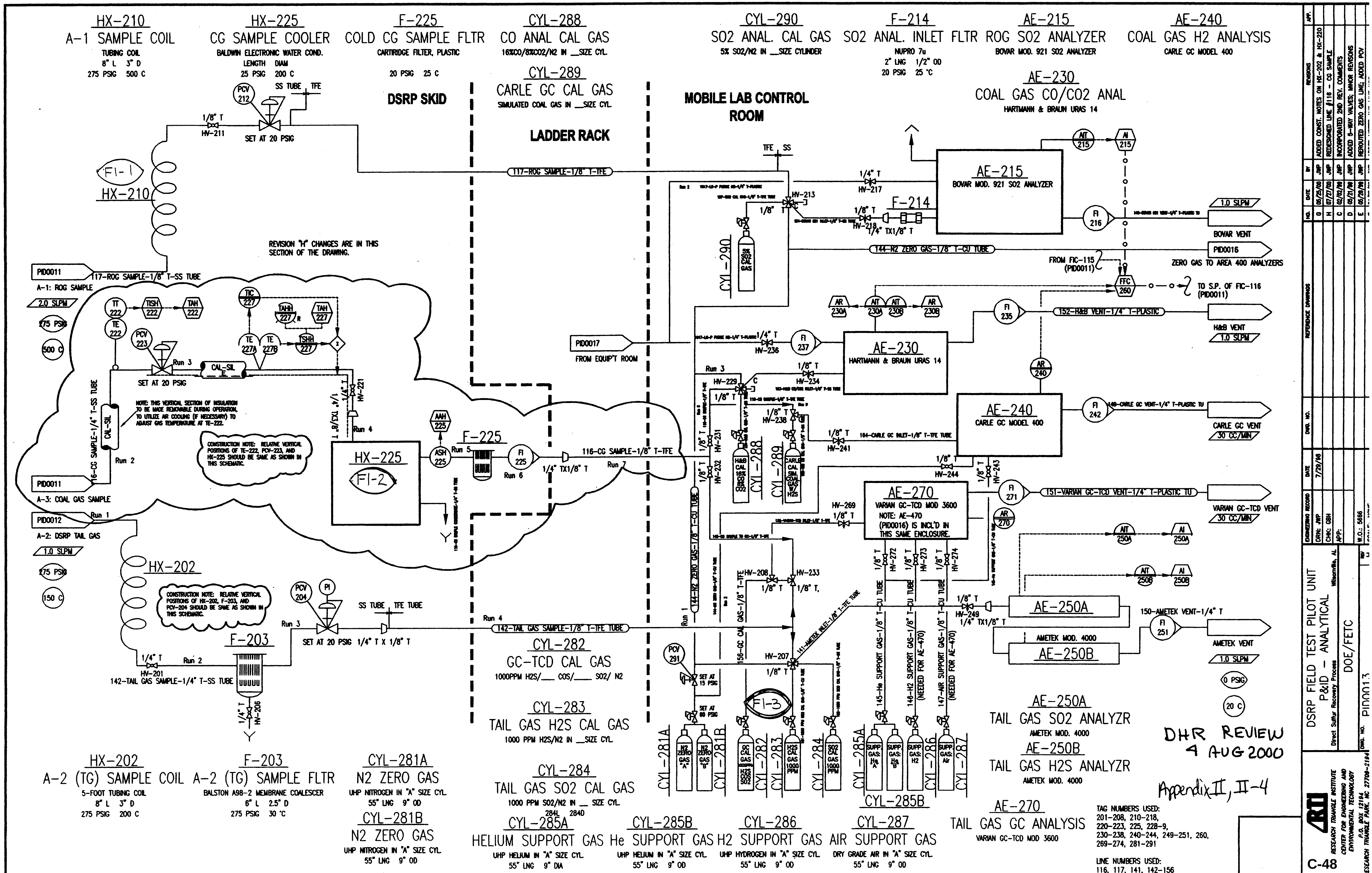
DHR REVIEW P&IDs


F-080
LO-P PURGE N2 FILTER
NUPRO 60u
2.5" LNG 3/4" OD
100 PSIA 25 C
F-092
SIM. ROG N2 FILTER
NUPRO 60u
2.5" LNG 3/4" OD
275 PSIA 25 C
F-085
LSO2 ROTAM. FILTER
NUPRO 7u
3" LNG 1" OD
350 PSIA 25 C
HX-090
SIM ROG PHTR COIL
TUBING COIL
LNG?? DIAM??
HTR-091
SIM ROG PHTR FURNACE
SPLIT TUBE FURNACE
FIR 089
A3-1
FIC 318-4
FC
FCV 089
46 SLPM
104 SCFH
PID0011
FROM PCV-612
3/8" T
HV-088
F-092
MFC
A3-5
A3-2
138-PROCESS N2 (DSRP)-3/8" T-SS TUBE
HX-090
A3-4
HTR-091
TE 094A
TE 094B
TIC 094
TISH 094
TAHH 094
TAH 094
TI 095
TE 095A
TE 095B
TT 095
PID0011
FROM PCV-165 & LINE #111
140-LOW-P N2 TO SIM ROG-1/4" T-SS TUBE
F-080
1/8" T
HV-084
HV-099
1/8" T
1/8" T
HV-083
Run 1
CA SILICATE
Run 2
PID0011
SIM ROG TO CKV-171
3/8" TX3/4" T
101-REGEN OFF-GAS-3/8" T-SS TUBE
1/8" T
HV-098
1/8" T
FCV-097
FE 097
DSRP SKID LIMIT
HS 081A
HS 081B
FROM WE-510
LSO2 WEIGH
SCALES
(PID0018)
WT 510
WIR 510
1/4" TX1/8" T
F-085
HV-086
1/8" T
1/8" T
HV-087
S
AS
FC
YV 081
0.25 GPH
15.4 CC/MIN
PID0018
FROM F-540 & HV-512
139-LSO2 TO DSRP-1/8" T-SS TUBE
ZSO 081B
ZSO 081A G
ZSC 081B
ZSC 081A R
PID0017
ROG FROM AHGP
Run 1
1012-ROG FROM AHGP-3/8" T-SS TUBE
DHR REVIEW
1 AUG 2000
TAG NUMBERS USED:
80-81, 83-92
94-95, 97-99
LINE NUMBERS USED
138-140
APPENDIX II, II-1
HTR-091
HX-090
F-80,85,92
C-45
RTI
RESEARCH TRIANGLE INSTITUTE
CENTER FOR ENGINEERING AND ENVIRONMENTAL TECHNOLOGY
P.O. BOX 12194
RESEARCH TRIANGLE PARK, NC 27709-2194
DSRP FIELD TEST PILOT UNIT
P&ID - SIM ROG SYSTEM
Direct Sulfur Recovery Process
Wilsonville, AL
DOE-FETC
DWG. NO. PID0010
REV F
DRN: JWP 4/6/98
CHK: BST 5/8/98
W.O.: 5666
A 5/20/98 JWP INCORPORATES CHECKER'S COMMENTS
B 02/11/99 JWP ADDED YV-081
C 5/20/99 JWP REVISED CNTRLS; CHANGED TO 1-Z FURNACE
D 02/02/00 JWP REVISED LINE ID'S AND LABELS
E 04/05/00 JWP ADDED TE-095; REVISED LOOP #094

