Greenhouse Gas Technology Verification Center

A USEPA Sponsored Environmental Technology Verification Organization

Testing and Quality Assurance Plan for the C. Lee Cook Division, Dover Corporation Static Pac® System

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APPENDIX

1.0 BACKGROUND AND INTRODUCTION

The Environmental Technology Verification (ETV) program was established by the United States Environmental Protection Agency (EPA) in response to the belief that there are many viable environmental technologies which are not being used for the lack of credible third-party performance testing. With the performance data developed under the program, technology buyers and permitters in the United States and abroad will be better equipped to make informed environmental technology purchase decisions. In late 1997, EPA selected Southern Research Institute to manage 1 of 12 ETV verification entities: The Greenhouse Gas Technology Verification Center (the Center). Eleven other ETV entities are currently operating throughout the United States conducting third-party verifications in a wide range of environmental media and industries.

In March of 1997, the Center met with members of the Executive Stakeholder Group. In that meeting it was decided that the oil and gas industries were good candidates for third-party verification of methane mitigation and monitoring technologies. As a consequence, in June 1998, the Center hosted a meeting in Houston, Texas with operators and vendors in the oil and natural gas industries. The objectives of the meeting were to: (1) gauge the need for verification testing in these industries, (2) identify specific technology testing priorities, (3) identify broadly acceptable verification and testing strategies, and (4) recruit industry stakeholders. Industry participants voiced support for the Center's mission, identified a need for independent third-party verification, and prioritized specific technologies and verification strategies. Since the Houston meeting, a 19 member Oil and Gas Industry Stakeholder Group was formed, vendors of GHG mitigation devices were solicited in several top-rated technology areas, and verification testing of one compressor leak mitigation device has started.

C. Lee Cook Division of the Dover Corporation has committed to participate in a long-term independent verification of their rod leak prevention technology. C. Lee Cook's Static Pac[1] is designed to reduce methane leaking from compressor rod seals during periods of compressor shutdown without full depressurization. There are over 13,000 natural gas compressors operating in the United States alone, a significant number of them experiencing frequent shutdowns. When the compressor remains pressurized during these periods, rod leaks continue at rates similar to

[1] Static Pac is a registered trademark of the C. Lee Cook Division of Dover Corporation.

those during normal operation. According to the Gas Research Institute/Environmental Protection Agency study "Methane Emissions From the Natural Gas Industry ("GRI Study"), compressor rod seal leaks during periods of shutdown represent a major source of methane emissions, and a significant loss of economic and natural resources.

A test of the Static Pac device will be carried out at a compressor station operated by ANR Pipeline Company (ANR) of Detroit, Michigan. This Test Plan describes the technology to be tested, and outlines the Center's plans to conduct the verification in a field setting.

Field testing of the Static Pac is scheduled to begin at the ANR site in June 1999, and will continue for a 4 to 6 month period. After initial installation and testing is complete, the Center will issue a Phase I Report, containing installation and initial verification measurements data (September 1999). After all testing is complete, a Phase II Report will be issued which contains longer-term technical and economic performance verification data (2 months after–completion of the field evaluation). The specific verification parameters associated with the Phase 1 and Phase II efforts are listed below. Determination of each parameter is discussed in Section 2.2.

<u>Phase I Static Pac Evaluation:</u>

- Document initial gas savings for primary baseline operating conditions (Case 1 and Case 2, see Section 2.2)
- Document capital, installation, and shakedown requirements and costs

<u>Phase II Static Pac Evaluation:</u>

- Document annualized gas savings for primary baseline conditions
- Document methane emission reduction
- Calculate and document Static Pac payback period

Phase I goals will be achieved through observation, collection and analysis of direct gas measurements, and use of site operator logs and vendor supplied cost information.

A primary goal of Phase II is determination of the Static Pac payback period. As a practical matter, the Center cannot conduct direct testing for the several years that would be required to determine payback entirely through direct gas and other measurements or for the myriad of variations in the frequency and duration of compressor operating/shutdown cycles. Thus, several Phase II goals will be accomplished through a combination of medium-term measurements (3 to 6 months), data extrapolation techniques, and collecting and presenting data adequate to calculate payback for various operating/shutdown cycles. Extrapolation and other assumptions will be transparent in the final report, allowing readers to make alternate assumptions and assessments if they wish.

2.0 TECHNOLOGY DESCRIPTION AND VERIFICATION APPROACH

2.1. STATIC PAC SYSTEM DESCRIPTION

The Static Pac is a gas leak containment device designed to prevent rod packing leaks from escaping into the atmosphere during compressor shutdown periods. The Static Pac system is installed in a conventional packing case by replacing several cups (typically 2) in the low-pressure side of the packing case (see Figure 1).

Upon shutdown of the compressor, the compressor control system activates the Static Pac control system and a pressurized gas is used to move a piston along the outer shell of the Static Pac seal, wedging a lip seal into contact with the rod (see Figures 1 and 2). When the actuating pressure is lowered, the piston retracts, releasing the Static Pac seal. Leaks that normally occur during periods of shutdown are reported by Cook to be completely or nearly eliminated.

Because the Static Pac requires modification of the conventional packing case, resulting in a "missing seal", it is speculated that increase in rod emissions can occur while the compressor is in operating mode. However, industry experience suggests that the Static Pac should not affect normal sealing during compressor operation. The Center has been unable to locate reliable data that verified this. Therefore, the verification test will include assessment of the effect (if any) of the Static Pac on normal sealing performance during compressor operation. This will be accomplished by fitting one rod on the test engine with a Static Pac and the second rod with a new conventional packing. A second engine will be fitted in the same manner to provide duplicate measurements.

"STATIC-PAC is a Registered Trademark of C. LEE COOK and covered by Patent No. 4469017."

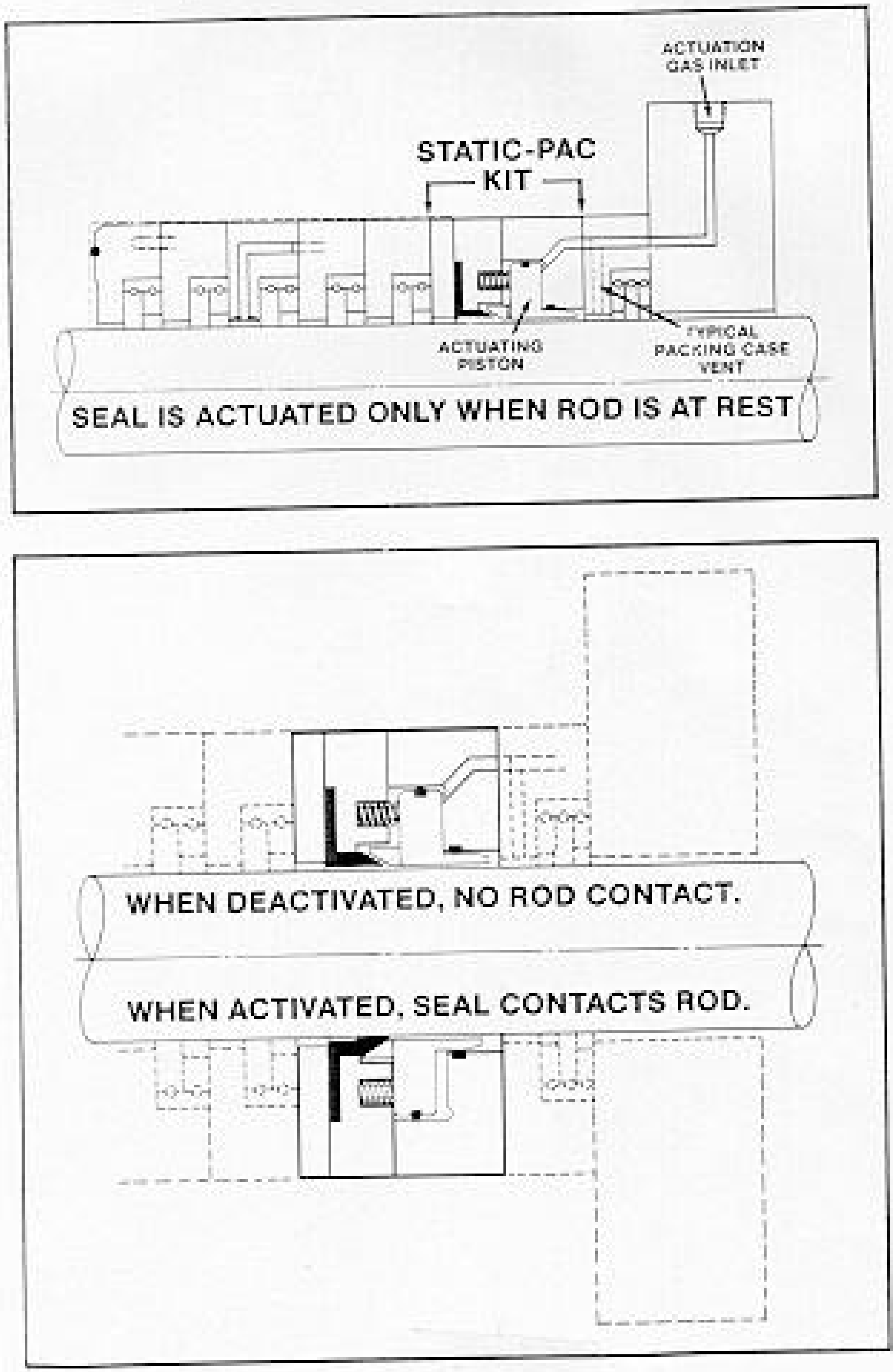

Figure 1-a. The Static Pac Activation and Deactivation Process

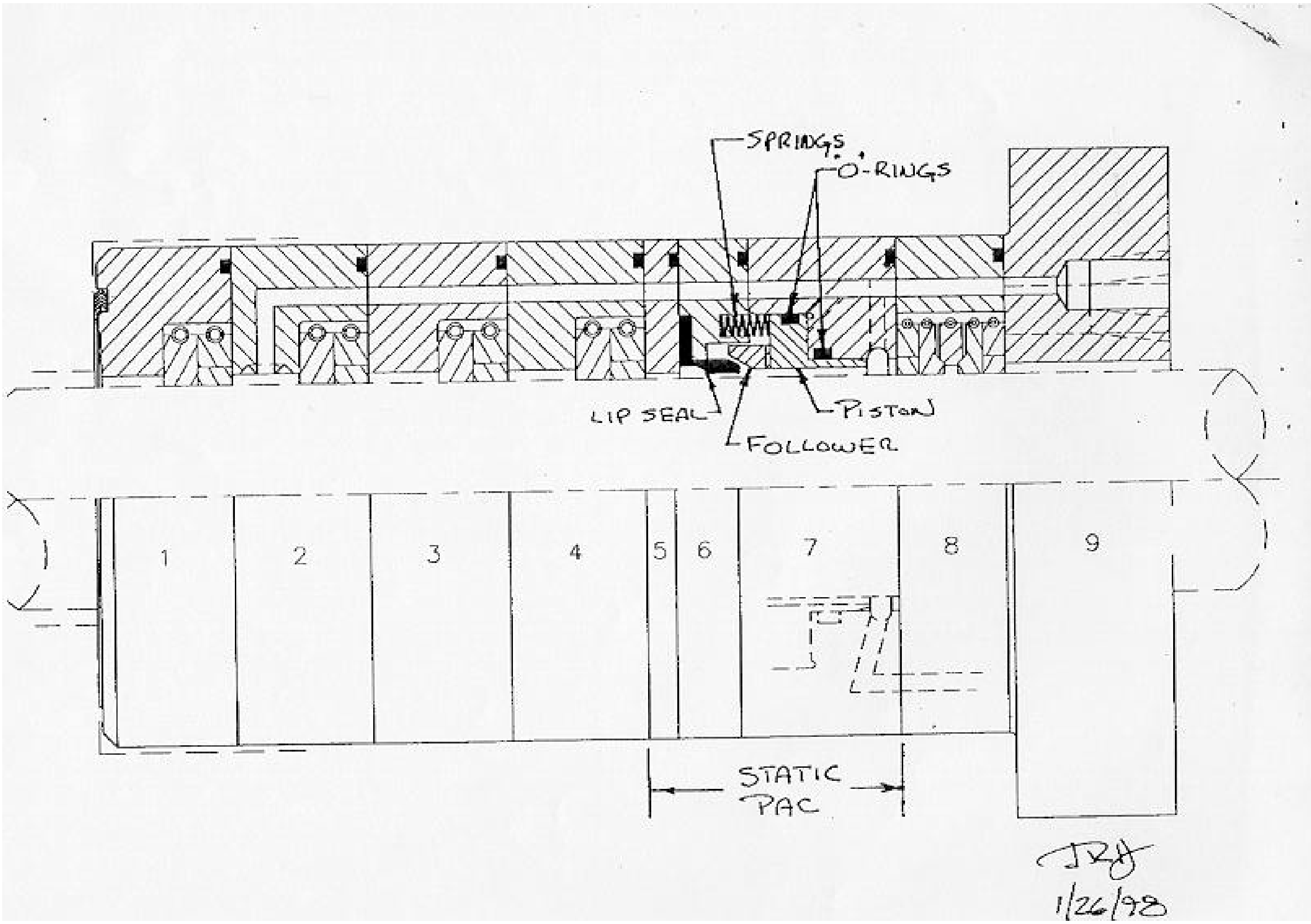

Figure 1-b. Rod Packing Cutaway With Static Pac

2.2. VERIFICATION PARAMETERS AND THEIR DETERMINATION

2.2.1. Approach

Because the Static Pac operates only when the compressor is shut down, the gas savings depend on the number and duration of shutdown periods. In addition, changes in operating procedures associated with installation of the static seal must be considered in determining net gas savings.

Normal compressor shutdown procedures vary from station to station. In general, the following procedures are used:

- Depressurize/blow-down all pressure (except a small residual pressure to prevent air inleakage) and vent the gas, either partially or completely, to the atmosphere,
- Maintain pressure, either with or without the unit isolation valves open,
- Depressurize to a lower pressure, either venting the gas to the atmosphere or to the station fuel system, or
- A combination of these procedures.

Adding a Static Pac to a compressor will result in varying levels of net gas savings and emission reductions depending on the current shutdown procedure. Evaluation of net emission reductions for Static Pac operation requires quantifying any significant leak rate changes resulting from normal Static Pac operation and related changes in operating procedures.

A station that currently leaves compressors pressurized during shutdown will realize net savings simply from the decrease in the rod packing leak rate due to the action of the static seal. If a station that currently blows down its compressors during shutdown were to add static seals, it is presumed that the station would also go to a pressurized shutdown condition. In this case, the savings result from the eliminated blow-down and the unit valve leak (the unit valves are prevented from leaking because the unit now remains pressurized). There is also the potential for increases in emissions at components now exposed to pressure during shutdown. This includes the rod packing (if the static seal is not 100 percent effective, valves, fittings, and other components.

Table 1 shows the relationship between operating procedures and emission changes for common compressor system shutdown scenarios.

Table 1. Common Shutdown Scenarios and Emissions Changes with Static Seals

CH_4 SOURCE	CASE #1	CASE #2	CASE #3	CASE #4	CASE #5
Current shut down procedure	Pressurized shutdown with unit valves open	Blow-down/ 100% vent to atmosphere	Pressurized shutdown with unit valves closed	Depressurize to a lower pressure a. Vent to atmosphere b. Vent to fuel system	Depressurize/ vent to fuel system, then vent to the atmosphere
Procedure with static seal	n/c	Pressurized shutdown	n/c	Pressurized shutdown	Pressurized shutdown
Emissions Changes with Static Seal					
Rod Seals	Decrease	small increase?	decrease	small increase?	small increase?
Blow-down volume	n/c	Decrease	n/c	a. decrease b. decrease	decrease
Unit valves	n/c	Decrease	n/c	a. decrease b. n/c	decrease
Blow-down valve	n/c	Increase	n/c	a. increase b. increase	increase
Pressure relief valve	n/c	Increase	n/c	a. increase b. increase	increase
Misc. valves, fittings, flanges, etc.	n/c	Increase	n/c	a. increase b. increase	increase

NOTES: n/c - no change/effectively no change

The evaluation of the Static Pac performance at ANR Pipeline Company will focus on two operating conditions, the pressurized when in idle mode operating condition (Base Case 1) and the compressor blow-down when idle operating condition (Base Case 2). These two operating procedures appear to represent the normal approach to compressor shutdown. Based on data contained in the GRI methane study (GRI 1996), about 57 percent of idle transmission compressors are maintained at operating pressure and 38 percent are blown-down to atmospheric. A smaller percentage (less than 5 percent) are blown-down to a lower pressure (in some cases venting to the fuel system). The following discussion highlights the verification issues for each case and outlines measurement and data collection activities needed to implement the verification test.

Case 1. The baseline for this case is a compressor that normally maintains full operating pressure during idle periods. The addition of the Static Pac should eliminate leaks that occur during idle periods and cause no increase in the leak rate while the compressor is operating.

Continuous measurements of the rod packing leak rate will be made during the entire test period. Emissions reductions will be determined by comparing uncontrolled emissions (with the Static Pac disabled) with emissions controlled by the Static Pac. A second measure of uncontrolled emissions will be obtained based on measurements of emissions during idle periods from a second rod on the same engine using conventional packing. This arrangement will be repeated on two separate engines in order to provide a more reliable and robust data set.

Continuous leak rate measurements on the control rods during operation will be used as a baseline for verifying that the Static Pac does not cause any increase in the operating leak rate of the rod packing.

Disabling the Static Pac is a manual operation that will require Center test personnel or a site operator to manually disable the Static Pac during a shutdown period for a sufficient period to allow the packing to cool and representative measurements to be obtained (several hours). This will require a scheduled shutdown and will be conducted during each of three intensive measurement periods to be conducted at the start of the test, at the end of Phase I, and at the end of the test. If additional quantifications are needed (due to variability in the leak rate or changes in operating conditions), site personnel can be called upon to perform additional shutdowns.

In addition, it is possible that there is a relationship between operating emissions and idle emissions with the Static Pac disabled. Data collected during the intensive measurement periods will allow assessment of whether there is a correlation. If a correlation is found, then operating emissions immediately before and after each shutdown period could be used to refine the analysis by providing greater capture of emissions changes over time.

To verify that the Static Pac does not cause any increase in the operating leak rate of the rod packing, continuous leak rate measurements will also be made on a second unit fitted with new seals at the time of Static Pac installation.

Because the unit pressure is essentially unchanged during both operating and idle periods, all other component leak rates (pressure relief valve, blown-down valve, unit valves, and miscellaneous flanges, valves, and fittings) can be anticipated to remain constant after installation of the Static Pac. This will be verified by manual measurements before and after installation.

Case 2. The baseline for this condition is a compressor that normally blows down from operating pressure to a minimum pressure level during idle periods. At such times, the pressure on compressor components is reduced to near zero and any rod packing, pressure relief valve and blown-down valve leaks cease. However, any leaking gas from the unit valves isolating the compressor is lost. The gas leaks into the compressor system and passes to the atmosphere through the open blown-down valve to the open-ended blow-down line. Based on available data, this loss from the unit valves can be substantial (see Table 2). To address this, unit valve leak rates will be measured (manually) periodically during the study.

In addition, the compressed gas contained in the compressor lines is lost during the blow-down. This will be calculated based on known volumes of compressor components and operating pressure.

For Case 2, emissions reductions are gained by changing the shutdown procedure to leaving the compressor pressurized during idle periods. This eliminates losses due to the blow-down volume and unit valve leaks. The Static Pac serves to eliminate the increase in rod packing emissions during idle periods that results from leaving the unit pressurized.

In order to determine net gas savings, any increase in leaks from the pressure relief valve, blow-down valve, and various flanges, connectors, and valves due to leaving the unit pressurized must be measured. The sum of any increase in leaks from these components offsets the gas savings described above.

Components that require quantification of gas leak rate during the evaluation are identified in Table 2. The table also presents estimates of the leak rate for each component (GRI 1996) and indicates gas savings or loss associated with each component for each test scenario.

Table 2. Leak Sources, Emissions, and Gas Savings

Emissions Sources	Notes	Gas Savings/Loss Associated with Emissions Packing (Mcf/yr)			Gas Savings/Loss
		high	low	avg	
Compressor Seal	**Unit Idle, Pressurized**	2,212	84	670	Case 1 Savings
Compressor Seal	**Unit Operating**	(0)	(0)	(0)	Case 1 Loss
		2,212	**84**	**670**	**Case 1 Net Gas Savings**
Blow-down Volume	**Loss eliminated due to change in operating procedure associated with static seal**	2,750	220	825	Case 2 Savings
Unit Valves	**Loss eliminated due to change in operating procedure associated with static seal**	2,916	67	1,491	Case 2 Savings
Blow-down Valve	**Unit Idle, Pressurized**	(587)	(235)	(436)	Case 2 Loss
Pressure Relief Valve	**Unit Idle, Pressurized**	(256)	(0)	(149)	Case 2 Loss
Misc. Components	**Unit Idle, Pressurized**	(75)	(52)	(64)	Case 2 Loss
Compressor Seal	**Unit Idle, Pressurized**	(0)	(0)	(0)	Case 2 Loss
Compressor Seal	**Unit Operating**	(0)	(0)	(0)	Case 2 Loss
		4,748	**0**	**1,668**	**Case 2 Net Gas Savings**

2.2.2. Phase I Static Pac Evaluation

<u>Document Initial Gas Savings for Baseline Operating Conditions (Case 1, Case 2)</u>

Initial gas leak prevention effectiveness will be determined and reported in the Phase I Report after at least 4 weeks of continuous monitoring data and two sets of manual leak tests have been collected and analyzed. Net gas savings will be determined separately for Case 1 and Case 2 as discussed above.

For Case 1, the savings consist solely of the gas prevented from leaking from the rod packing during idle periods. This is the difference between the leak rate without the Static Pac and the leak rate (if any) with the Static Pac. The leak rate without the Static Pac (uncontrolled emissions) will be measured directly by disabling the Static Pac during scheduled shutdowns. It may also be possible to use the running leak rate (when the Static Pac is inactive) as a surrogate for uncontrolled emissions - provided that a sound correlation can be established between the running leak rate and true uncontrolled emissions. Finally, if it is determined that the Static Pac causes any increase in emissions during operation, these emissions must be subtracted from the gas savings.