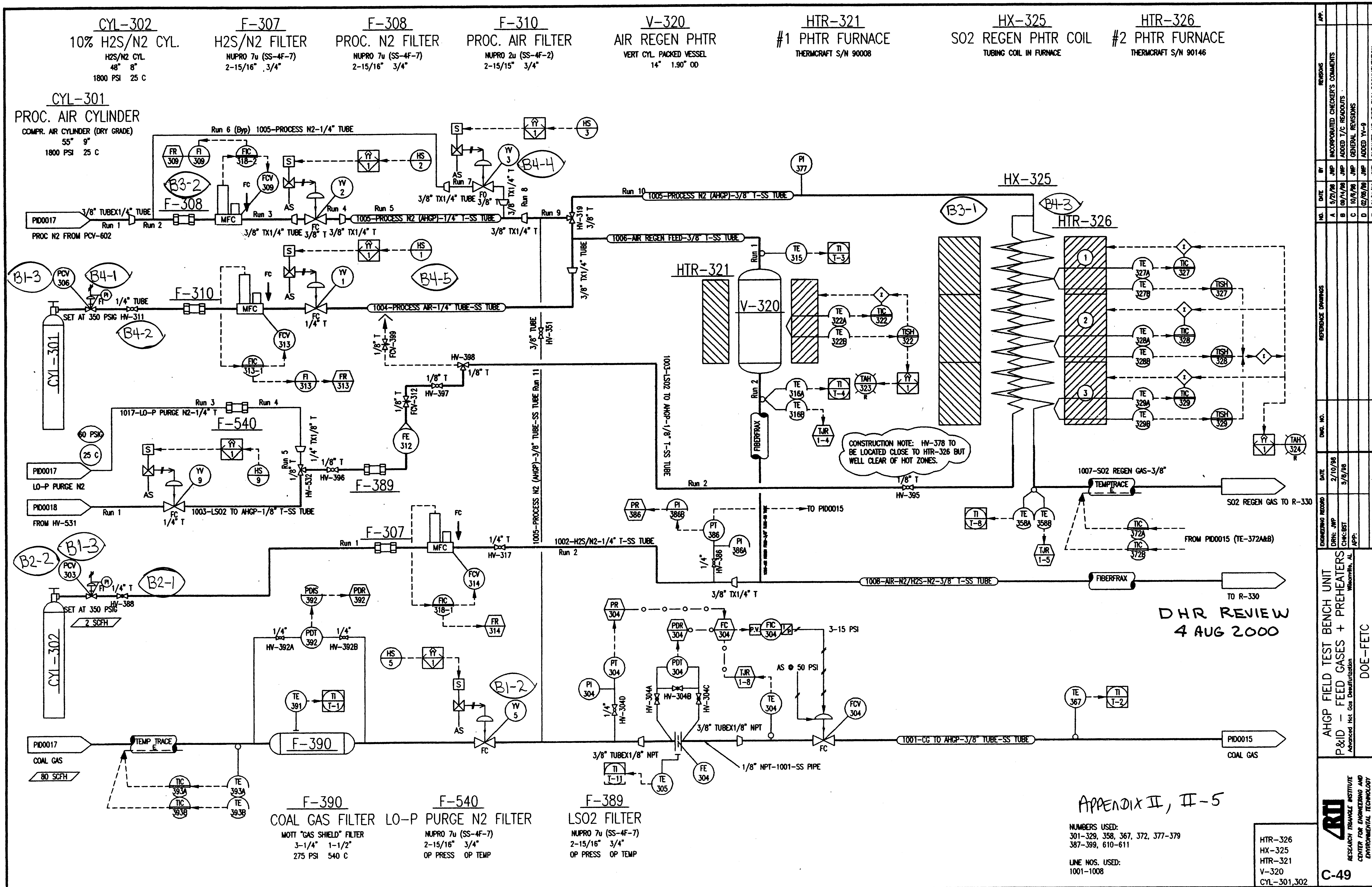


F-110
REGEN OFF-GAS FILTER
BALSTON TYPE 37/25 w/CERAMIC ELEM.
10-1/4" 2-3/4" D
275 PSIG 200 C
F-111
ROG BLOWBACK FILTER
BALSTON TYPE 85 w/CERAMIC ELEMENT
5.04" 2.46"
50 PSIG 30 C
HX-180
ROG PREHEATER COIL
TUBING COIL
44" LNG 6-1/2" D
275 PSIG 500 C
HTR-181
ROG PREHEATER
FURNACE
R-130
DSRP REACTOR
FLUID-BED REACTOR/VERT. CYL. VESSE
49" LNG 6-5/8"
275 PSIG 600 C
HTR-131
REACTOR FURNACE
FURNACE
117-ROG SAMPLE-1/8" T-SS TUBE
PID0013
"A-1" ROG TO ANAL. SYS.
121-VENT HEADER-1" T-SS TUBE
PID0012
VENT SYSTEM
115-RXTR EMER. VENT-3/4" T
114-REACTOR MAKE-3/4" T
PID0012
REACTOR MAKE
101-REGEN OFF-GAS-3/4" T
PID0010
SIM ROG FROM HX-090
PID0010
TO F-080
PID0010
TO F-092 & FCV-089
PID0014
TO F-308 & FCV-309
FROM PSDF
REVISION "M" CHANGES IN THIS SECTION OF DRAWING
SCS-1-COAL GAS-1/2" T-HAST
COAL GAS
102-FILTERED ROG-3/4" T-SS TUBE
106-F-110 BLOWDOWN N2-1/2"
108-BACK-PULSE N2-1/2" T
140-LOW-P N2 TO SIM ROG-1/4" T-SS TUBE
105-COAL GAS-3/8" T
107-F-120 BLOWDOWN N2-1/2" T
109-F-120 FILTD BLOWDN-1/2"
103-PREHEATED ROG-3/4" T-SS TUBE
113-MIXED RXTR FEED-3/4" T
125-FLTR'D COAL GAS-3/8" T-SS TUBE
1001-CG TO AHGP-3/8" T-SS TUBE
SEE PID0017
CG TO AHGP
116-CG SAMPLE-1/4" T-SS TUBE
PID0013
"A-3" CG TO ANAL. SYS.
TO FFC-260 (PID0013)
FROM FFC-260 (PID0013)
SET AT 540 C
SET AT 20 PSIG
CA SILICATE
TEMPTRACE
CAL-SIL
HX-180
HTR-181
F-110
F-111
F-120
F-121
R-130
HTR-131
RTI SKID LIMIT
DHR REVIEW
31 JULY 2000
1 AUG 2000
2 AUG 2000
3 AUG 2000
F-120
COAL GAS FILTER
POROUS METAL FILTER ELEMENT W/HOUSI
18" LNG 3-1/2" D
275 PSIG 540 C
F-121
CG BLOWBACK FILTER
CERAMIC ELEMENT CARTRIDGE FILTER
5.04" 2.46"
50 30 C
APPENDIX II, II-2
Last No. Used: 183
Not Used: 142,145,162,166,168
Last Line No. Used: 121
Line No. Not Used: 118-120
HTR-181
HX-180
HTR-131
R-130
F-120,121
F-110,111
DSRP FIELD TEST PILOT UNIT
P&ID - FILTERS & REACTOR
Direct Sulfur Recovery Process
DOE/FETC
PID0011
RESEARCH TRIANGLE INSTITUTE
CENTER FOR PROCESS RESEARCH
C-46

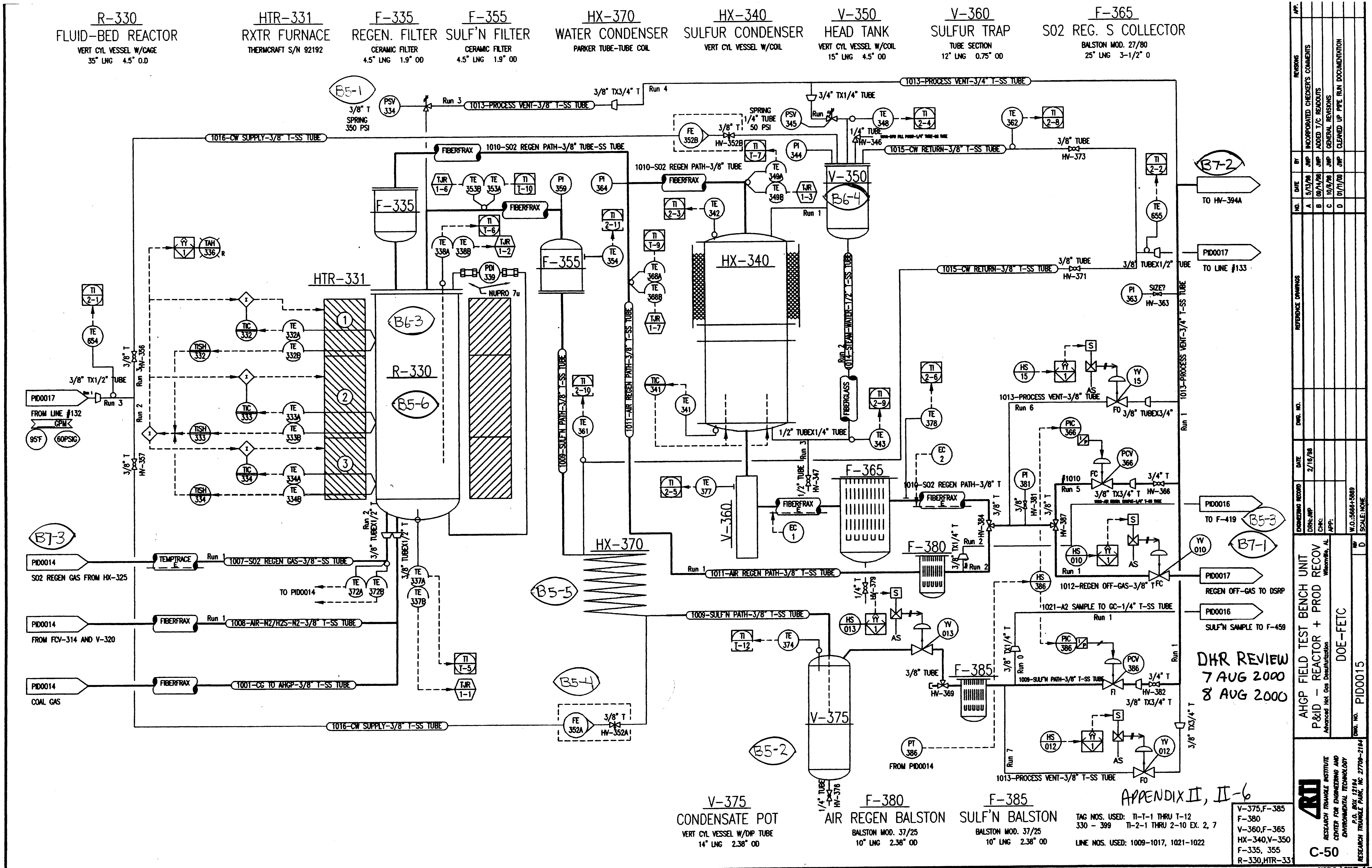

HX-140
SULFUR CONDENSER
COIL IN VERT CYL FLANGED VESSEL
42" 8-1/2" O
50 PSIG 130 °C
HTR-141
CONDENSER HEATER
IMMERSION HEATERS W/INSULATION
V-190
CONDENSER HEAD TANK
FLANGED PRESSURE VESSEL
6-5/8" 24"
50 PSIG 130 °C
HX-160
REHEATER COIL
TUBING COIL
22-1/2" 4-1/2" D
275 PSIG 200 °C
HTR-161
REHEATER
FURNACE
F-195
DSRP OFF-GAS FILTER
CERAMIC ELEMENT CARTRIDGE FILTER
260 PSIG 200 °C
REVISION "K" CHANGES ARE IN THIS AREA OF DRAWING.
STEAM VENT HEADER DISCHARGE TO PAD
125-STEAM VENT HEADER-1/2"-SS TUBE
121-VENT HEADER-1" T-SS TUBE
133-CW RETURN-1/2" T-SS TUBE
PID0011
VENT SYSTEM
FROM PID0017
132-CW SUPPLY-1/2"-SS TUBE
RTI SKID LIMIT
1.0 GPM
63 g/s
87 PSIG
7 BAR
25 °C
PID0011
REACTOR MAKE
114-REACTOR MAKE-3/4" T-ALONIZED
SPRING 3/8" 200 PSIG
TO PID0017
131-REHEATED DSRP OG-3/4 T"
CA SILICATE
137-LP. DSRP OG-1" T
IAS
SET AT 260 PSIG
RTI SKID LIMIT
CONSTRUCTION NOTE:
V-150 AND HX-160 TO BE CLOSE COUPLED
THIS LINE TO BE AS SHORT AS POSSIBLE
FIBERGLASS
130-DSRP OG-1/2"
122-VENT GAS-3/4"-SS TUBE
SPRING 1/2" 400 PSIG
127-CONDENSATE-1" T
126-STEAM WATER-1"
124-STEAM VENT-3/8"
123-STEAM VENT-3/8" T
S.S. ALONIZED
Run 1
142-TAIL GAS SAMPLE-1/4" T-SS TUBE
PID0013
"A-2" TG TO ANAL. SYS.
135-VENT GAS-1/2"-SS TUBE
REVISION "K" CHANGES ARE IN THIS AREA OF DRAWING.
128-SULFUR + DSRP OG-1/2"
NOTE: SERIES CONNECTION IS REQ'D BETWEEN 2 PCS OF HEAT TRACE CABLE
134-DSRP OG-PRESSURIZING-1/4"-SS TUBE
129-SULFUR-3/4"-SS TUBE
SPRING 1/4" NPT 350 PSIG
V-150
SULFUR SEPARATOR POT
VERTICAL CYL. FLANGED TOP
6-5/8" 28"
275 150 C
HTR-151
SEPARATOR POT HEATER
T-CRAFT FURNACE
V-188
SULFUR CANISTER
VERT. CYL. P-VESSEL W/LINER
28" LOA x 12" O.D.
300 PSIG 150 °C
DHR REVIEW
2 AUG 2000
3 AUG 2000
4 AUG 2000
Last Tag No. Used: 199
Last Line No. Used: 139
Appendix II, II-3
V-190
V-188
HX-160,HTR-161
V-150,HTR-151
HX-140,HTR-141
C-47
DSRP FIELD TEST PILOT UNIT
P&ID - SULFUR COLLECTION
Direct Sulfur Recovery Process
DOE/FETC
PID0012
RESEARCH TRIANGLE INSTITUTE
CENTER FOR PROCESS RESEARCH
P.O. BOX 12194
RESEARCH TRIANGLE PARK, NC 27709-2194
DATE 12/12/94
W.O.: 5656
SCALE: NONE
ADDED HEAT TRACING & INSUL. DETAIL
MOVE LOOP #144,CHG LOOP#158,ADD HV-199
ISSUED FOR SKID ASSEMBLY
CONVERTED DWG TO AUTOCAD REL 14
ADDED V-188, DUAL T/C'S