This is represented mathematically in Equation 1.

$$\mathbf{G\_1_i = [Q_d - Q_s] * t} \qquad \text{(Eqn. 1)}$$

Where,
G_1 = gas savings for Case 1, scf
Q_d - uncontrolled leak rate (Static Pac disabled), scfm
Q_s - average hourly leak rate (cfm) during shutdown, scfm
t - shutdown period (minutes) = $[t_e – t_s]$
t_s – time at start of shutdown period
t_e – time at end of shutdown period
I = shutdown interval

Alternatively, if correlation analysis supports using running emissions before and after each shutdown period as a surrogate for uncontrolled emissions, then the refined formula for gas recovery is given by Equation 1a.

$$\mathbf{G\_1_i = [Q_r(t_e) – Q_r(t_s)]/2 – Q_s] * t} \qquad \text{(Eqn. 1a)}$$

where,
$Q_r(t)$ – running leak rate (cfm) at time “t” - corrected for correlation with the uncontrolled rate Q_d
Q_s - average hourly leak rate (cfm) during shutdown
t - shutdown period (minutes) = $[t_e – t_s]$
t_s – time at start of shutdown period
t_e – time at end of shutdown period

In both cases (Equations 1 and 1a), the Total gas savings for the test period is

$$\mathbf{G\_1 = \Sigma\, G\_1_i - V_m} \qquad \text{(Eqn. 1b)}$$

where V_m is the increase in operating emissions (if any) over the test period due to the Static Pac. V_m will be determined based on comparison with rod leak rate measurements on a duplicate unit fitted with new seals at the same time the Static Pac is installed.

An important consideration in this approach is that it may take some time after start up for the running leak rate to stabilize. Thus, $Q_r(t_e)$ should be obtained once the leak rate has stabilized. For the Phase 1 evaluation, cumulative gas savings and hourly average gas savings during idle periods will be calculated and reported as Case 1 gas savings. Details of the measurement methods, tests to be conducted, QA/QC and schedule are given in Section 5.

For Case 2, gas savings consists of the blown-down volume (times the number of idle periods) and the unit valve leak rate (times the duration of idle periods). In addition, there are gas losses due to leakage from the blown-down valve, pressure relief valve and miscellaneous components (see Table 2). An additional loss is any gas that escapes past the Static Pac (since the baseline for this case is a blown-down compressor, rod packing leakage would be zero). For Case 2, the gas savings for each idle period will be calculated as follows.

$$\mathbf{G\_2_i = BDV + Q_{uv} * [t_e - t_s] - [Q_{prv} + Q_{bdv} + Q_{misc} + Q_s(t)] * [t_e - t_s]} \quad \text{(Eqn. 2)}$$

Where,
G_i is the gas savings cf
BDV is the blow-down volume, cf
Q_{uv} is the unit valve leak rate, cfm
Q_{prv} is the pressure relief valve leak rate, cfm
Q_{bdv} is the blow-down valve leak rate, cfm
Q_{misc} is the aggregate leak rate for miscellaneous components
$Q_s(t)$ is the leak rate (cfm) during shutdown at time "t"

The total gas savings for the test period is

$$\mathbf{G\_2 = \sum G\_2_i - V_m} \quad \text{(Eqn. 1b)}$$

where V_m is (once again) the total increase in operating emissions (if any) over the test period due to the Static Pac.

The blow-down volume for the test unit has been calculated by ANR personnel to be 200 cf at 800 psi or roughly 55,000 scf. For the other components, manual leak rate measurements will be needed. These measurements will be made during intensive measurement periods at the start and end of the Phase 1 evaluation. Details of the measurement methods, tests to be conducted, QA/QC and schedule are given in Section 5.

<u>Document Capital, Installation, and Shakedown Requirements and Costs</u>

C. Lee Cook has prepared installation instructions for the Static Pac system. These instructions are outlined in Table 3. The Static Pac will be installed by ANR site personnel, with supervision and guidance provided by a C. Lee Cook engineer. The ANR staff will also conduct leak checks on the complete system, and correct loose fittings or valves. Center personnel will be on-site throughout the installation and shakedown process, and will document any modifications made or difficulties encountered. The Center will also document key decisions made regarding placement of equipment or adjustments made for site-specific conditions.

C. Lee Cook will provide an Operator's Manual that provides instructions on start-up activities and routine monitoring and maintenance requirements (see Appendix A and Appendix B). For the start-up instructions, the manual lists step-by-step procedures for: initiating Static Pac start-up, obtaining optimum gland activation pressure, checking for its design activation pressure, and verifying functionality of integral monitoring sensors. The Center will document any problems encountered or changes made to the start-up and shakedown activities, and report the final procedures in the Verification Report.

To determine the payback period, it will be necessary to document accurately Static Pac capital and installation costs. Table 4 is a listing of the capital equipment required to assemble and install the Static Pac. This table includes preliminary cost data, and identifies where final data will be obtained. The list is specific to the conditions encountered at the host site (e.g., shaft diameter.) The staff performing the installation will provide the piping, valves, and fittings. Although the list is believed to be complete, C. Lee Cook may add or delete items necessary to accommodate site specific conditions. The Center will obtain the "as-built" equipment list from C. Lee Cook after installation is complete, and will document total equipment and installation costs based on invoices and labor logs. The Center will multiply the logged hours by the hourly rates charged by all participating contractors and ANR staff to calculate total installation cost. The sum of the capital equipment costs and installation costs will represent the net Static Pac initial cost. This cost will not include the capital or installation costs associated with the flow monitors and other devices required for the verification test.

Table 3. Preliminary Static Pac Installation Instructions

A.	The Static Pac sealing system is installed in accordance with standard station procedures for replacement of rod seals.
B.	The Static Pac control will automatically engage and disengage the compressor packing Static Pac with commands from the engine control system when properly installed. Install as follows:
1.	Disconnect the starting air command signal from the engine control system from the pilot of the starting air valve and connect it to bulkhead Number 5 of the Static Pac control.
2.	Connect the pilot of the starting air valve to bulkhead Number 1 of the Static Pac control.
3.	Install a tee fitting in the ignition command line from the engine control panel and connect the branch of the tee to bulkhead Number 3 of the Static Pac control. (If an ignition-ON command signal is not available, the fuel-ON signal can be used instead.)
4.	Connect bulkhead Number 2 to pilot (operator) of high pressure valve 100-1.
5.	Connect high-pressure gas supply to blocked inlet port of valve 100-1.
6.	Connect Static Pac to opposite port.
7.	Pipe third port (vent) to a safe, unrestricted vent system to atmosphere.
8.	Connect bulkhead Number 4 to indicator 19 R-1, after indicator has been positioned in desired location.
9.	Connect 60 to 125 psig filtered gas supply to bulkhead Number 6.
10.	Installation is complete.

Table 4. Documentation of Initial Capital and Installation Costs

Description	Units Required	Price/Unit	Source of Data
Capital Equipment Costs:			
Static Pac Case for 4: Rod GMW	2	$2,650.29	C. Lee Cook
Renewal Rings	2	$797.79	C. Lee Cook
Automatic Control P/W 502957	1	$1,638.00	C. Lee Cook
Miscellaneous Tubings, Fittings	---	$200.00	Station Purchase Records
Installation Costs:			
Static Pac Assembly Installation (includes time required to remove cylinder, install Static Pac, make Control System adjustments, and check the system	16 hours	$45 - $65 / hour	Station Maintenance Logs

2.2.3. Phase II Static Pac Evaluation

The Phase II evaluation represents an extended period of performance testing and includes trends analyses to project emissions beyond the period of the field test. Calculation of the payback period based on these measurements and analyses is another key element of Phase II. Phase II will represent up to 4 months of continuous rod packing leak rate measurements and at least 3 intensive periods of manual measurements. A discussion of verification issues and actions for each Phase II verification parameter are given in the following sections.

<u>Document Annualized Gas Savings for Primary Baseline Operating Conditions</u>

Case 1 and Case 2 gas savings for each idle period during the entire field test will be computed in the same manner as for the Phase 1 testing (see Equations 1 and 2). Since the test will not span an entire year, it will be necessary to project gas savings over this longer period. The most direct method would be to simply compute average gas savings over the study period (for Case 1 and Case 2) and multiply by the number of expected idle hours during a year. However, this approach could yield an overly conservative estimate of annual gas savings - especially for Case 1 (see the "Average Gas Savings" in Figure 2).

It is expected that rod packing emissions (and possibly the leak rates for other components) will increase over time. Since Case 1 gas savings are due entirely to eliminating rod packing leaks during idle periods, neglecting an increasing leak trend would lead to an underestimate of gas savings over an extended period of time. It is also possible that leak rates for components contributing to Case 2 gas savings and losses could change over time. Thus, it is necessary to consider any trend in emissions from all the components of interest that is revealed by the test data.

To determine annual gas savings, an increasing trend in gas savings in the test data will be projected in two straightforward ways: a conservative case, and a likely case. The conservative case assumes that the gas savings rate after the test will not be lower than the gas savings rate at the end of the test (unless a component is repaired or replaced). The likely case attempts, based on available data, to project future increases in emissions, and take this into account in calculating gas savings (see Figure 2).

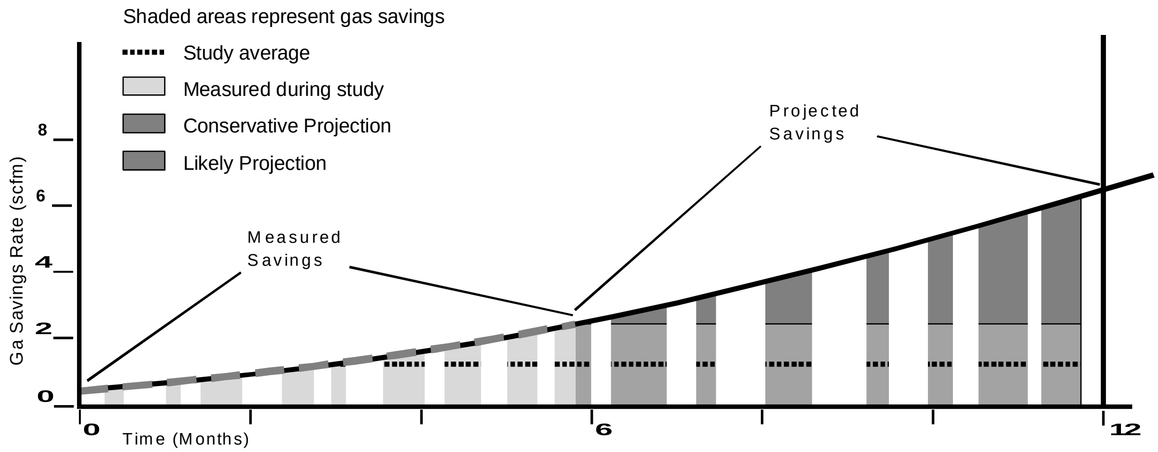

Figure 2. Methods of Projecting Gas Savings

<u>Document Methane Emission Reduction</u>

The net methane emission reduction is simply the cumulative gas savings calculated as described in the previous sections. The measured leak rates for the major components will be reported to allow users to assess the trends observed, use alternate assumptions and data interpretations, and apply results of this evaluation to differing operating conditions as needed.

Calculate and Document Static Pac Payback Period

Payback occurs when the capital and operating costs (including cost of money) of the Static Pac are balanced by the value of the gas saved. The operating and maintenance costs for the Static Pac system is expected to be minimal, but will be documented and included in payback calculations.

Complete O&M logs on both the Static Pac and the compressor will be maintained. This will include selected monitored parameters for the engine/compressor system, and manual logs of key O&M activities. Table 5 lists the operational and maintenance parameters that will be collected.

Table 5. Operational and Maintenance Data to be Collected During Testing

Description	Source of Data
Static Pac, Compressor, and Engine Operating Parameters Logged:	
Engine rpm	Operating Station Data
Rod temperature (both rods)	
Unit discharge pressure	
Unit discharge temperature	
Unit suction pressure	
Static Pac actuation status	
Maintenance Requirements Logged:	
Labor required to start/stop the system, conduct routine leak checking on the entire Static Pac assembly, repair leaks, respond to malfunctions, and perform Static Pac adjustments	Operator logs
Equipment replacement or repair costs for failed units	
Labor required to replace or repair failed units	
Compressor/Engine downtime costs caused by failures in the Static Pac apparatus	

Periodic checks on Static Pac actuator pressure and adjustment as necessary will be performed. After initial measurements are complete, the site operators will perform routine Static Pac control system operational checks in accordance with the O&M instructions for the Static Pac, and if significant deviations from specifications are present, the Operator's Manual will be followed to determine appropriate action. The time required to conduct these activities will be logged. In the event that any of the Static Pac components fail and need repair or replacement, ANR site personnel will log the purchase cost of each component, and the time and materials expended in installing and checking the new components. Although unlikely, if failure in the Static Pac system causes malfunctioning of the compressor or the engine, ANR site operators will be consulted to help quantify the costs associated with the failure.

The procedure for calculating payback is outlined below.

1. Total cost will be determined by adding the Static Pac capital costs, installation costs, and O&M costs determined as outlined above. Capital costs will be amortized over the payback period assuming a discount rate of return of 10 percent. Payback is achieved when the total cost = the value of the gas saved.

$$\textbf{Total Cost} = \textbf{(Gas Savings)} * \textbf{(GP)} \qquad \text{(Eqn. 3)}$$

Where: Total Costs = sum of capital, installation, O&M costs and cost of money
Total Gas Saved = net volume of methane (SCF) required to achieve payback
GP = gas price ($2/MCF)

2. Total gas savings over the payback period will necessarily include measured and projected values. Savings will be projected in the same manner as described for determining annual gas savings. For each case,

$$\textbf{Total Gas Saved} = \textbf{Gas Saved}_{\textbf{Test}} + \textbf{Gas Saved}_{\textbf{Est}} \qquad \text{(Eqn 4)}$$

Where: Gas $\text{Saved}_{\text{Test}}$ = total measured net volume of gas saved during the test period.
Gas $\text{Saved}_{\text{Est}}$ = total estimated net volume of gas to be saved after the test period.

The payback projections will, likewise include a conservative and a likely case. These will be calculated just as described for projecting annual emissions reductions - except over the payback period.

2.3. SITE SELECTION, DESCRIPTION, AND STATIC PAC INSTALLATION

2.3.1. Site Selection and Description

The natural gas transmission engine/compressor selected to host this evaluation is operated by ANR Pipeline Company. This station operates six Cooper-Bessemer engines (8-cylinder, 2000 Hp), each equipped with two-stage reciprocating compressors operating in series (4,275 cubic inch displacement, 4" rods). Geographic location was not seen as a significant factor in the evaluation, but extremes of environment, very hot or very cold, were avoided.

The low speed engines at the test site are not typical of newer high speed engines in use, but the rods and packings have the same basic design and functionality as most reciprocating compressors used now and planned for use in the future within the transmission sector. Reciprocating compressors are the dominant types in use, although newer compressor designs, such as screw-type, are beginning to be placed into service. The rod packing system used at this station is typical of those being built or retrofitted within the industry. The rod packing is essentially a dry seal system, using a few ounces of lubricant per day. Traditionally, wet seals, which use high-pressure oil to form a barrier against escaping gas, have been employed. According to the natural Gas STAR partners, dry seal systems have come into favor recently because of lower power requirements, improved compressor and pipeline operating efficiency and performance, enhanced compressor reliability, and reduced maintenance. The STAR industry partners report that about 50 percent of new seal replacements consist of dry seals.

In order to provide necessary experimental controls (see Section 2.2), the Emissions Packing will be installed on one compressor on each of two engines (engine Id's 801 and 802). The packing on the second rod on each engine will be replaced with a new packing at the same time that the Emissions Packing is installed. The two engines are the same age and have similar operating hours (this is part of ANR's operating practice). They were both overhauled at the same time in 1996, including replacement of the rod packings. Actual operating hours on each engine will be logged at installation. ANR's operation and maintenance practices are the same for each of the units.

2.3.2. Static Pac Installation and Operation

The host site presents a typical installation for the Static Pac system and no application specific engineering is required. The Static Pac system is designed to accommodate the conditions (pressure, existing sealing system) at the test site. The Static Pac will be installed in a modified packing case with new seals. A representative of C. Lee Cook has visited the test site and confirmed all necessary requirements. The Static Pac will be installed by a Cook representative on one rod on each of two engines. This will require two separate actuation systems. Costs used for determining payback will be based on equipment needed for installation on a single engine with a single actuator. As normal operations dictate, operators will perform and document normal system maintenance and adjustments to maintain Static Pac performance, maximizing gas containment.

2.4. FIELD TEST OVERVIEW

The field testing will include both continuous and manual measurements. The continuous measurements will quantify the gas savings from the rod packing leaks due to the action of the Static Pac during idle periods. These measurements allow quantification of the Case 1 gas savings (for a compressor that remains pressurized while shut down). The manual measurements are necessary to quantify leak rates for the unit valves, blown-down valve, pressure relief valve and miscellaneous components that make up additional data needed to quantify Case 2 gas savings (for a compressor that would normally blow-down prior to installing the Static Pac).

2.4.1. Continous Leak Rate Measurements

At the test compressors, emissions from the packing case vent and fugitive emissions from around the rod are both vented into the distance piece or doghouse and then vented to atmosphere through the doghouse vent. The doghouse vent and oil drain are the only paths by which the leaking gas can leave the doghouse. For the test, the doghouse drain will be sealed using a liquid trap so that all emissions will be forced out the doghouse vent. To measure these emissions, flow meters will be installed on the doghouse vent lines for each of the compressors to be tested.

The station operates automatically and compressors are shut down or brought on line on demand. Continuous measurements and automated data logging are needed to be certain of measuring emissions during each shutdown period. The meters must present a minimal restriction to flow in order not to influence the leak rate, have a wide range, and be resistant to oil vapor present in the emissions.

The meters selected for the test are a type of rate meter (similar to a rotameter) designed for measuring methane emissions from sludge digesters, landfills, and other low-pressure applications. They have wide range (25:1 turndown), a very low pressure drop (2-inches water) and should not be affected by oil mist present in the emissions. The meters produce a 4-20 mA full-scale linear output that will be recorded locally on a datalogger equipped with modem communications. Hourly averaged leak rate data will be stored continuously on site and retrieved remotely once each day for review. The data will be archived at the Center's Research Triangle Park, NC facility.

During installation and during periodic intensive measurement periods, the methane concentration of the gas leaking from the doghouse will be measured with a portable hydrocarbon analyzer. At these times, flow meter performance will be checked against direct measurements using GRI's Hi-Flow™ device.

2.4.2. Manual Leak Rate Measurements

Manual measurements will be made of leak rates for the unit valves, blow-down valve, pressure relief valve and miscellaneous components.

The leak rate for the unit valves will be measured at an existing port located immediately downstream of the unit valve in the suction line to the compressor (see Figure 3). With the compressor shut down and blown-down, any unit valve leak will exit through the opened port. The leak rate will be measured with GRI's Hi-Flow™ device.

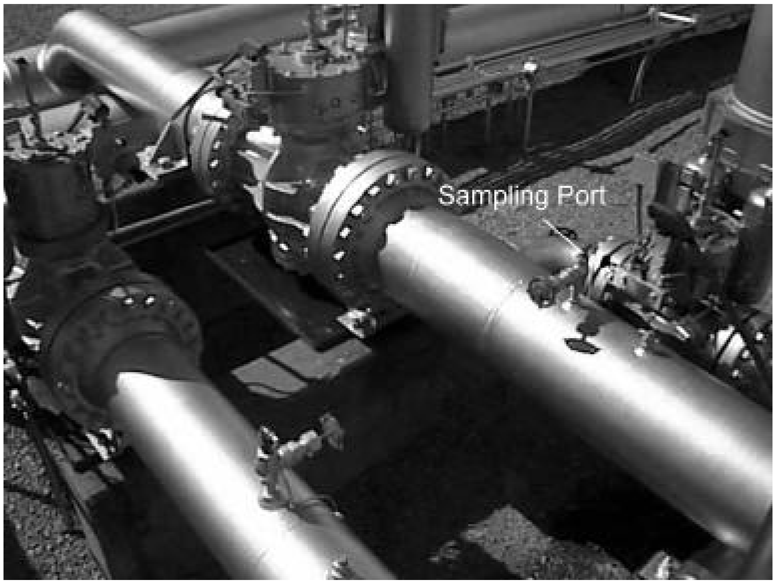

Figure 3. Unit Valve Sampling Port

The leak rates for the blow-down valve and pressure relief valve will be made with the unit shut down and pressurized. The leak rate for the blow-down valve will be measured at the flange located at the exit of the valve (see Figure 4). To make this measurement it will be necessary to unbolt the flange. The flange will then be separated about 1-inch and a disk will be inserted and clamped into place. The disk will capture the leak and direct it outward. The disk will be made of high-density polyethylene about 1-inch thick and machined to fit the flange. A borehole will be provided radially into the disk that will allow any leaking gas to escape for measurement using the Hi-Flow.