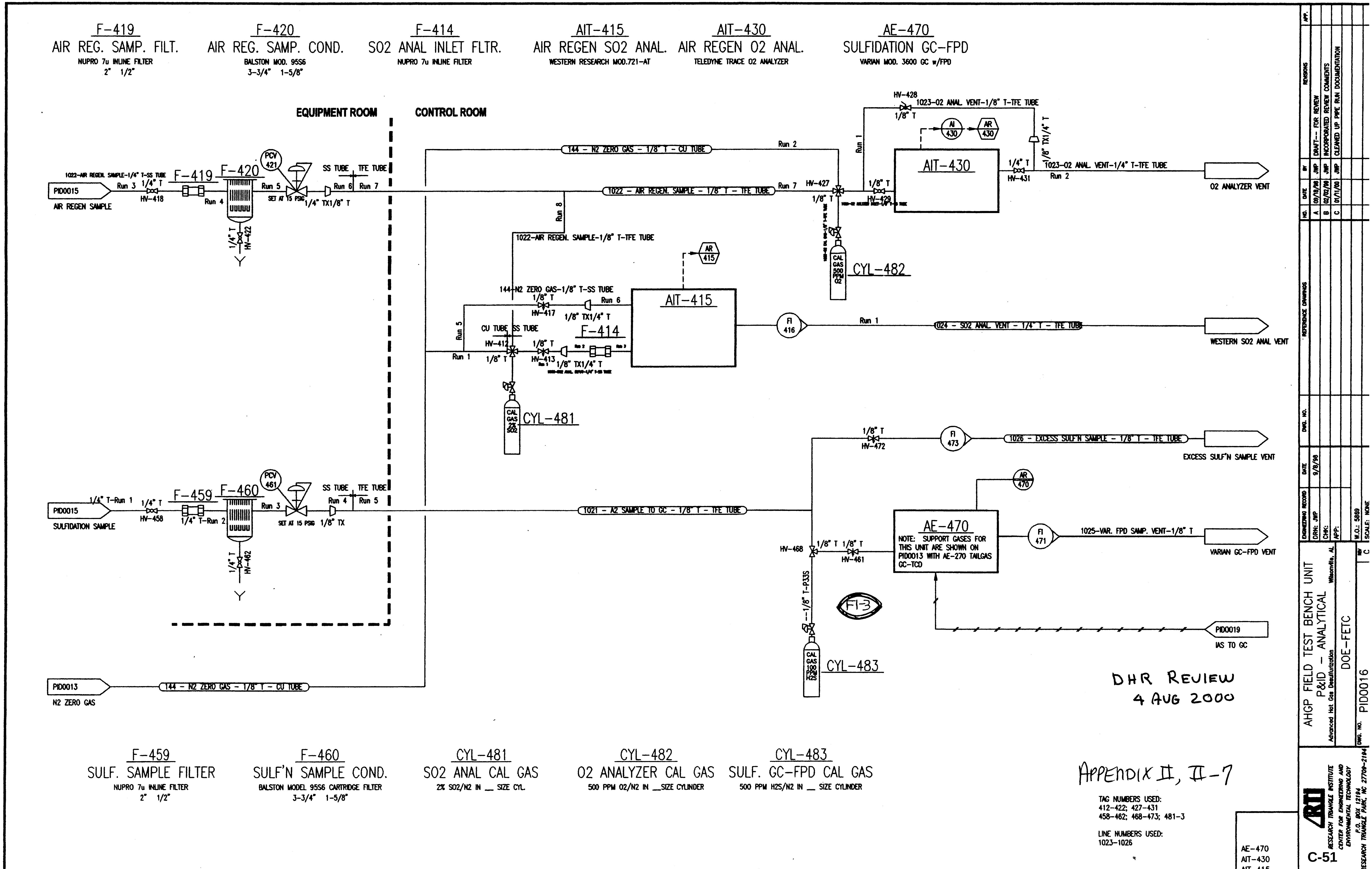


HX-210
A-1 SAMPLE COIL
TUBING COIL
8" L 3" D
275 PSIG 500 C
HX-225
CG SAMPLE COOLER
BALDWIN ELECTRONIC WATER COND.
LENGTH DIAM
25 PSIG 200 C
F-225
COLD CG SAMPLE FLTR
CARTRIDGE FILTER, PLASTIC
20 PSIG 25 C
CYL-288
CO ANAL CAL GAS
16%CO/8%CO2/N2 IN __SIZE CYL.
CYL-289
CARLE GC CAL GAS
SIMULATED COAL GAS IN __SIZE CYL.
CYL-290
SO2 ANAL. CAL GAS
5% SO2/N2 IN __SIZE CYLINDER
F-214
SO2 ANAL. INLET FLTR
NUPRO 7u
2" LNG 1/2" OD
20 PSIG 25 °C
AE-215
ROG SO2 ANALYZER
BOVAR MOD. 921 SO2 ANALYZER
AE-240
COAL GAS H2 ANALYSIS
CARLE GC MODEL 400
AE-230
COAL GAS CO/CO2 ANAL
HARTMANN & BRAUN URAS 14
DSRP SKID
LADDER RACK
MOBILE LAB CONTROL ROOM
REVISION "H" CHANGES ARE IN THIS SECTION OF THE DRAWING.
117-ROG SAMPLE-1/8" T-TFE
117-ROG SAMPLE-1/8" T-SS TUBE
A-1: ROG SAMPLE
A-3: COAL GAS SAMPLE
A-2: DSRP TAIL GAS
SET AT 20 PSIG
NOTE: THIS VERTICAL SECTION OF INSULATION TO BE MADE REMOVABLE DURING OPERATION, TO UTILIZE AIR COOLING (IF NECESSARY) TO ADJUST GAS TEMPERATURE AT TE-222.
CONSTRUCTION NOTE: RELATIVE VERTICAL POSITIONS OF TE-222, PCV-223, AND HX-225 SHOULD BE SAME AS SHOWN IN THIS SCHEMATIC.
116-CG SAMPLE-1/8" T-TFE
FROM EQUIP'T ROOM
144-N2 ZERO GAS-1/8" T-CU TUBE
FROM FIC-115 (PID0011)
ZERO GAS TO AREA 400 ANALYZERS
TO S.P. OF FIC-116 (PID0011)
BOVAR VENT
152-H&B VENT-1/4" T-PLASTIC
H&B VENT
CARLE GC VENT
151-VARIAN GC-TCD VENT-1/4" T-PLASTIC TU
VARIAN GC-TCD VENT
AE-270
VARIAN GC-TCD MOD 3600
NOTE: AE-470 (PID0016) IS INCL'D IN THIS SAME ENCLOSURE.
AE-250A
AE-250B
AMETEK MOD. 4000
150-AMETEK VENT-1/4" T
AMETEK VENT
HX-202
CONSTRUCTION NOTE: RELATIVE VERTICAL POSITIONS OF HX-202, F-203, AND PCV-204 SHOULD BE SAME AS SHOWN IN THIS SCHEMATIC.
F-203
142-TAIL GAS SAMPLE-1/4" T-SS TUBE
142-TAIL GAS SAMPLE-1/8" T-TFE TUBE
SS TUBE TFE TUBE
CYL-282
GC-TCD CAL GAS
1000PPM H2S/___ COS/___ SO2/ N2
CYL-283
TAIL GAS H2S CAL GAS
1000 PPM H2S/N2 IN __SIZE CYL.
CYL-284
TAIL GAS SO2 CAL GAS
1000 PPM SO2/N2 IN __ SIZE CYL.
HX-202
A-2 (TG) SAMPLE COIL
5-FOOT TUBING COIL
8" L 3" D
275 PSIG 200 C
F-203
A-2 (TG) SAMPLE FLTR
BALSTON A98-2 MEMBRANE COALESCER
6" L 2.5" D
275 PSIG 30 °C
CYL-281A
N2 ZERO GAS
UHP NITROGEN IN "A" SIZE CYL.
55" LNG 9" OD
CYL-281B
N2 ZERO GAS
UHP NITROGEN IN "A" SIZE CYL.
55" LNG 9" OD
CYL-285A
HELIUM SUPPORT GAS
UHP HELIUM IN "A" SIZE CYL.
55" LNG 9" DIA
CYL-285B
He SUPPORT GAS
UHP HELIUM IN "A" SIZE CYL.
55" LNG 9" OD
CYL-286
H2 SUPPORT GAS
UHP HYDROGEN IN "A" SIZE CYL.
55" LNG 9" OD
CYL-287
AIR SUPPORT GAS
DRY GRADE AIR IN "A" SIZE CYL.
55" LNG 9" OD
AE-250A
TAIL GAS SO2 ANALYZR
AMETEK MOD. 4000
AE-250B
TAIL GAS H2S ANALYZR
AMETEK MOD. 4000
AE-270
TAIL GAS GC ANALYSIS
VARIAN GC-TCD MOD 3600
TAG NUMBERS USED:
201-208, 210-218, 220-223, 225, 228-9, 230-238, 240-244, 249-251, 260, 269-274, 281-291
LINE NUMBERS USED:
116, 117, 141, 142-156
DHR REVIEW 4 AUG 2000
Appendix II, II-4
DSRP FIELD TEST PILOT UNIT
P&ID - ANALYTICAL
Direct Sulfur Recovery Process
Wilsonville, AL
DOE/FETC
PID0013
RESEARCH TRIANGLE INSTITUTE
CENTER FOR ENGINEERING AND ENVIRONMENTAL TECHNOLOGY
P.O. BOX 12194
RESEARCH TRIANGLE PARK, NC 27709-2194
DRN: JWP
CHK: GBH
DATE 7/29/98
C-48



CYL-302
10% H2S/N2 CYL.
H2S/N2 CYL. 48" 8" 1800 PSI 25 C
F-307
H2S/N2 FILTER
NUPRO 7u (SS-4F-7) 2-15/16" 3/4"
F-308
PROC. N2 FILTER
NUPRO 7u (SS-4F-7) 2-15/16" 3/4"
F-310
PROC. AIR FILTER
NUPRO 2u (SS-4F-2) 2-15/15" 3/4"
V-320
AIR REGEN PHTR
VERT CYL PACKED VESSEL 14" 1.90" OD
HTR-321
#1 PHTR FURNACE
THERMCRAFT S/N 90008
HX-325
SO2 REGEN PHTR COIL
TUBING COIL IN FURNACE
HTR-326
#2 PHTR FURNACE
THERMCRAFT S/N 90146
CYL-301
PROC. AIR CYLINDER
COMPR. AIR CYLINDER (DRY GRADE) 55" 9" 1800 PSI 25 C
PROC N2 FROM PCV-602
LO-P PURGE N2
FROM HV-531
COAL GAS
SO2 REGEN GAS TO R-330
TO R-330
FROM PID0015 (TE-372A&B)
1005-PROCESS N2 (AHGP)-1/4" TUBE-SS TUBE
1006-AIR REGEN FEED-3/8" T-SS TUBE
1004-PROCESS AIR-1/4" TUBE-SS TUBE
1003-LSO2 TO AHGP-1/8" T-SS TUBE
1002-H2S/N2-1/4" T-SS TUBE
1007-SO2 REGEN GAS-3/8"
1008-AIR-N2/H2S-N2-3/8" T-SS TUBE
1001-CG TO AHGP-3/8" TUBE-SS TUBE
CONSTRUCTION NOTE: HV-378 TO BE LOCATED CLOSE TO HTR-326 BUT WELL CLEAR OF HOT ZONES.
DHR REVIEW
4 AUG 2000
F-390
COAL GAS FILTER
MOTT "GAS SHIELD" FILTER 3-1/4" 1-1/2" 275 PSI 540 C
F-540
LO-P PURGE N2 FILTER
NUPRO 7u (SS-4F-7) 2-15/16" 3/4" OP PRESS OP TEMP
F-389
LSO2 FILTER
NUPRO 7u (SS-4F-7) 2-15/16" 3/4" OP PRESS OP TEMP
APPENDIX II, II-5
NUMBERS USED:
301-329, 358, 367, 372, 377-379
387-399, 610-611
LINE NOS. USED:
1001-1008
HTR-326
HX-325
HTR-321
V-320
CYL-301,302
C-49
RESEARCH TRIANGLE INSTITUTE
CENTER FOR ENGINEERING AND ENVIRONMENTAL TECHNOLOGY
AHGP FIELD TEST BENCH UNIT
P&ID - FEED GASES + PREHEATERS
Advanced Hot Gas Desulfurization
DOE-FETC
REVISIONS
A 5/21/98 JWP INCORPORATED CHECKER'S COMMENTS
B 08/14/98 JWP ADDED T/C READOUTS
C 10/6/98 JWP GENERAL REVISIONS
D 02/05/99 JWP ADDED YV-9
E 01/11/00 JWP CLEANED UP PIPE RUN DOCUMENTATION
DRN: JWP 2/10/98
CHK: BST 5/6/98
W.O.: 5889


R-330
FLUID-BED REACTOR
VERT CYL VESSEL W/CAGE
35" LNG 4.5" O.D
HTR-331
RXTR FURNACE
THERMCRAFT S/N 92192
F-335
REGEN. FILTER
CERAMIC FILTER
4.5" LNG 1.9" OD
F-355
SULF'N FILTER
CERAMIC FILTER
4.5" LNG 1.9" OD
HX-370
WATER CONDENSER
PARKER TUBE-TUBE COIL
HX-340
SULFUR CONDENSER
VERT CYL VESSEL W/COIL
V-350
HEAD TANK
VERT CYL VESSEL W/COIL
15" LNG 4.5" OD
V-360
SULFUR TRAP
TUBE SECTION
12" LNG 0.75" OD
F-365
SO2 REG. S COLLECTOR
BALSTON MOD. 27/80
25" LNG 3-1/2" 0
1013-PROCESS VENT-3/8" T-SS TUBE
1013-PROCESS VENT-3/4" T-SS TUBE
1016-CW SUPPLY-3/8" T-SS TUBE
1010-SO2 REGEN PATH-3/8" TUBE-SS TUBE
1015-CW RETURN-3/8" T-SS TUBE
1009-SULF'N PATH-3/8" T-SS TUBE
1011-AIR REGEN PATH-3/8" T-SS TUBE
1007-SO2 REGEN GAS-3/8"-SS TUBE
1008-AIR-N2/H2S-N2-3/8" T-SS TUBE
1001-CG TO AHGP-3/8" T-SS TUBE
1012-REGEN OFF-GAS-3/8" T
1021-A2 SAMPLE TO GC-1/4" T-SS TUBE
PID0017
TO HV-394A
PID0017
TO LINE #133
PID0017
FROM LINE #132
PID0014
SO2 REGEN GAS FROM HX-325
PID0014
FROM FCV-314 AND V-320
PID0014
COAL GAS
PID0016
TO F-419
PID0017
REGEN OFF-GAS TO DSRP
PID0016
SULF'N SAMPLE TO F-459
FROM PID0014
V-375
CONDENSATE POT
VERT CYL VESSEL W/DIP TUBE
14" LNG 2.38" OD
F-380
AIR REGEN BALSTON
BALSTON MOD. 37/25
10" LNG 2.38" OD
F-385
SULF'N BALSTON
BALSTON MOD. 37/25
10" LNG 2.38" OD
TAG NOS. USED: TI-T-1 THRU T-12
330 - 399 TI-2-1 THRU 2-10 EX. 2, 7
LINE NOS. USED: 1009-1017, 1021-1022
DHR REVIEW
7 AUG 2000
8 AUG 2000
APPENDIX II, II-6
REVISIONS
A 5/13/98 JMP INCORPORATED CHECKER'S COMMENTS
B 08/14/98 JMP ADDED T/C READOUTS
C 10/6/98 JMP GENERAL REVISIONS
D 01/11/00 JMP CLEANED UP PIPE RUN DOCUMENTATION
AHGP FIELD TEST BENCH UNIT
P&ID - REACTOR + PROD RECOV
Advanced Hot Gas Desulfurization
Wilsonville, AL
DOE-FETC
PID0015
RESEARCH TRIANGLE INSTITUTE
CENTER FOR ENGINEERING AND ENVIRONMENTAL TECHNOLOGY
P.O. BOX 12194
RESEARCH TRIANGLE PARK, NC 27709-2194
C-50
V-375,F-385
F-380
V-360,F-365
HX-340,V-350
F-335, 355
R-330,HTR-331



F-419
AIR REG. SAMP. FILT.
NUPRO 7u INLINE FILTER
2" 1/2"
F-420
AIR REG. SAMP. COND.
BALSTON MOD. 95S6
3-3/4" 1-5/8"
F-414
SO2 ANAL INLET FLTR.
NUPRO 7u INLINE FILTER
AIT-415
AIR REGEN SO2 ANAL.
WESTERN RESEARCH MOD.721-AT
AIT-430
AIR REGEN O2 ANAL.
TELEDYNE TRACE O2 ANALYZER
AE-470
SULFIDATION GC-FPD
VARIAN MOD. 3600 GC w/FPD
EQUIPMENT ROOM
CONTROL ROOM
PID0015
AIR REGEN SAMPLE
1022-AIR REGEN. SAMPLE-1/4" T-SS TUBE
HV-418
PCV 421
SET AT 15 PSIG
SS TUBE
TFE TUBE
144 - N2 ZERO GAS - 1/8" T - CU TUBE
1022 - AIR REGEN. SAMPLE - 1/8" T - TFE TUBE
1022-AIR REGEN. SAMPLE-1/8" T-TFE TUBE
HV-422
HV-427
HV-428
1023-02 ANAL. VENT-1/8" T-TFE TUBE
AI 430
AR 430
HV-429
HV-431
1023-02 ANAL. VENT-1/4" T-TFE TUBE
O2 ANALYZER VENT
CYL-482
CAL GAS 500 PPM O2
AR 415
144-N2 ZERO GAS-1/8" T-SS TUBE
HV-417
1/8" TX1/4" T
CU TUBE
SS TUBE
HV-412
HV-413
FI 416
024 - SO2 ANAL. VENT - 1/4" T - TFE TUBE
WESTERN SO2 ANAL VENT
CYL-481
CAL GAS 2% SO2
HV-472
FI 473
1026 - EXCESS SULF'N SAMPLE - 1/8" T - TFE TUBE
EXCESS SULF'N SAMPLE VENT
AR 470
PID0015
SULFIDATION SAMPLE
F-459
F-460
HV-458
PCV 461
SET AT 15 PSIG
HV-462
1021 - A2 SAMPLE TO GC - 1/8" T - TFE TUBE
HV-468
HV-461
NOTE: SUPPORT GASES FOR THIS UNIT ARE SHOWN ON PID0013 WITH AE-270 TAILGAS GC-TCD
FI 471
1025-VAR. FPD SAMP. VENT-1/8" T
VARIAN GC-FPD VENT
FI-3
PID0019
IAS TO GC
CYL-483
CAL GAS 100 PPM H2S
PID0013
N2 ZERO GAS
144 - N2 ZERO GAS - 1/8" T - CU TUBE
DHR REVIEW
4 AUG 2000
F-459
SULF. SAMPLE FILTER
NUPRO 7u INLINE FILTER
2" 1/2"
F-460
SULF'N SAMPLE COND.
BALSTON MODEL 95S6 CARTRIDGE FILTER
3-3/4" 1-5/8"
CYL-481
SO2 ANAL CAL GAS
2% SO2/N2 IN __ SIZE CYL.
CYL-482
O2 ANALYZER CAL GAS
500 PPM O2/N2 IN __ SIZE CYLINDER
CYL-483
SULF. GC-FPD CAL GAS
500 PPM H2S/N2 IN __ SIZE CYLINDER
APPENDIX II, II-7
TAG NUMBERS USED:
412-422; 427-431
458-462; 468-473; 481-3
LINE NUMBERS USED:
1023-1026
AE-470
AIT-430
AIT-415
REVISIONS
A 10/18/98 JWP DRAFT-- FOR REVIEW
B 02/02/99 JWP INCORPORATED REVIEW COMMENTS
C 01/11/00 JWP CLEANED UP PIPE RUN DOCUMENTATION
REFERENCE DRAWINGS
DRN: JWP 9/8/98
W.O.: 5869
SCALE: NONE
AHGP FIELD TEST BENCH UNIT
P&ID - ANALYTICAL
Advanced Hot Gas Desulfurization
Wilsonville, AL
DOE-FETC
PID0016
REV C
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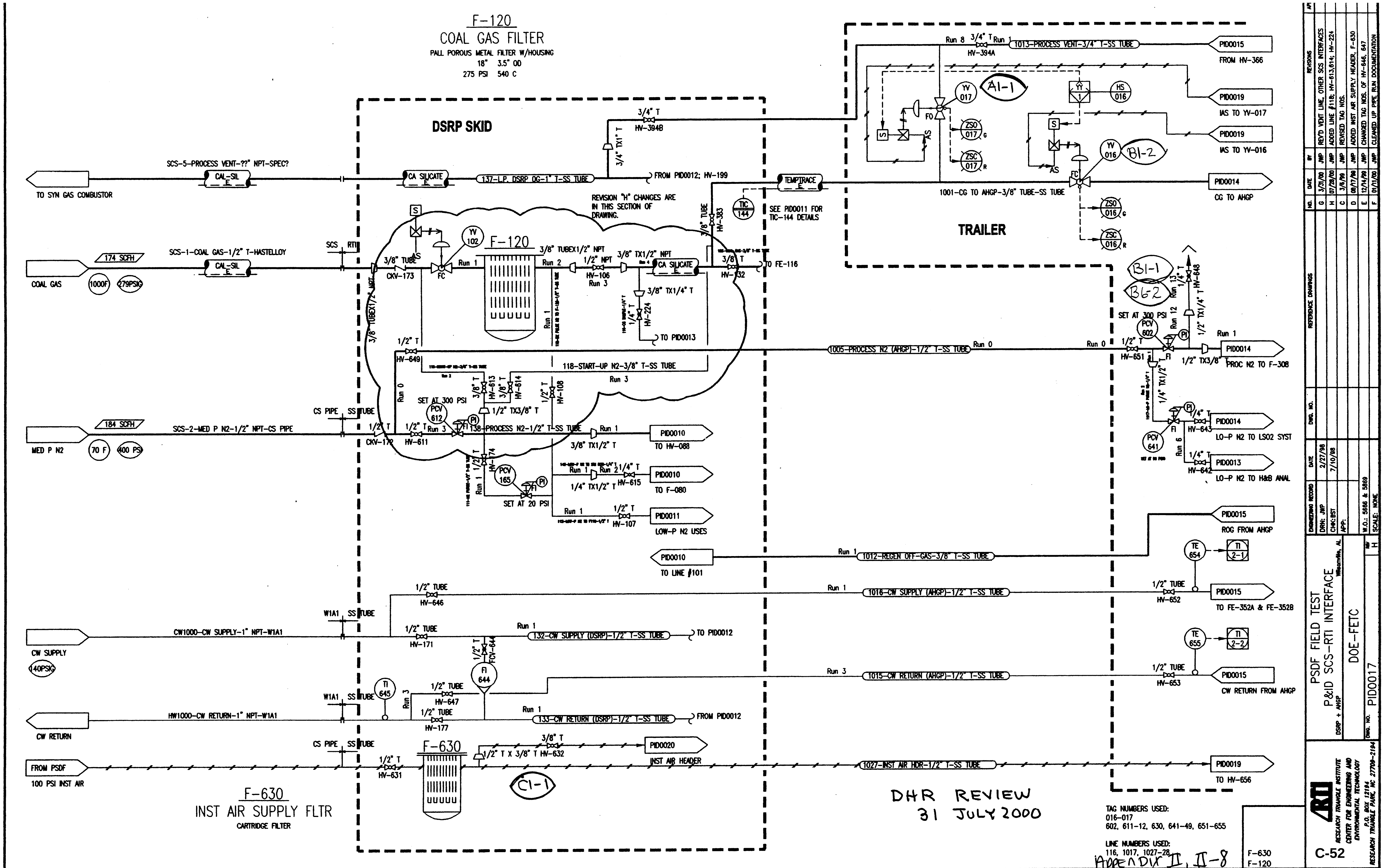
C-51