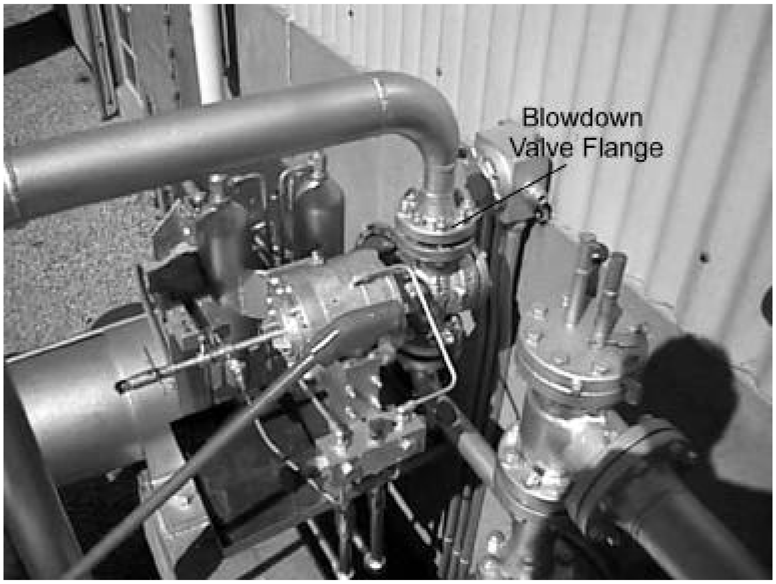

Figure 4. Blown-down Valve Sampling Location

The pressure relief valve normally vents through a 4-inch standpipe extending to the roof of the compressor building. The simplest way to measure the leak rate is to cap the standpipe, allowing a port to channel emissions for measurement using the Hi-Flow.

The miscellaneous components at the test site consist of metering ports and valving used to recover gas to the fuel system during shutdowns (the host station normally vents to the fuel system during shutdowns). Significant leaks are not expected at these locations; however, all components will be soap screened and any leaks identified will be quantified using the Hi-Flow or the EPA protocol tent/bag method, where needed.

The manual leak rate measurements will require scheduled shutdowns that proceed as follows:

- Unit shutdown - remains pressurized, leak rates for the pressure relief valve, blow-down valve and miscellaneous components will be measured (several hours)
- Static Pac disabled, Hi-flow determination of leak rate and continuous flow monitoring (at least one hour)
- Unit blown-down, unit valve leak rate measured (about one hour)
- Unit brought back on line

Nearly one full day will be needed to conduct this suite of measurements.

The station has agreed to a limited number of scheduled shutdowns. These will be used to characterize the quantities as discussed above, but will not contribute to the gas savings during idle periods. It is proposed to conduct 3 such scheduled shutdowns during the first week of the test, after installation of the static seal and after the rod packing (with the static seal) has had time to stabilize (approximately 24 hours). In order to address possible changes over time, this series of measurements will be repeated on two other occasions at approximately 2 months and 4 months after installing the SS. Thus, the manual measurements will be repeated a total of 9 times in order to capture the magnitude and variability of the various quantities involved.

2.5. SCHEDULE OF ACTIVITIES

A site survey visit has already been completed. Field testing is scheduled to begin in June of 1999, but the exact date of start-up will depend on the availability of equipment and the extent to which difficulties are encountered during start-up and shakedown. Uncertainty in the start-up date impacts the dates for the subsequent activities in the schedule.

Allowing time for data analysis to be completed, a draft Phase I Report should be available for review in September, 1999. All field activity should be completed by October 30, 1999. A draft Phase II Report should be available no later than December 31, 1999. A final Phase I Report should be available for distribution in November, 1999 and a final Phase II Report should be available for distribution in February, 2000.

3.0 DATA QUALITY OBJECTIVES

Data quality objectives state the values of key data quality indicators for each measured quantity. These objectives must be achieved in order to draw conclusions from the measurements with the desired level of confidence. The process of establishing data quality objectives for measurements starts with determining the desired level of confidence in the primary verification parameters (e.g., confidence level in the verified payback period).

The next step is to identify all measured values impacting the primary verification parameters, and determine the error allowed. Formal error propagation techniques can help to systematize these determinations. With error propagation, the cumulative effect of all measured variables on the primary data quality objective can be determined. This allows individual measurement methods to be chosen which perform well enough to satisfy the data quality objective for the primary verification parameter.

The primary quantitative objective for this study is to establish the payback period associated with installation and use of the Static Pac. Inherent in this objective is documentation of the Static Pac's gas loss reduction performance. Based on meetings with the Stakeholders, a payback period of three years would represent acceptable performance. An error in this value of about +/- 3 to 4 months, or about 10 percent, is used as a basis in determining the data quality requirements.

Payback occurs when the total cost of the Static Pac (amortized capital and installation costs, and operation and maintenance costs) equals the savings that the system provides (net gas loss prevented). For the field test, the costs will be based on actual costs and the errors are zero. Gas loss reduction will be measured directly during the study, then projected for the periods immediately before and after the test is done. Specific data quality objectives address the error in the direct measurements only; however, a discussion of the errors in the projections is also provided below.

3.1. CONTINUOUS MEASUREMENTS

For a three year payback to occur for Case 1, the gas savings rate would have to average about 9.5 cfm - or 4.75 cfm per rod (assuming $10,000 total cost for two rods, gas value of $2/MCF, and 33 percent downtime). This implies a minimum gas savings rate of interest of about 0.5 cfm per rod (~10 percent of 4.75 cfm) based on a 10 percent error in the payback period.

As discussed above (see Equation 1), the gas savings for each idle period will be taken as the difference between the leak rate with the static seals disabled (or a surrogate using the running leak rate) and the leak rate with the static seals engaged. By error propagation, the total error in the difference is the sum of the absolute error in each measurement (in measured units). The accuracy of the meters is +/- 2 percent full scale and the full-scale range of the meters is about 3-scfm methane, so the absolute error is +/- 0.06 scfm. The total error in the difference (the gas savings) is then +/- 0.12 scfm. This is well below the minimum leak rate of interest, and meets the 10 percent data quality objective for a three year payback**. For payback periods longer than about 9 years (gas savings rates less than 1.6 scfm/rod), the +/- 10 percent objective might not be met. The minimum response of the meters chosen for the test is to a flow of about 0.125-scfm methane.

**For completeness, it should be noted that this assumes that the percentage errors during each idle period are roughly consistent. This is because the total gas savings is computed as the sum of the gas savings for each idle period over the duration of the test. By propagation, the error in the total gas savings is the sum of the errors in the gas savings for each idle period. If the fractional, or percentage error for each idle period is the same, then the percentage error in the total gas savings is the same as the error for each idle period.

3.2. MANUAL MEASUREMENTS

Manual measurements will be based on use of GRI's Hi-Flow device and/or EPA's protocol tent/bag method. The GRI Hi-Flow device draws a metered volume of ambient air past the leak interface to capture the leaking gas. Flow metering is accomplished using a thermal anemometer calibrated to flow. The concentration of methane in the sample stream is measured using a Bascom-Turner CGI-201 hydrocarbon analyzer which has an effective range from about 500 ppm to greater than 50 percent methane. The leak rate is determined simply as the product of flow and concentration.

The device can meter sample flows in the range from about 4 to 8 scfm. This gives the device an effective leak rate quantification range from about 0.02 to 4 scfm. The device has been shown in laboratory testing to be able to quantify leak rates to within 10 percent of the actual value (Lott, 1995).

Since the Hi-Flow draws a high volume of air past the sample point, it will be important to take measures to ensure that the sampler does not act to increase the leak rate by pulling excess gas from the leak source. This issue is important for this test since some of the leak points to be tested are expected to be passive, very low-pressure seeps to the atmosphere. These locations include the doghouse vent and the unit valve sampling port.

This issue can be effectively addressed with proper sampling technique. The Hi-Flow is capable of leak quantification over a range of sample flows. The sample flow used must be no higher than necessary to capture the leak. Repeated measurements at different sample flows can be used to verify that this occurs. Initially, the leak should be quantified using the lowest possible sample flow. The measurement is then repeated at a higher flow. If the measured leak rate remains constant at both flows, this indicates that the leak has been completely captured and that no excess gas has been sampled. If the leak rate increases at the higher flow, this could indicate better leak capture or sampling of excess gas. To control for this ambiguity, leak capture should be ensured by constructing a partial enclosure around the Hi-Flow sampling hose and the leak interface that allows ambient dilution air to enter, but effectively channels all leaking gas to the Hi-Flow.

It is possible that some leaks may not be readily quantifiable using the Hi-Flow device. This would be the case if the leak interface were such that the Hi-Flow alone could not capture the leak. In such cases, EPA's tent/bag method may be used. EPA's tent/bag method is nominally accurate to within +/- 20 percent (EPA 1993), but has been shown to be capable of accuracies better than +/- 10 percent when carefully applied (SRI 1996). Thus, the methods should be capable of producing data at or near the desired level of confidence.

As a practical matter, the real limitation on the accuracy and the representativeness of the manual measurements is their relative infrequency. Although the frequency of a measurement does not affect the accuracy of an individual measurement, a larger number of measurements does improve the "accuracy" (i.e., decrease the confidence interval for the mean). For this reason, the manual measurements will be repeated in triplicate during each of the three intensive measurement periods planned for the overall test (Phase I and Phase II). If significant variability is encountered in the three samples, three additional samples will be collected.

The other quantity to be considered for Case 2 is the blow-down volume. This will be quantified based pressure readings at the station controls, and the volume of piping and manifolds in the compressor system. These valves are critical for station operation and the accuracy of station metering is carefully checked and documented. Station calibration records will be obtained and corded. Unit pressure (measured at the station) will be used to convert the volume to scfm.

3.3. PROJECTIONS

As discussed above (Section 2.2), projections beyond the test period will include a conservative case and a likely case. In both cases, idle periods will be based on the previous year's operation for the test unit. In the conservative case, emissions projections are straight lined from the end of the test period and the uncertainties are small - no more than uncertainty in the final set of measurements used for the projected value. In the likely case, projections will be based on the trends in the measured data. In this case, the uncertainty may be estimated based on the fit of the projected curve to the measured data.

4.0 DATA QUALITY INDICATORS

This section specifies data quality indicators that will be used as measures of data quality for the test data and states how values for each indicator will be determined through calibrations, QC checks, and other appropriate measures. This is presented in Table 6.

Table 6. Data Quality Indicators						
Measurement	**Method**	**Range**	**Completeness/ Frequency**	**Accuracy**	**Precision**	**How Verified/ Determined**
Doghouse Vent Emissions	Continuous flow meter	0.2 to 4 scfm methane	90 % of hourly data over test period	2 % full scale, or +/- 0.2 scfm methane	2 % of reading	Comparison against manual flow tube measurements
Unit Valve Leak Rate	Hi-Flow	0.1 to 4 scfm methane	9 total measurements (3 sets of 3)	10 %	10 %	Laboratory calibration against NIST certified mass flow meter
Blow down valve leak rate	Hi-Flow	0.1 to 4 scfm methane	9 total measurements (3 sets of 3)	10 %	10 %	Laboratory calibration against NIST certified mass flow meter
Pressure relief valve leak rate	Hi-Flow	0.1 to 4 scfm methane	9 total measurements (3 sets of 3)	10 %	10 %	Laboratory calibration against NIST certified mass flow meter
Misc. components leak rate	Hi-Flow or EPA Tent/Bag	0.1 to 4 scfm methane	9 total measurements (3 sets of 3)	10 %	10 %	Repeat measurements

5.0 SAMPLING/ANALYTICAL AND QA/QC PROCEDURES

5.1. CONTINUOUS FLOW MEASUREMENTS

Static Pac leak prevention is determined using a flow meter on each doghouse vent to measure any leaks. The meters selected for the test are a type of rate meter (similar to a rotameter) designed for measuring methane emissions from sludge digesters, landfills, and other low-pressure applications. Since they are rate meters, they will require external temperature and pressure correction to obtain flow readings at standard conditions. Since the meters will be vented to atmosphere, local barometric pressure data will be used to correct for pressure. Gas temperature is not expected to vary significantly (within data quality objectives), therefore, temperature corrections will be based on spot checks conducted during the manual measurement intensives.