F-120
COAL GAS FILTER
PALL POROUS METAL FILTER W/HOUSING
18" 3.5" OD
275 PSI 540 C
DSRP SKID
TRAILER
TO SYN GAS COMBUSTOR
SCS-5-PROCESS VENT-??" NPT-SPEC?
CAL-SIL
CA SILICATE
137-LP. DSRP OG-1" T-SS TUBE
FROM PID0012; HV-199
3/4" T
HV-394B
3/4" TX1" T
TEMPTRACE
TIC 144
SEE PID0011 FOR TIC-144 DETAILS
REVISION "H" CHANGES ARE IN THIS SECTION OF DRAWING.
COAL GAS
174 SCFH
1000F
279PSIG
SCS-1-COAL GAS-1/2" T-HASTELLOY
SCS RTI
3/8" TUBE
CKV-173
FC
YY 102
F-120
Run 1
Run 2
3/8" TUBEX1/2" NPT
1/2" NPT
HV-106
Run 3
3/8" TX1/2" NPT
3/8" TX1/4" T
HV-224
TO PID0013
HV-383
HV-132
TO FE-116
1/2" T
HV-649
118-START-UP N2-3/8" T-SS TUBE
HV-613
HV-614
HV-108
SET AT 300 PSI
PCV 612
1/2" TX3/8" T
MED P N2
184 SCFH
70 F
400 PSI
SCS-2-MED P N2-1/2" NPT-CS PIPE
CS PIPE SS TUBE
CKV-172
HV-611
138-PROCESS N2-1/2" T-SS TUBE
PID0010
TO HV-088
3/8" TX1/2" T
HV-174
PCV 165
SET AT 20 PSI
HV-615
PID0010
TO F-080
1/4" TX1/2" T
HV-107
PID0011
LOW-P N2 USES
PID0010
TO LINE #101
1012-REGEN OFF-GAS-3/8" T-SS TUBE
1005-PROCESS N2 (AHGP)-1/2" T-SS TUBE
Run 0
SET AT 300 PSI
PCV 602
HV-651
HV-648
PID0014
PROC N2 TO F-308
1/2" TX3/8" T
PCV 641
HV-643
PID0014
LO-P N2 TO LSO2 SYST
HV-642
PID0013
LO-P N2 TO H&B ANAL
PID0015
ROG FROM AHGP
TE 654
TI 2-1
1/2" TUBE
HV-652
PID0015
TO FE-352A & FE-352B
1016-CW SUPPLY (AHGP)-1/2" T-SS TUBE
TE 655
TI 2-2
HV-653
PID0015
CW RETURN FROM AHGP
1015-CW RETURN (AHGP)-1/2" T-SS TUBE
Run 8
3/4" T
HV-394A
1013-PROCESS VENT-3/4" T-SS TUBE
PID0015
FROM HV-366
YY 017
HS 016
PID0019
IAS TO YY-017
PID0019
IAS TO YY-016
YY 016
ZSO 017
ZSC 017
ZSO 016
ZSC 016
1001-CG TO AHGP-3/8" TUBE-SS TUBE
PID0014
CG TO AHGP
A1-1
B1-2
B1-1
B6-2
CW SUPPLY
140PSIG
CW1000-CW SUPPLY-1" NPT-W1A1
W1A1 SS TUBE
HV-646
HV-171
132-CW SUPPLY (DSRP)-1/2" T-SS TUBE
TO PID0012
FCV-644
FI 644
TI 645
HV-647
HV-177
CW RETURN
HW1000-CW RETURN-1" NPT-W1A1
133-CW RETURN (DSRP)-1/2" T-SS TUBE
FROM PID0012
FROM PSDF
100 PSI INST AIR
F-630
HV-631
HV-632
PID0020
INST AIR HEADER
1027-INST AIR HDR-1/2" T-SS TUBE
PID0019
TO HV-656
C1-1
F-630
INST AIR SUPPLY FLTR
CARTRIDGE FILTER
DHR REVIEW
31 JULY 2000
TAG NUMBERS USED:
016-017
602, 611-12, 630, 641-49, 651-655
LINE NUMBERS USED:
116, 1017, 1027-28
Appendix II, II-8
F-630
F-120
PSDF FIELD TEST
P&ID SCS-RTI INTERFACE
DSRP + AHGP
DOE-FETC
PID0017
RTI
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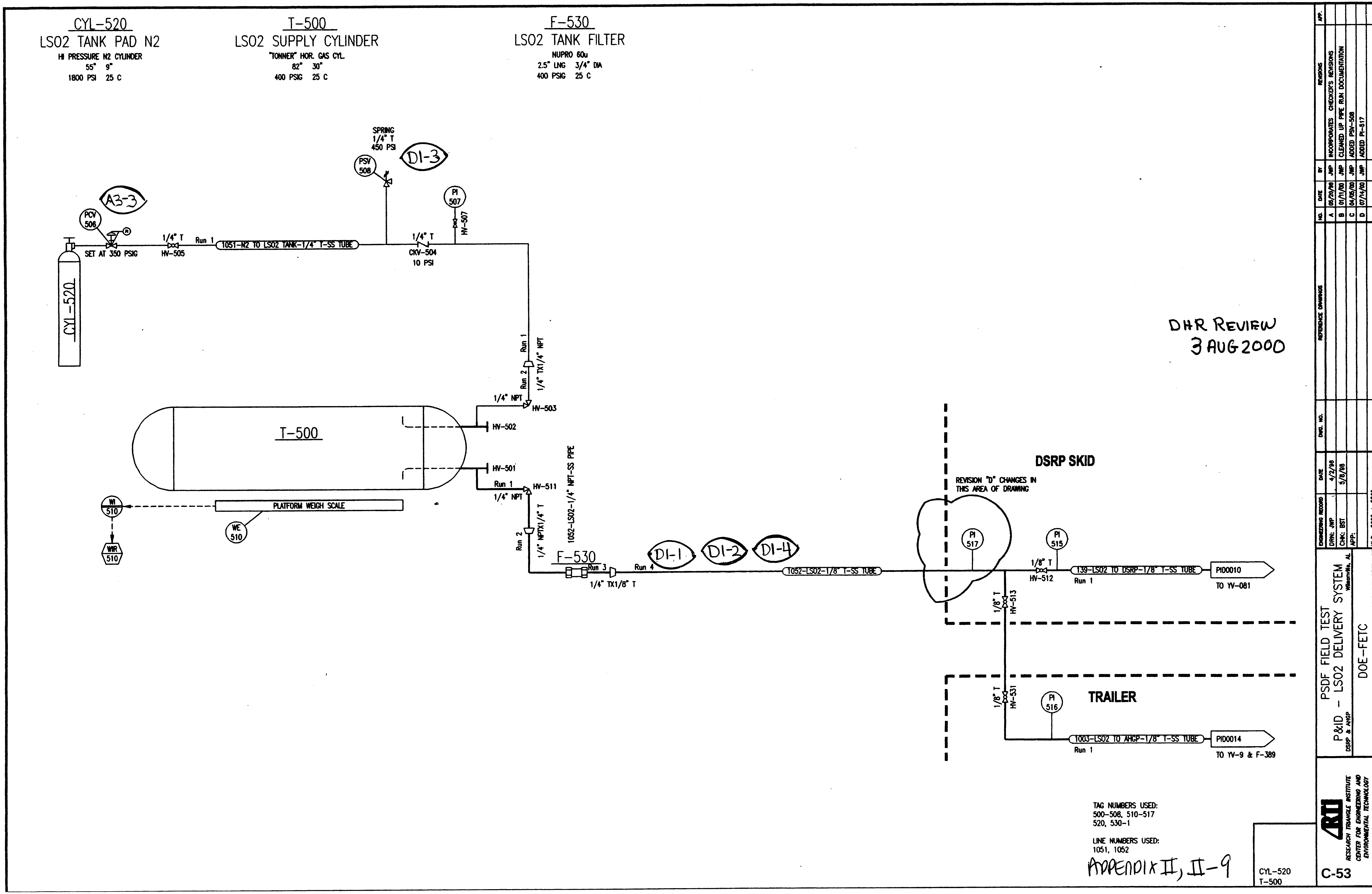
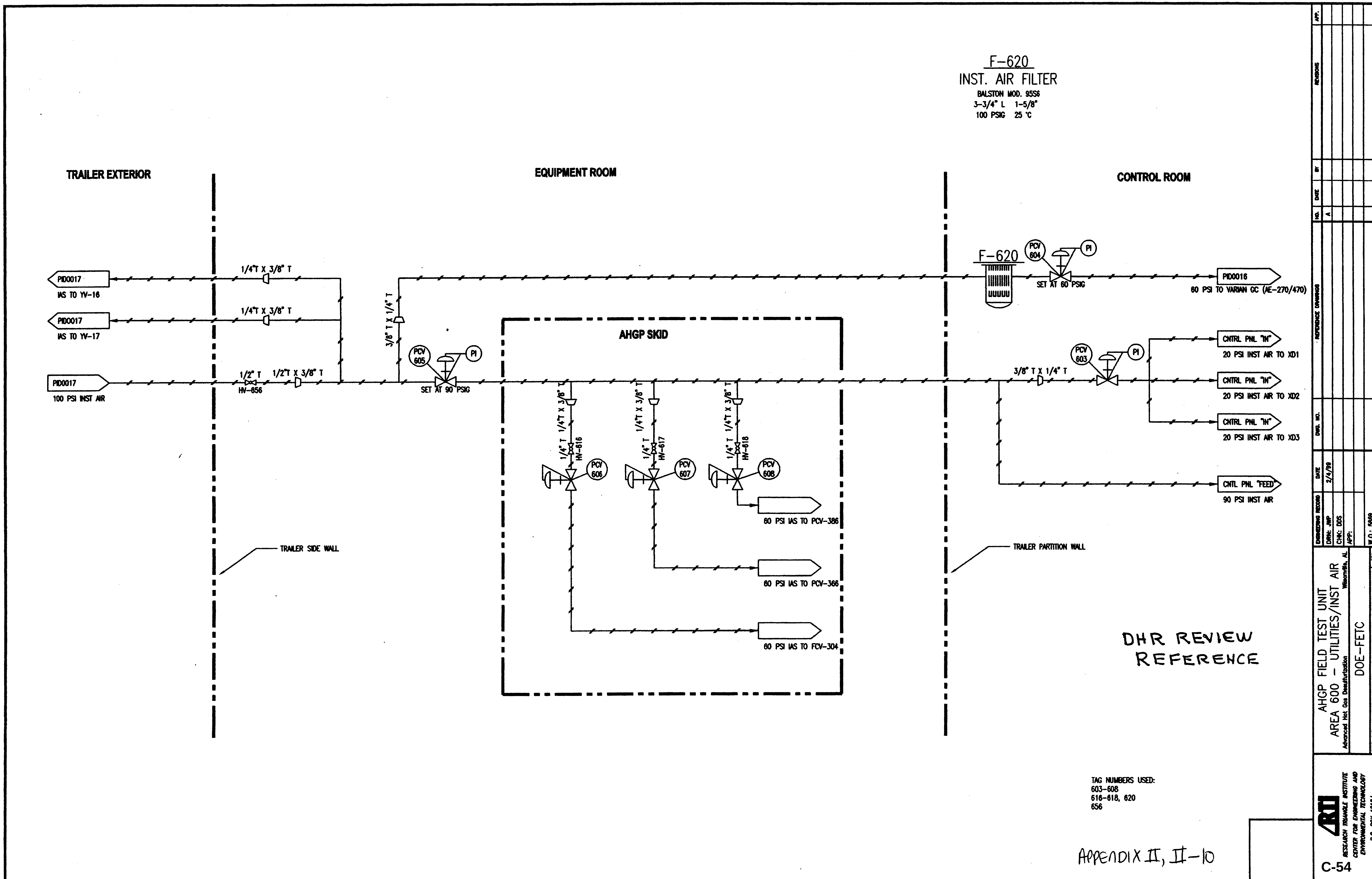
C-52
REVISIONS
G 3/31/00 JWP REV'D VENT LINE, OTHER SCS INTERFACES
H 07/28/00 JWP ADDED LINE #118; HV-613,614; HV-224
C 3/8/99 JWP REVISED TAG NOS.
D 08/17/99 JWP ADDED INST AIR SUPPLY HEADER, F-630
E 12/14/99 JWP CHANGED TAG NOS. OF HV-646, 647
F 01/11/00 JWP CLEANED UP PIPE RUN DOCUMENTATION
REFERENCE DRAWINGS
ENGINEERING RECORD
DRN: JWP 2/27/98
CHK: BST 7/10/98
W.O.: 5666 & 5869
SCALE: NONE