The flow meters and barometric pressure transducer will be installed and tied in to the data acquisition system approximately one week before the Static Pac installation. This will provide a record of normal operations prior to installing the Static Pac and allow time for testing and shakedown.

The flow meters are designed to operate unattended continuously after installation. Configuration testing will be completed during the initial shakedown period. This will include manufacturer's startup checks and reasonableness and manual flow checks. In addition, manual checks of meter performance will be conducted using the Hi-Flow. A sampling port will be provided upstream of the meters that allows the meters to be isolated and emissions to vent directly into the Hi-Flow. The manufacturer is providing a calibration certificate for each of the flow meters. The meters should not require re-calibration over the duration of the test.

Once the system is operational, average hourly flow data will be reviewed daily. The daily review will include reasonableness screening as well as emissions trends and changes that could indicate system problems.

5.2. MANUAL LEAK RATE MEASUREMENTS

A general description of the manual measurements of the leak rates for the unit valves, blow-down valve, pressure relief valve and miscellaneous components is given in Section 2.4. The manual leak rate measurements will require scheduled shutdowns that proceed as follows:

- Unit shutdown - remains pressurized. Leak rates for the pressure relief valve, blow-down valve and miscellaneous components will be measured (several hours). The gas recovery system will be disabled for the testing.
- SS disabled. Leak rate recorded by continuous flow monitor and Hi-Flow measurement (at least one hour)
- Unit blown-down, unit valve leak rate measured (about one hour)
- Unit brought back on line

Nearly one full day will be needed to complete this suite of measurements. The station has agreed to a limited number of scheduled shutdowns. It is proposed to conduct three such scheduled shutdowns during the first week of the test, after installation of the SS and after the rod packing (with the SS) has had time to stabilize (approximately 24 hours). In order to address possible changes over time, this series of measurements will be repeated on two other occasions at approximately 2 months and 4 months after installing the Static Pac. Thus, the manual measurements will be repeated a total of 9 times in order to capture the magnitude and variability of the various quantities involved.

Detailed procedures for each type of measurement follow.

5.2.1. Blow-down Valve, and Pressure Relief Valve

The leak rates for the blow-down valve and pressure relief valve will be measured with the unit shut down and pressurized. The leak rate for the blow-down valve will be measured at the flange located at the exit of the valve (see Figure 3). To make this measurement it will be necessary to unbolt the flange. The flange will then be separated about 1 inch and a disk will be inserted and clamped into place. The disk will capture the leak and direct it outward radially. The disk will be made of high-density polyethylene about 1 inch thick and machined to fit the flange. A borehole will be provided radially into the disk that will allow any leaking gas to escape for measurement using the Hi-Flow. The procedure is as follows:

- Shutdown the unit, leaving pressurized. Vent gas recovery system should be disabled.
- Record suction and discharge line pressures (obtain from station operator).
- Unbolt the flange and jack up the blow-down vent pipe approximately 1-2 inches.
- Insert the leak capture disk and clamp into place.
- Complete Hi-Flow measurement of leak rate.
- Log all results in the field data log.

The pressure relief valve normally vents through a standpipe extending to the roof of the compressor building. The simplest way to measure the leak rate is to cap the standpipe, allowing a port to channel emissions for measurement using the Hi-Flow. The procedure is as follows:

- The unit should still be shut down and pressurized.
- Record suction and discharge line pressures (obtain from station operator).
- Ascend to the roof of the compressor building - observing station safety rules (tie-offs).
- Cap vent pipe with ported sampling cap.
- Complete Hi-Flow measurement of leak rate.
- Log all results in the field data log.

Quality control for the blow-down and pressure relief valve measurements consists of checking the proper function of the Hi-Flow (function check, zero/span check, leak check) and ensuring that the Hi-Flow has been calibrated in the laboratory since the last set of manual measurements was performed (a calibration certificate should be attached to the Hi-Flow). The laboratory calibration of the Hi-Flow consists of (1) calibrating the flows against a laboratory mass flow meter which has, in turn, been calibrated against a NIST traceable orifice transfer standard and (2) calibrating the hydrocarbon analyzer according to manufactures specification (zero and 2.5 percent methane) with the addition of a span gases at 10, 50, 75 and 100 percent methane. Documentation of all calibrations will be maintained on file.

5.2.2. Miscellaneous Components

The miscellaneous components at the test site consist of metering ports, the bypass valve and the vent gas recovery system used to recover gas to the fuel system during shutdowns (the host station normally vents to the fuel system during shutdowns). These tests will be conducted with the unit shut down and fully pressurized. Significant leaks are not expected at these locations; however, all components will be soap screened and any leaks identified will be quantified using the GRI High Flow (Lott, 1995) or the EPA protocol tent/bag method (EPA 1993). Sampling/analytical and QA/QC procedures for these methods are published elsewhere (EPA 1993, Lott 1995). With either method, the basic principle is to measure the methane concentration in a known volume of clean air and compute the leak rate as the product of the methane concentration and the sampling rate.

In both cases, a Bascom-Turner CGI-201 methane analyzer will be used to determine methane concentration. The CGI-201 is very stable and need only be calibrated prior to each set of intensive measurements. Calibration will be done in the Center's Research Triangle Park, NC laboratory facility using a certified gas mixture. Field checks consist of an automated zero cycle conducted prior to each set of measurements.

5.2.3. Unit Valves

After the leak rates for the blown-down valve, pressure relief valve, and miscellaneous components have been measured, the unit will be blown-down to measure the combined leak rate from both unit valves. Whenever the unit is shut down, the suction and discharge lines are connected via a bypass valve and line. The combined leak rate for the unit valves will be measured at an existing port located immediately downstream of the suction side unit valve. With the compressor blown-down, the combined leak from both unit valves will exit through the sampling port. The leak rate will be measured with the Hi-Flow. The procedure is as follows.

- Blow-down the unit (station operator).
- Open the sampling port.
- Complete high flow measurements of the leak rate.
- Log all results in the field data log.

Quality control for the unit valve measurements is the same as for the other manual measurements using the Hi-Flow for quantification.

5.3. DATA ACQUISITION

Each continuous flow meter produces a 4 to 20 mA linearized output over the full-scale range of the sensor. The barometric pressure transducer provides a linear 0 to 5 VDC output. All signals will be logged using a Campbell 21X data logger with a serial connection to a laptop computer. The laptop computer will provide remote access to the logger via modem communications. A telephone connection will be made available at the station for daily data downloads and status checks. Power for all components will be provided from the station 24V DC power supply which is equipped with a battery back-up system. The logger will read data continuously and provide aggregation of sampled data into hourly values.

In addition to the direct measurements, data on engine and compressor operation that relate to the test are stored in the station computer and will be retrieved and transmitted to the Center periodically. Table 7 lists all parameters that will be collected and stored by both the Station computer and the project data system and their purpose.

Data will be checked daily and summary statistics and trend plots will be generated to check for unusual or changing conditions. Details of the daily review are given in Section 6. Data will be automatically downloaded from the DAS each midnight. Summary statistics and time series plots will be produced from the data and reviewed at the start of each day.

Table 7. Data Record Contents and Significance

PARAMETER	SIGNIFICANCE
Date	
Time	
Rod Seal #1 Leak Rate	Leak rate
Rod Seal #1 Gas Temperature	Temp. Correction for #1 leak rate
Rod Seal #2 Leak Rate	Leak rate
Rod Seal #1 Gas Temperature	Temp. Correction for #2 leak rate
Barometric pressure	Pressure correction for #1/#2 leak rates
Engine RPM	Unit on/off status
Unit Suction Pressure	Unit operating status
Unit Discharge Pressure	Unit operating status

6.0 DATA REDUCTION, VALIDATION, AND REPORTING

6.1. DATA REDUCTION

This section documents calculations that will be used to obtain final results from raw measurements.

6.1.1. Continuous Measurements

The continuous flow meters provide a linearized 4 to 20 mA output over the full scale range of the sensor. The reading in cfm (at calibrated conditions) is given by:

acfm = (mA - 4)/16 * FS

where, mA is the mA output from the meter electronics and FS is the full-scale reading in cfm.

The meters will be calibrated specific to methane at 70 degrees F. and 1 atmosphere pressure. To adjust for variations in gas temperature and pressure and correct to standard conditions.

scfm = acfm * (P/760 * 294.26/T)^0.5

where P is the absolute barometric pressure (torr) at the site and T is the gas temperature (in Kelvins). The exponent of 0.5 (square root) is necessary due to the physics of rate meters.

6.1.2. Manual Measurements

Leak rates for the blow-down valve, pressure relief valve, and unit valves are determined using the Hi-Flow which measures sample flow and concentration. The flow will be calibrated specific to methane in the laboratory and the calibration parameters (slope and intercept) will be used to convert directly from the thermal anemometer output (arbitrary units) to flow rate (in scfm) as follows.

$$scfm = v * m + b$$

where v is the anemometer output, m is the slope of the calibration curve, and b is the intercept.

If miscellaneous components are found to be leaking (using soap solution), then the leak rates will be quantified using the GRI high flow or the EPA protocol (Method 21) tent/bag method. For each of these methods, the leak rate is found as the product of the methane concentration and the sampled flow rate. The methane concentration will be read directly from a Bascom-Turner CGI-201 analyzer calibrated specific to methane.

6.1.3. Gas Savings and Payback period

Formulae for calculating gas savings (Case 1 and Case 2) and for determining the payback period are given in Section 2.2 of this plan.

6.1.4. Unit Conversions

Engineering units in common use at the test site and within the host industry will be used for reporting and summarizing results. For pressure, the units are psi or inches water column. For flow, the units are cfm and scfm (1 atmosphere, 70 degrees F or 294.26 K). For gas velocity, the units are fpm. For concentration, percentage by volume or ppm are used.

6.2. DATA REVIEW AND VALIDATION

Calibrations and quality control checks for each measurement are described in Section 5 - Sampling and Analytical Procedures. Table 8 summarizes the calibrations and quality control checks to be performed. Upon review, all data collected will be classified as either valid, suspect or invalid. In general, valid results are based on measurements meeting data quality objectives. All data are considered valid unless a specific performance limit is exceeded or operational check is failed.

It is often the case that anomalous data are identified in the process of data review. All outlying or unusual values will be investigated as fully as possible using test records and logs. Anomalous data may be considered suspect if no specific operational cause to invalidate the data are found. All data - valid, invalid, and suspect will be included in the final report. Report conclusions will be based on valid data only. The reasons for excluding any data will be justified in the report. Suspect data may be included in the analyses, but may be given special treatment as specifically indicated. All continuous sensor data will be reviewed on a daily basis. All anomalous or outlying values will be identified and investigated to find a cause for the unusual condition. Manual measurements data will be reviewed in the field as they are collected and any anomolous conditions will be documented in field log book and, if possible, corrected.