CYL-520
LSO2 TANK PAD N2
HI PRESSURE N2 CYLINDER
55" 9"
1800 PSI 25 C
T-500
LSO2 SUPPLY CYLINDER
"TONNER" HOR. GAS CYL.
82" 30"
400 PSIG 25 C
F-530
LSO2 TANK FILTER
NUPRO 60u
2.5" LNG 3/4" DIA
400 PSIG 25 C
SPRING
1/4" T
450 PSI
PSV 508
D1-3
A3-3
PCV 506
PI 507
HV-507
SET AT 350 PSIG
1/4" T
HV-505
Run 1
1051-N2 TO LSO2 TANK-1/4" T-SS TUBE
1/4" T
CKV-504
10 PSI
CYL-520
Run 1
Run 2
1/4" TX1/4" NPT
1/4" NPT
HV-503
T-500
HV-502
HV-501
Run 1
HV-511
1/4" NPT
1052-LSO2-1/4" NPT-SS PIPE
WI 510
PLATFORM WEIGH SCALE
WE 510
WIR 510
Run 2
1/4" NPTX1/4" T
F-530
Run 3
1/4" TX1/8" T
Run 4
D1-1
D1-2
D1-4
1052-LSO2-1/8" T-SS TUBE
DSRP SKID
REVISION "D" CHANGES IN THIS AREA OF DRAWING
PI 517
PI 515
1/8" T
HV-512
139-LSO2 TO DSRP-1/8" T-SS TUBE
Run 1
PID0010
TO YV-081
1/8" T
HV-513
DHR REVIEW
3 AUG 2000
1/8" T
HV-531
PI 516
TRAILER
1003-LSO2 TO AHGP-1/8" T-SS TUBE
Run 1
PID0014
TO YV-9 & F-389
TAG NUMBERS USED:
500-508, 510-517
520, 530-1
LINE NUMBERS USED:
1051, 1052
APPENDIX II, II-9
CYL-520
T-500
C-53
RESEARCH TRIANGLE INSTITUTE
CENTER FOR ENGINEERING AND ENVIRONMENTAL TECHNOLOGY
PSDF FIELD TEST
P&ID - LSO2 DELIVERY SYSTEM
DSRP & AHGP
Wilsonville, AL
DOE-FETC
REVISIONS
INCORPORATES CHECKER'S REVISIONS
CLEANED UP PIPE RUN DOCUMENTATION
ADDED PSV-508
ADDED PI-517


F-620
INST. AIR FILTER
BALSTON MOD. 95S6
3-3/4" L 1-5/8"
100 PSIG 25 °C
TRAILER EXTERIOR
EQUIPMENT ROOM
CONTROL ROOM
PID0017
IAS TO YV-16
PID0017
IAS TO YV-17
PID0017
100 PSI INST AIR
1/4"T X 3/8" T
1/4"T X 3/8" T
1/2" T
HV-656
1/2"T X 3/8" T
3/8" T X 1/4" T
PCV 605
PI
SET AT 90 PSIG
AHGP SKID
1/4"T X 3/8" T
1/4" T
HV-616
PCV 606
1/4"T X 3/8" T
1/4" T
HV-617
PCV 607
1/4"T X 3/8" T
1/4" T
HV-618
PCV 608
60 PSI IAS TO PCV-386
60 PSI IAS TO PCV-366
60 PSI IAS TO FCV-304
TRAILER SIDE WALL
F-620
PCV 604
PI
SET AT 60 PSIG
PID0016
60 PSI TO VARIAN GC (AE-270/470)
PCV 603
PI
3/8" T X 1/4" T
CNTRL PNL "IN"
20 PSI INST AIR TO XD1
CNTRL PNL "IN"
20 PSI INST AIR TO XD2
CNTRL PNL "IN"
20 PSI INST AIR TO XD3
CNTL PNL "FEED"
90 PSI INST AIR
TRAILER PARTITION WALL
DHR REVIEW
REFERENCE
TAG NUMBERS USED:
603-608
616-618, 620
656
APPENDIX II, II-10
AHGP FIELD TEST UNIT
AREA 600 - UTILITIES/INST AIR
Advanced Hot Gas Desulfurization
Wilsonville, AL
DOE-FETC
DWG. NO. PID0019
DRN: JMP
CHK: DDS
APP:
DATE 2/4/99
W.O.: 5669
SCALE: NONE
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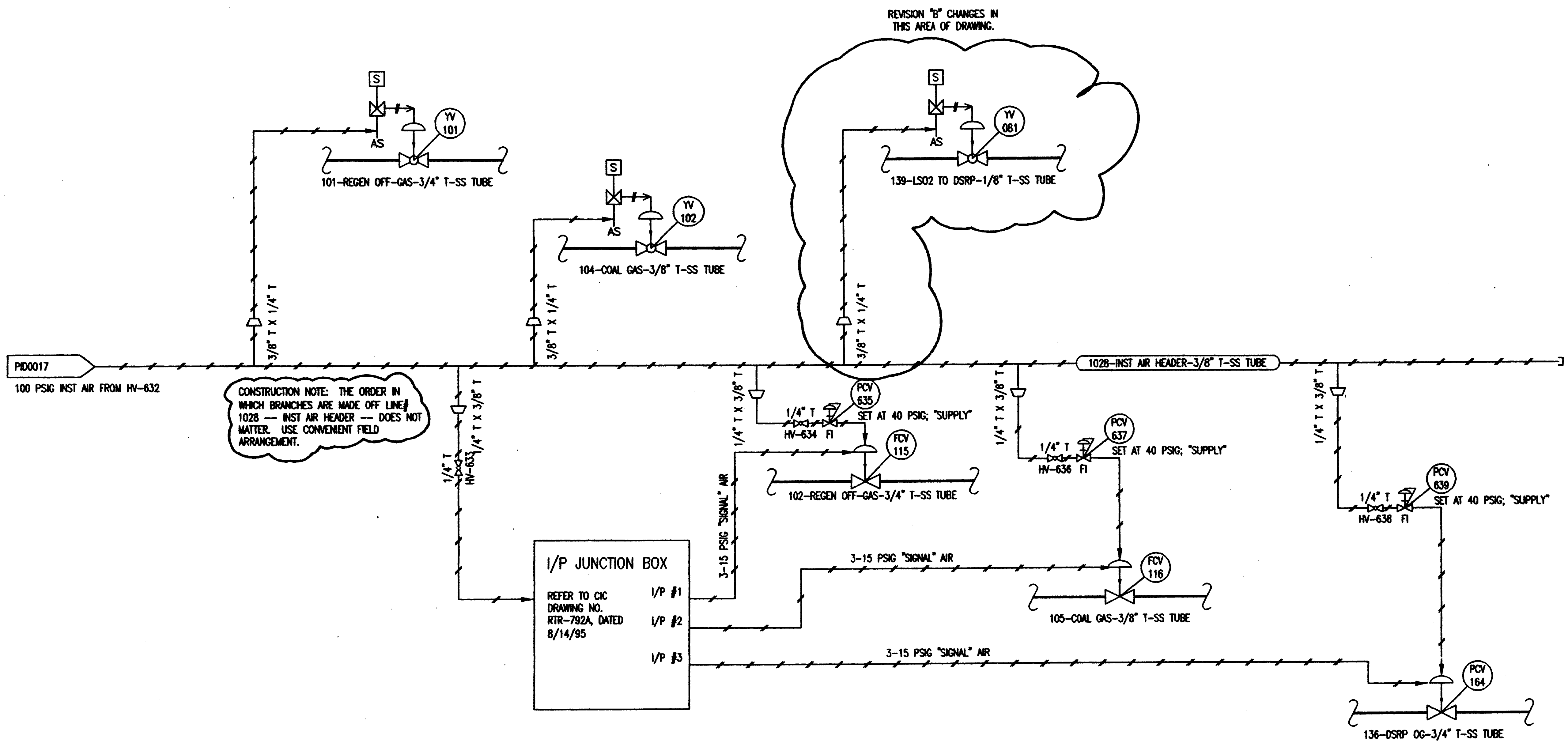
RESEARCH TRIANGLE PARK, NC 27709-2194
C-54



DHR REVIEW
3 AUG 2000

TAG NUMBERS USED:
633 - 639

LINE NUMBERS USED:
1028

APPENDIX II, II-11

NO.	DATE	BY	REVISIONS	APP
A	12/14/99	JWP	UPDATED #1028 LINE SIZE	
B	03/31/00	JWP	ADDED YV-081	

DWG. NO.	DATE	REFERENCE DRAWINGS
RTR-792A	08/16/99	ENVIROPOWER DSRP I/P JUNCTION BOX (CIC DRAWING)

ENGINEERING RECORD
DRN: JWP
CHK:
APP:
W.O.: 5666
SCALE: NONE

DSRP FIELD TEST PILOT UNIT
P&ID – INSTRUMENT AIR
Direct Sulfur Recovery Unit — Wilsonville, AL
DOE/FETC
DWG. NO. PID0020 REV B

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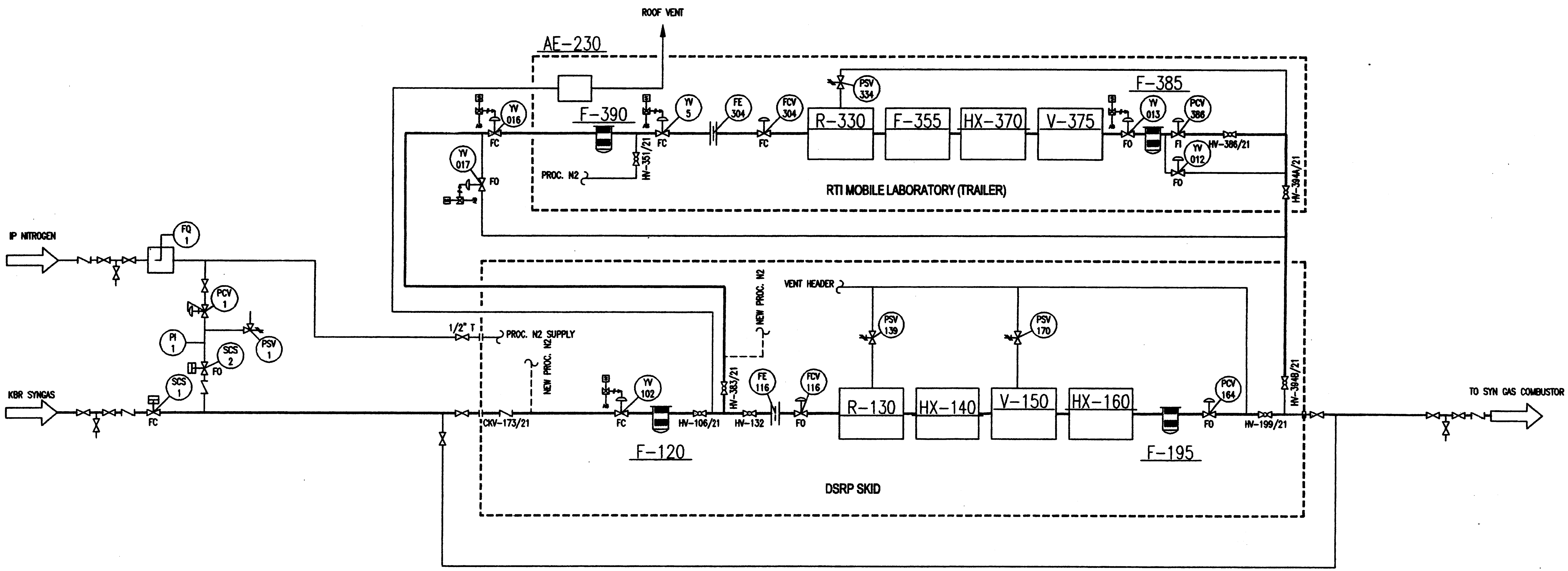
RESEARCH TRIANGLE PARK, NC 27709-2194

CADFILE–DSRP_FTI\P
W.O.L.– 03/31/00

AE-230 CO/CO2 ANALYZER | F-390 COAL GAS FILTER | R-330 FLUID-BED REACTOR | F-355 SULF'N FILTER | HX-370 WATER CONDENSER | V-375 CONDENSATE POT | F-385 SULF'N BALSTON



F-120 COAL GAS FILTER | R-130 DSRP REACTOR | HX-140 SULFUR CONDENSER | V-150 SULFUR SEPARATOR POT | HX-160 REHEATER COIL | F-195 DSRP OFF-GAS FILTER

DHR REVIEW REFERENCE

APPENDIX II, II-12

PSDF FIELD TEST
P&ID - SYN GAS LINES
DOE-FETC
PID0021

RESEARCH TRIANGLE INSTITUTE

C-56

APPENDIX A

PROCESS DESCRIPTION
(Direct Sulfur Recovery Process/Advanced Hot Gas Process)

Process Research Program

Direct Sulfur Recovery Process

- Catalyst Development
- Literature Studies and Thermodynamic Evaluation
- Sorbent Development
- Specialized Process Testing
- Material Characterization
- Process Development
- Process Research Home

Sponsor: Department of Energy

The DSRP was originally developed to treat the regeneration off-gas from metal oxide sorbent-based coal gas desulfurization processes. In these processes, the regeneration of the sorbent produces a diluted sulfur dioxide off-gas that is available at elevated pressure and temperature. Depending on the specifics of the regeneration conditions, the SO_2 content can vary. Simplified chemistry is as follows, where MO represents a generic metal oxide sorbent:

Desulfurization: $MO + H_2S \rightarrow MS + H_2O$

Regeneration: $MS + O_2 \rightarrow MO + SO_2$

The DSRP uses a stream of a reducing gas -- typically a slipstream of coal gas containing CO and H_2 in the case of coal gas desulfurization -- to convert sulfur dioxide to elemental sulfur. The feed gas is at elevated temperature and pressure, and the following (simplified) reaction takes place in a gas phase, single-stage catalytic reactor:

$$SO_2 + 2H_2 \text{ (or 2 CO)} \rightarrow 2H_2O \text{ (or } 2CO_2) + S$$

Figure 1, a simplified process flow diagram, shows how the DSRP can be integrated with hot gas desulfurization to produce a clean process gas and an elemental sulfur by-product.

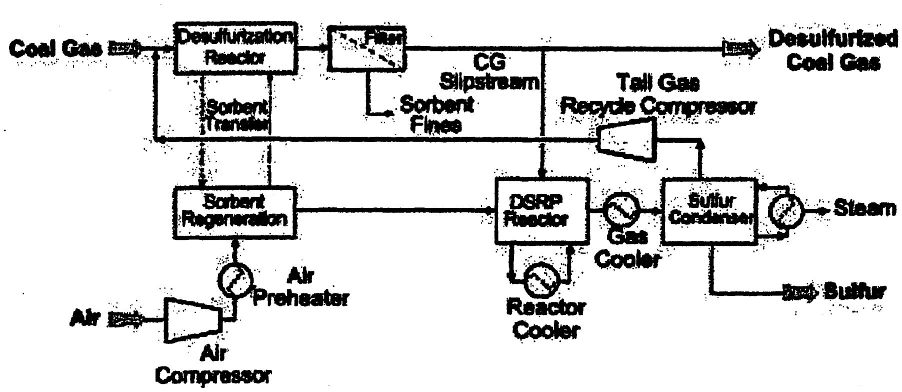


Figure 1. Conceptual DSRP integrated with hot coal gas desulfurization.

A main advantage of the DSRP is that it is a simple (single-stage) stand-alone process. It can be adapted to a variety of SO_2-containing feed gas compositions and, combined with sorbent-based desulfurization, can process a variety of H_2S-containing process gases. The disadvantage is that a valuable synthesis gas (H_2 and CO) is consumed in proportion to the amount of elemental sulfur produced. The DSRP has been extensively tested at the bench scale in the laboratory and in the field, using both simulated and actual coal gas streams. Rugged catalysts for the reaction are commercially available.

DSRP Process Development:

- Lab-scale proof-of-concept
- Laboratory testing - bench scale
- Field testing -- bench scale
- Field testing -- pilot scale.

Laboratory -- Scale Proof-of-Concept

In the late 1980s, the U.S. Department of Energy (DOE) initiated a program to develop the hot coal gas desulfurization concept. The most promising results were obtained with mixed metal oxide-based refractory sorbents. Regeneration of those sorbents with air resulted in the production of a dilute, SO_2-containing off-gas. While investigating several process concepts for the treatment of that stream, RTI's discoveries led to the concept of the Direct Sulfur Recovery Process.

The initial proof-of-concept studies were conducted in a 1-inch diameter, fixed-bed, tubular reactor ("laboratory" scale) containing 25 to 50 cm^3 of catalyst. The focus of these studies was on optimizing the operating conditions of temperature, pressure, space velocity, gas composition, and feed stoichiometry. Pressure was the most important variable, with higher pressures (over the range of 1.5 to 20 atmospheres) leading to significantly greater single-stage conversions of SO_2 to elemental sulfur. Higher temperatures (over the range of 675 to 925 K) also led to higher conversions. The DSRP reaction, unlike similar reactions encountered with the well-known Claus process for sulfur recovery, was insensitive to the steam content of the reaction mixture over the range studied.

Laboratory Testing -- Bench Scale

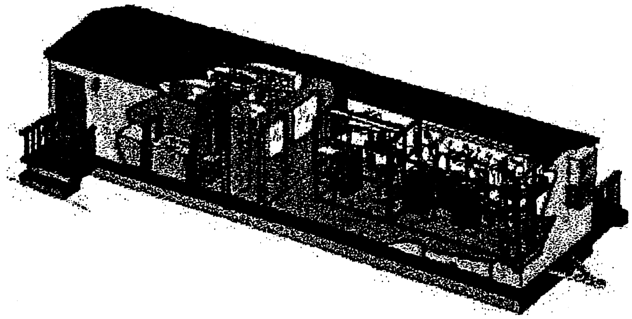


Figure 2. Artist's Conception of Mobile Laboratory showing Analytical/Control Room and Process Equipment Room.

Following the success with laboratory-scale testing, a larger apparatus was built in the early 1990s to include two stages of reaction with intermediate cooling and condensate removal. With 4-inch diameter reactor vessels holding 2-inch or 3-inch catalyst "cages," this apparatus could accommodate up to 1000 cm^3 of catalyst per reactor. It was used to screen several different catalyst formulations and to further refine the operating parameters. Various molten sulfur recovery strategies were evaluated empirically. The two reaction stages, with a different catalyst in the second stage, were integrated on the same process equipment skid, and runs of several hours' duration were achieved. In addition to the fixed-bed configuration, fluidized-bed concepts were tested.

Field Testing -- Bench Scale

Figure 3. Mobile Laboratory in place at DOE-FETC (Morgantown).

To meet the objective of testing the DSRP catalyst and process concept with actual coal gas (from a working gasifier) RTI built a Mobile Laboratory to house the already-constructed bench-scale test apparatus, control system, and gas analyzers. Constructed in a modified office trailer, the portable unit was outfitted at RTI's site in North Carolina, then transported to DOE's pilot gasifier in Morgantown, West Virginia. Testing was conducted during several gasifier campaigns, over a period of two years, and led to two important conclusions:

- a simple, single-stage process provided acceptable conversion of SO_2 to elemental sulfur (>98%)
- the presence of trace contaminants in coal gas had no deleterious effect on catalyst activity (over the time period studied).

Field Testing -- Pilot Scale

To accomplish larger scale testing of the DSRP, a skid-mounted unit with a 6.0-inch diameter reactor was designed and fabricated, as the photographs show. The current emphasis is on development of a fluid-bed reactor-based process to handle the highly exothermic DSRP reactions. The SO_2 concentration in the sorbent regeneration off-gas in the more-recent hot gas desulfurization process designs is higher, resulting in higher heat densities in the DSRP reaction. In addition, demonstration of extended operation with actual coal gas and consistent production of elemental sulfur is necessary to gain commercial acceptance of the technology.

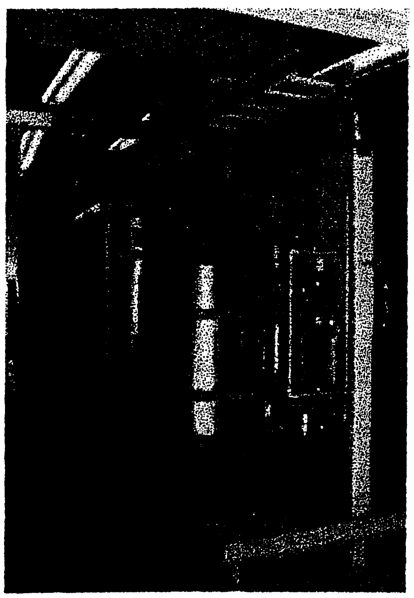


Figure 4. DSRP Field Test Pilot Unit being fabricated in RTI shop: gas inlet end of unit.

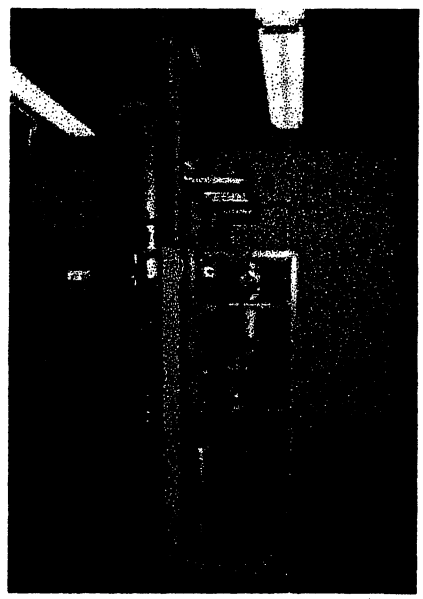


Figure 5. DSRP Field Test Pilot Unit being fabricated in RTI shop: gas outlet end of unit.

For field testing it is planned that the DSRP skid, under a shed roof, will sit alongside the Mobile Laboratory, which is being refitted to be used as a control room, shown below in Figure 6.

Preparations are actively under way for conducting a long-duration field test of the skid-mounted DSRP in the fluid-bed mode, with a slipstream of actual coal gas at the Power Systems Development Facility (PSDF) in Wilsonville, Alabama. Modifications of the skid-mounted DSRP unit are being made in the RTI shop, consistent with specific site requirements. The Mobile Laboratory refitting is also being done at RTI, and it, along with the skid-mounted DSRP will be moved to Wilsonville, Alabama, for the testing to be conducted in the 1999 - 2000 time frame.