Table 8. Summary of Calibrations and QC Checks

Measurement	Cal/QC Check	When Performed/ frequency	Expected or Allowable Result	Response to Check Failure or Out of Control Condition
Continuous flow measurements (including flow rate, temperature and pressure)	Hi-Flow verification	Startup and during bi-monthly intensive measurement periods	+/- 10 % Agreement	Identify cause of discrepancy and correct
	Sensor diagnostics	Startup and daily	No error condition	Identify cause of any problem and correct
	Data review	Daily	Reasonable values/trends	Identify cause of any problem and correct, flag suspect data
Manual Hi-Flow measurements	Hi-Flow zero, span and response checks	Each measurement	+/- 5 percent of calibrated values	Identify cause of any problem and correct
	Laboratory calibration	Prior to startup and intesive measurement periods	obtain calibration slope and intercept	n/a
Manual EPA Method 21	Methane analyzer calibration	Prior to startup and intesive measurement periods	set to standard	n/a
	Flow system calibration	Prior to startup and intesive measurement periods	obtain calibration slope and intercept	n/a
	Flow system leak check	Each measurement	no leak	Identify cause of any problem and correct

6.3. DATA ANALYSIS AND REPORTING

After data reduction, review and validation, the primary Phase 1 data analyses will include the following:

- Document initial gas savings (methane emission reduction) for primary baseline operating conditions

  The gas savings and methane emission reduction is the amount of gas that is prevented from leaking to the atmosphere either by the static seals themselves (Case I) or by changes in shut down procedure associated with installation of the static seals (Case II).

- Document capital, installation, and shakedown requirements and costs

  This is a broad assessment of effort and costs required to install the Static Pac and ensure that it is operating properly. Any problems encountered during installation and shakedown - and their resolutions will be described. Capital and installation costs will be based on the actual installed cost for the system. For the test, flow sensors are being installed that might not be installed in a normal situation. Once the system is operational, host site personnel will be interviewed to determine whether flow sensors to document gas savings would be considered necessary in a permanent installation.

The following is a preliminary outline of the content of the Phase 1 verification report.

Preliminary Outline
C. Lee Cook Static Pac Seal System
Phase I Verification Report

Verification Statement

Section 1 Executive Summary

- ETV Overview
- Verification Objectives
- Technology Description
- Verification Approach
- Verification Results and Performance Evaluation
  - Initial gas savings (methane emission reduction) for primary baseline operating conditions
  - Installation and Shakedown Requirements
  - Initial Capital and Installation Costs
- Data Quality Assessment

Section 2 Verification Test Design and Description

- Static Pac Description
- Site Selection, Description, and Static Pac Installation
- Verification Parameters and Their Determination
  - Initial gas savings (methane emission reduction) for primary baseline operating conditions
  - Installation and Shakedown Requirements
  - Initial Capital and Installation Costs
- Sampling and Analytical Procedures
  - Continuous Measurements
  - Manual Measurements
  - Data Acquisition System
- Quality Assurance and Quality Control Measures
  - Calibration Procedures
  - Quality Control Checks, Audits, and Corrective Actions
  - Data Reduction
  - Data Validation
  - Data Analysis and Reporting

Section 3 Phase I Verification Results and Evaluation

  - Initial gas savings (methane emission reduction) for primary baseline operating conditions
  - Installation and Shakedown Requirements
  - Initial Capital and Installation Costs
  - Data Quality Assessment

Section 4 Additional Technical and Performance Data from C. Lee Cook Division

References

The Phase II report will include key data from the Phase I report. The Phase II report will incorporate the results from the entire evaluation process, and will focus on longer-term performance of the system and the payback period. Phase II verification parameters include:

- Annualized gas savings for primary baseline conditions
- Methane emission reduction
- Calculate Static Pac payback period

7.0 AUDITS

An internal systems audit is planned for this test. The audit will be conducted by Southern’s independently managed QA staff. This will include field verification, procedural, and documentation components using this plan as the basis for the audit. An external audit may be performed at EPA's discretion by EPA QA staff or a qualified contractor. A performance audit on sensors used in the study is not considered necessary since the Hi-Flow will be laboratory certified before each intensive measurement period and the continuous flow meters are rugged devices designed for industrial applications. An internal audit of data quality will be conducted once data collection and analyses are complete. The final report will contain a summary of results from all audits.

8.0 CORRECTIVE ACTION

Table 8 in Section 6.2 lists allowable values for each of the calibrations and quality control checks and also indicates actions to be taken in response to an out of control condition. Other issues may arise that require corrective actions or plan changes to ensure that data quality objectives are met. Southern's quality management plan provides general procedures for corrective action that will be followed in such instances.

9.0 PROJECT ORGANIZATION

Southern Research Institute's Greenhouse Gas Technology Verification Center has overall responsibility for planning and ensuring successful implementation of the verification test. C. Lee Cook is providing the Static Pac technology, equipment, and engineering for the test installation. ANR Pipeline is providing access to the host site, and logistical and manpower assistance in the installation and operation of the Static Pac, and in conducting the test. Good working relationships have been established between the Center, C. Lee Cook, and ANR which have proved valuable in the planning up to this stage. All parties have signed a formal agreement (documented in the Letter of Commitment and associated documents) specifying details of financial, technical, and managerial responsibilities.

EPA's APPCD is the sponsor of the ETV Greenhouse Gas Pilot and is providing broad oversight and QA support for the project. The project organization is presented in Figure 5.

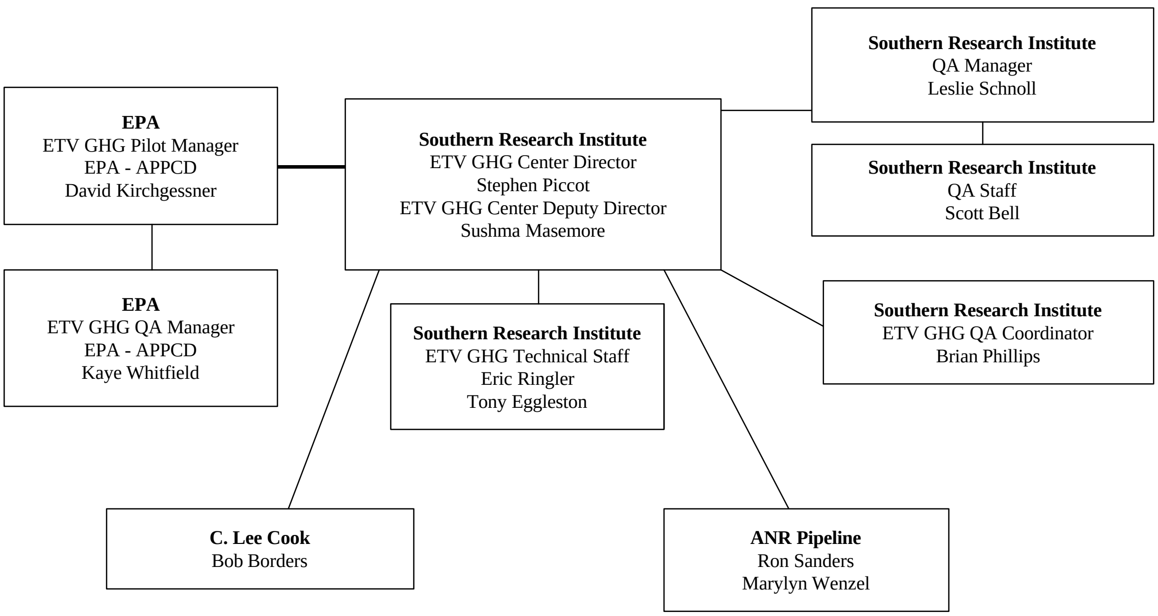

Figure 5. Project Organization

10.0 TEST PROGRAM HEALTH AND SAFETY

This section applies to Center personnel only. Other organizations involved in the project have their own health and safety plans - specific to their roles in the project.

Since the site is part of a pipeline facility, ANR's safety policies are regulated in part by the US Department of Transportation. The Center previously provided a scope of work equivalent to the scope of this plan to the National Compliance Management Service Company, which is a compliance and safety program management company specializing in DOT regulated industries. Their assessment is that the Center's on-site job function is not covered by the Research and Special Programs Administration, DOT pipeline safety regulations covered by 49 CFR Parts 192, 193, and 195. If the scope of work changes significantly, this determination would be re-evaluated.

Southern staff will comply with all known ANR, state/local and Federal regulations relating to safety at ANR's Celestine compressor station. This includes use of personal protective gear (flame resistant clothing, safety glasses, hearing protection, safety toe shoes) as required and completion of site safety orientation (site hazard awareness, alarms and signals, etc.).

Other than normal industrial hazards, the most significant hazard at the Station is the potential for explosive concentrations of natural gas. Southern plans to use only intrinsically safe apparatus in the compressor building. Should use of any equipment not so rated be required, Southern will not use this equipment until advised by site personnel that it is safe to do so.

Some test procedures will require that special safety precautions be observed. In particular, when conducting manual sampling of the blow-down valve leak rate, the automated blow-down valve control should be disabled to prevent a blown-down during sampling.

11.0 REFERENCES

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Lott, Robert A., Indaco Air Quality Services, Inc. GRI Hi-FlowTM Sampler for Leak Detection and Measurement, June 1998.

Southern Research Institute. Evaluation of the High Volume Collection System (HVCS) for Quantifying Fugitive Organic Vapor Leaks, EPA/600/SR-95/167, February 1996.

Southern Research Institute. Environmental Technology Verification Greenhouse Gas Technology Verification Quality Management Plan. Research Triangle Park, NC. October, 1998.

APPENDIX A

Static Pac Operator's Manual
Automatic Control System

INSTALLATION AND OPERATION

A. INSTALLATION

The Static-Pac Automatic Control is designed to be used with a pneumatic engine control system which includes a pneumatically operated cranking air valve, pneumatic ignition switch, and/or a pneumatically operated fuel gas valve.

The Static-Pac control will automatically engage and disengage the compressor packing Static-Pac(s) with commands from the engine control system when properly installed.

The starting air command signal from the engine control system is to be disconnected from the pilot of the starting air valve and connected to bulkhead no. 5 of the Static-Pac control. The pilot of the starting air valve should be connected to bulkhead no. 1 of the Static-Pac control. Install a tee fitting in the ignition command line from the engine control panel and connect the branch of the tee to bulkhead no. 3 of the Static-Pac control (If an ignition-ON command signal is not available, the fuel-ON signal can be used instead). Connect bulkhead no. 2 to pilot (operator) of high pressure valve 100-1; connect high pressure gas supply to blocked inlet port of valve 100-1, connect Static-Pac(s) to opposite port, pipe third port (vent) to a safe, unrestricted vent system to atmosphere. Connect bulkhead no. 4 to indicator 19R-1, after indicator has been positioned in desired location. Connect 60 to 125 psig filtered supply air to bulkhead no. 6. Installation is complete.

B. OPERATION

Engine/compressor is stopped. Supply air and engine panel Starting Air and Ignition (or fuel) command signals are connected to Static-Pac control. High pressure gas is connected to the inlet of control valve 100-1 which is piped to Static-Pac(s) and to vent.