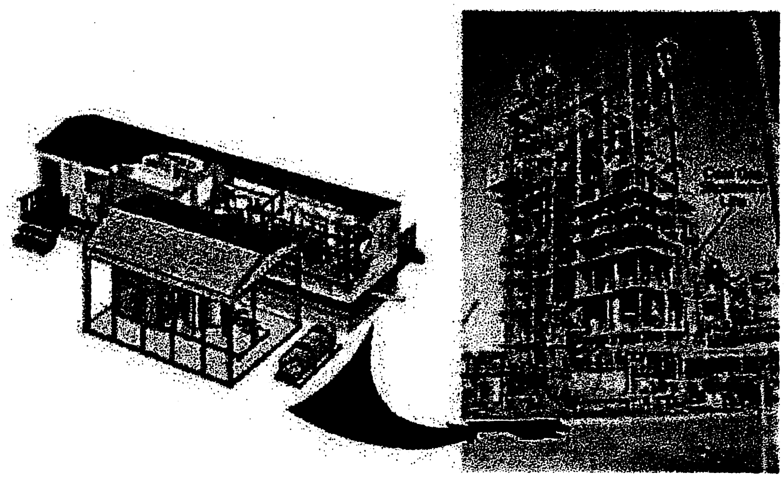


Figure 6. Planned field test of the DSRP at DOE's Power System Development Facility in Wilsonville, AL.

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- Santosh Gangwal, phone:(919) 541-8033, fax:(919)541-8000, skg@rti.org
- Jeffrey Portzer, phone:(919)541-8025, fax:(919)541-8000, jwp@rti.org

References:

PATENTS:

Dorchak, T.P., S.K. Gangwal, and S.M. Harkins, U.S. Patent 5,366,717. Method for Producing Elemental Sulfur from Sulfur-Containing Gases. Nov. 11, 1994.

Dorchak, T.P., S.K. Gangwal, and S.M. Harkins, U.S. Patent 5,798,088. Method for Producing Elemental Sulfur from Sulfur-Containing Gases. Aug. 25, 1998.

PUBLICATIONS:

Dorchak, T.P., S.K. Gangwal, and W.J. McMichael. 1991. The Direct Sulfur Recovery Process. *Environmental Progress* 10(2):68.

Portzer, J.W., and S.K. Gangwal. 1994. "Slipstream Testing of the Direct Sulfur Recovery Process" in *Proceedings of the Coal-Fired Power System 94-Advances in IGCC and PFBC Review Meeting*, 246-255. DOE/METC-94/1008, Vol. 1.

NTIS/DE94012252. Springfield, VA: National Technical Information Service.

Portzer, J.W., and S.K. Gangwal. 1995. "Slipstream Testing of Hot-Gas Desulfurization with Sulfur Recovery." In *Proceedings of the Advanced Coal-Fired Power Systems '95 Review Meeting*, 220-228. DOE/METC-95/1018, Vol. 1. NTIS/DE95009732. Springfield, VA: National Technical Information Service.

Portzer, J.W., B.S. Turk, and S.K. Gangwal. 1996. "Durability Testing of the Direct Sulfur Recovery Process." In *Proceedings of the Advanced Coal-Fired Systems Review Meeting July 16-19, 1996.* (CD-ROM). U.S. Department of Energy, Morgantown, WV.

Portzer, J.W., and S.K. Gangwal. 1997. "Bench-Scale Demonstration of Hot-Gas Desulfurization Technology." In *Proceedings of the Advanced Coal-Based Power and Environmental Systems '97 Conference. July 22-24, 1997.* (CD-ROM). DOE/FETC-97/1046. U.S. Department of Energy, Federal Energy Technology Center.

Portzer, J.W., and S.K. Gangwal. 1998. "Bench-Scale Demonstration of Hot-Gas Desulfurization Technology." In *Proceedings of the Advanced Coal-Based Power and Environmental Systems '98 Conference.* July 21-23, 1998.

General inquiries may be directed to listen@rti.org.
Inquiries and comments about these pages may be directed to webmaster@rti.org.

Research Triangle Institute, 3040 Cornwallis Road, Research Triangle Park, North Carolina 27709 USA
Telephone: 919-541-6000

Advanced Hot Gas Process

Specifically oriented to H_2S-containing process gas streams, such as coal gas in an IGCC power plant, the Advanced Hot Gas Process (AHGP) combines metal oxide sorbent-based desulfurization with special sorbent regeneration for **direct production of elemental sulfur**. The intermediate, dilute SO_2 stream -- which arises from oxygen regeneration of the sulfided sorbent -- that the DSRP is designed to treat is eliminated, as is the slipstream of coal gas needed for the reduction reaction. In the AHGP a recycle stream of high concentration SO_2 oxidizes the absorbed hydrogen sulfide directly to elemental sulfur. In addition, a portion of the sorbent is regenerated with oxygen (introduced into the recycle SO_2 stream) in a "polishing" regeneration that also produces sulfur dioxide to balance the consumption. The simplified overall reactions are as follows (where MO represents a generic metal oxide sorbent):

Desulfurization: $MO + H_2S \rightarrow MS + H_2O$

SO_2 regeneration: $2\ MS + SO_2 \rightarrow 2\ MO + 3\ S$

O_2 regeneration: $MS + 3/2\ O_2 \rightarrow MO + SO_2$

Figure 7 shows a conceptual process design for the AHGP to regenerate the desulfurization sorbent directly to elemental sulfur with minimal consumption of coal gas. In this process, a zinc-iron sorbent is used and the regeneration is carried out in two stages with SO_2 and O_2, respectively. The iron sulfide is regenerated by SO_2 in one stage to elemental sulfur. In the other stage, zinc sulfide and any remaining iron sulfide are regenerated by O_2 to provide the required SO_2. The sorbent is then returned to the desulfurizer.

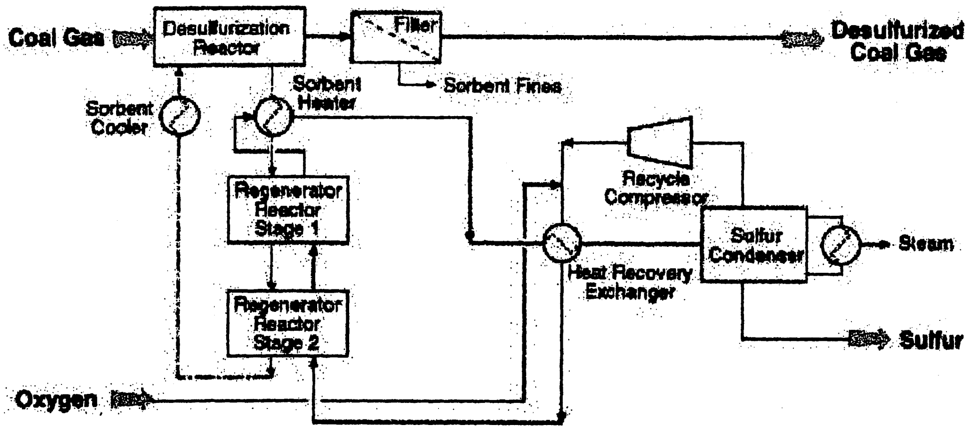

Figure 7. AHGP Conceptual Process Flow Diagram.

The key chemical reactions of interest are as follows:

1. Sulfidation

$Fe_2O_3 + 2H_2S + H_2 \dashrightarrow 2FeS + 3H_2O$

$ZnO + H_2S \dashrightarrow ZnS + H_2O$

2. SO_2 regeneration

$4FeS + 3SO_2 \dashrightarrow 2Fe_2O_3 + 7/2\ S_2$

3. O_2 regeneration

$2FeS + 7/2\ O_2 \dashrightarrow Fe_2O_3 + 2SO_2$

$ZnS + 3/2\ O_2 \dashrightarrow ZnO + SO_2$.

AHGP Process Development

- lab-scale proof-of-concept
- laboratory testing -- bench scale
- engineering analysis

Laboratory-Scale Proof-of-Concept

The feasibility of SO_2 regeneration of combined zinc-iron sorbents was demonstrated using a thermogravimetric analyzer and high-pressure microreactor. Zinc sulfide shows essentially no SO_2 regeneration at temperatures of interest (500 to 600 degrees C), but zinc is needed to act as a polishing agent in the desulfurizer.

Laboratory Testing -- Bench Scale

A number of sorbents were prepared and tested at the bench scale ove multiple cycles. Based on these tests, a highly attrition-resistant sorbent (R-5-58) was prepared and the process was demonstrated over 50 cycles in a 7.5-cm I.D. bench-scale fluidized bed reactor.

The results showed that R-5-58 removed H_2S down to 50- to 100-ppm levels with stable desulfurization activity over the duration. The surface area and pore volume of the sorbent did not change appreciably and the attrition index before and after the test was 3.6% and 1.2%, respectively. Sulfur balances were adequate and the SO_2 regeneration step accounted for up to 70% of the total regeneration of the sorbent. This compares to a theoretical limit of approximately 80%, assuming complete regeneration by SO_2 of the iron component

Engineering Analysis

An engineering and economic evaluation of the DSRP and AHGP for large-scale IGCC plants was conducted in partnership with the Chemical Engineering Department at North Carolina State University (NCSU) using ASPEN PLUS® computer process simulation software and published generalized cost estimating methods (Gangwal*et al.* 1998) . For both processes the scope of the equipment and process steps included in the simulations were the same: coal gas desulfurization (but not the high temperature particulate removal), regeneration of the desulfurizing sorbent, and production, isolation, and short term storage of elemental sulfur.

The recovered sulfur was assumed to have a market value, and thus generate a cost credit. Coal gas consumed in the process was evaluated at a cost based on the potential power generation that was lost. High pressure steam generated in the process was assumed to provide a cost credit based on the power that could be recovered from it. Base case simulations of both processes assumed 0.85 mol% H_2S in the coal-gas feed. Such an H_2S concentration in the coal gas would be produced by an oxygen-blown Texaco gasification using a roughly 3.6 wt% sulfur-containing coal. Both base cases generate 260 MWe from the clean coal gas.

Figure 8 summarizes the results of the engineering analysis. The ASPEN simulations of DSRP and AHGP revealed the complexity of both hot gas desulfurization processes.

The AHGP appears to be the more difficult process to operate and may require more employees than the DSRP. Capital costs for the AHGP are higher than those for the DSRP--development of DSRP is also much closer to commercialization than AHGP. However, annual operating costs for the AHGP appear to be considerably less than those of the DSRP. Preliminary economic comparison shows that the total cost (capital plus cumulative operating cost) of implementing AHGP will be less than that of implementing DSRP after as little as 2 years of operation. Thus, despite its greater complexity, the potential savings with the AHGP encourage further development and scaleup of this advanced process.

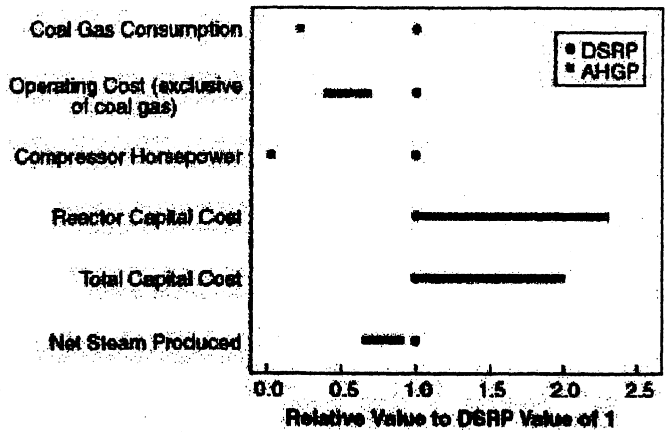

Figure 8. Comparison of key elements of AHGP and DSRP.

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