Supply air enters through bulkhead no. 6 to the inlet of valve 9-1. If 9-1 is not manually latched closed, air passes through 9-1 to bulkhead no. 2 and bulkhead no. 4. Pressure from bulkhead no. 2 engages pilot (operator) of valve 100-1, shifting valve so that high pressure gas passes through valve to Static-Pac(s) on compressor, causing them to engage. Pressure from bulkhead no. 4 is routed to to indicator 19R-1, shifting it to the red position to show that the Static-Pac(s) are engaged.

When the engine control system sends the starting air command signal to bulkhead no. 5, air will flow to shuttle valve 15-1 and on through flow control valve 13-2 in the unrestricted direction to immediately fill volume chamber 20-2, shifting valve 9-1. Valve 9-1 when shifted vents bulkheads 2 & 4, allowing valve 100-1 to vent the Static-Pac(s) and indicator 19R-1 which returns to the black position. The Static-Pac(s) are now disengaged.

Simultaneously, air is flowing through flow control valve 13-1 in the restricted direction to slowly fill volume chamber 20-1 which is connected to the pilot of valve 8-1. Valve 13-1 is adjusted for a 15 second delay after which valve 8-1 shifts to the open position, allowing pressure to flow through bulkhead no. 1 to the pilot of starting air valve, cranking the engine. The time delay insures that the Static-Pac(s) are disengaged before the engine rolls. At the proper time, the engine control panel will send a Ignition-ON (or Fuel-ON) signal to Static-Pac control bulkhead no. 3. This signal will remain while engine is running and through shuttle valve 15-1 will keep signal to pilot valve 100-1 vented, keeping Static-Pac(s) on compressor disengaged.

Starting air signal at bulkhead no. 5 will be vented after engine has attained firing speed and valve 8-1 will return to the normally closed position, venting the pilot of the starting air valve, stopping all cranking. Check valve 80-1 insures that pilot air is vented from the starting air valve immediately on the loss of the starting air command signal. The engine is now running with the Static-Pac(s) on the compressor disengaged.

When the engine control system signals a shut down by venting pressure from bulkhead no. 3, the air trapped in volume chamber 20-2 will be slowly vented through flow control valve 13-2 in the restricted direction and on through shuttle valve 15-1 to bulkhead no. 3. Valve 13-2 is adjusted to provide a time delay (up to two minutes) before valve 9-1 shifts to permit the engine/compressor to come to a full stop before engaging the compressor Static-Pac(s). When the pressure is removed from the pilot of valve 9-1, the valve will return to the normally open position allowing pressure to flow through from bulkhead no. 6 to bulkheads no. 2 & 4 causing valve 100-1 to apply pressure to the Static-Pac(s) and to indicator 19R-1, returning is to the red position "STATIC-PAC(s) ENGAGED".

The Static-Pac control can be operated manually to disengage the compressor Static-Pac(s) for maintenance when the engine/compressor is shut down. Raise the red lever on valve 9-1 to disengage the Static-Pac(s), lower the lever to re-engage. Should the lever be accidently left in the manually disengaged position, it will automatically return to normal after the next start/stop sequence.

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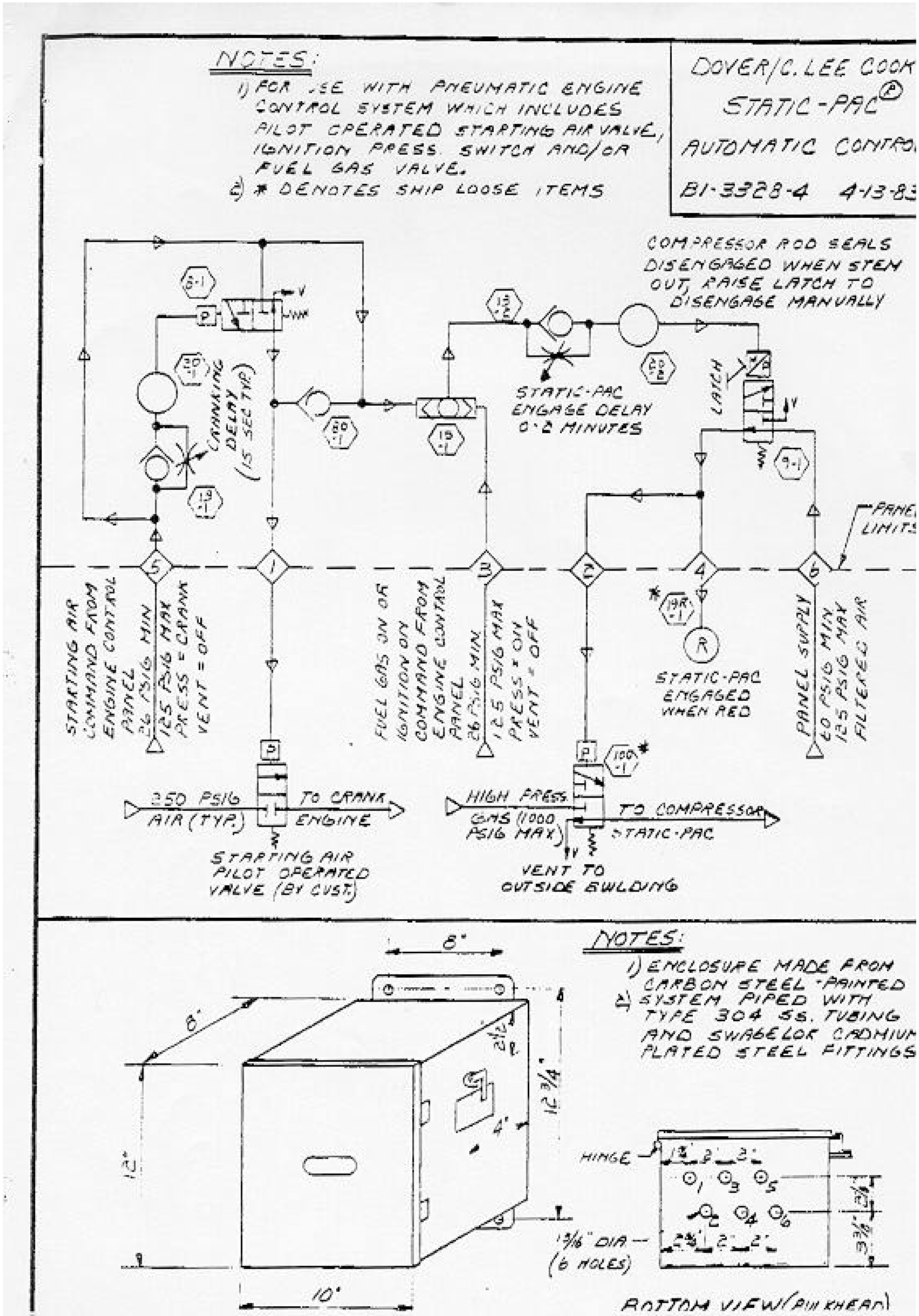
NOTES:
1) FOR USE WITH PNEUMATIC ENGINE CONTROL SYSTEM WHICH INCLUDES PILOT OPERATED STARTING AIR VALVE, IGNITION PRESS. SWITCH AND/OR FUEL GAS VALVE.
2) * DENOTES SHIP LOOSE ITEMS
DOVER/C. LEE COOK
STATIC-PAC®
AUTOMATIC CONTROL
B1-3328-4 4-13-83
COMPRESSOR ROD SEALS DISENGAGED WHEN STEM OUT, RAISE LATCH TO DISENGAGE MANUALLY
CRANKING DELAY (15 SEC TYP)
STATIC-PAC ENGAGE DELAY 0-2 MINUTES
LATCH
PANEL LIMITS
STARTING AIR COMMAND FROM ENGINE CONTROL PANEL 26 PSIG MIN 125 PSIG MAX PRESS = CRANK VENT = OFF
FUEL GAS ON OR IGNITION ON COMMAND FROM ENGINE CONTROL PANEL 26 PSIG MIN. 125 PSIG MAX PRESS = ON VENT = OFF
STATIC-PAC ENGAGED WHEN RED
PANEL SUPPLY 60 PSIG MIN 125 PSIG MAX FILTERED AIR
250 PSIG AIR (TYP)
TO CRANK ENGINE
STARTING AIR PILOT OPERATED VALVE (BY CUST.)
HIGH PRESS. GAS (1000 PSIG MAX)
TO COMPRESSOR STATIC-PAC
VENT TO OUTSIDE BUILDING
NOTES:
1) ENCLOSURE MADE FROM CARBON STEEL - PAINTED
2) SYSTEM PIPED WITH TYPE 304 SS. TUBING AND SWAGELOK CADMIUM PLATED STEEL FITTINGS
8"
12 3/4"
12"
10"
4"
HINGE
13/16" DIA (6 HOLES)
BOTTOM VIEW (BULKHEAD)

APPENDIX B

Static Pac Operator's Manual
Manual Control System

INSTALLATION AND OPERATION

A. INSTALLATION

The Static-Pac Manual Control is designed to be used with engine/compressors which use manually operated cranking air valves and manually operated fuel gas valves. An Automatic version is available for automatically controlled machines.

The Static-Pac control will automatically engage and disengage the compressor packing Static-Pac(s) with commands derived from the normal manual starting sequence when properly installed.

Using an existing tap or a new tee fitting, a tubing connection is made from the engine side of the manual starting air valve to bulkhead no. 5 of the Static-Pac control. Relay valve 101-1 is shipped loose and should be mounted close to the manual fuel gas valve. Again using an existing tap or a new tee fitting, make a tubing connection from a point in the engine fuel gas line on the engine side of the manual fuel gas valve to the pilot of relay valve 101-1. Connect a tubing line from Static-Pac bulkhead no. 7 to the normally closed inlet port of valve 101-1 and a tubing line from the outlet of the valve to bulkhead no. 3. Connect bulkhead no. 2 to pilot (operator) of high pressure valve 100-1; connect high pressure gas supply to blocked inlet port of valve 100-1, connect Static-Pac(s) to opposite port, pipe third port (vent) to a safe, unrestricted vent system to atmosphere. Connect bulkhead no. 4 to indicator 19R-1, after indicator has been positioned in desired location. Connect 60 to 125 psig filtered supply air to bulkhead no. 6. Installation is complete.

B. OPERATION

Engine/compressor is stopped. Supply air and Starting Air are connected to Static-Pac control. Fuel gas is connected to the pilot of relay valve 101-1. High pressure gas is connected to the inlet of control valve 100-1 which is piped to Static-Pac(s) and to vent.

Supply air enters through bulkhead no. 6 to the inlet of valve 9-1. If 9-1 is not manually latched closed, air passes through 9-1 to bulkhead no. 2 and bulkhead no. 4. Pressure from bulkhead no. 2 engages pilot (operator) of valve 100-1, shifting valve so that high pressure gas passes through valve to Static-Pac(s) on compressor, causing them to engage. Pressure from bulkhead no. 4 is routed to to indicator 19R-1, shifting it to the red position to show that the Static-Pac(s) are engaged.

BEFORE STARTING ENGINE: Raise latch on Static-Pac control valve 9-1 to disengage Static-Pac(s).

An auxilliary back-up circuit is provided to disengage the Static-Pac(s) should the operator fail to raise the valve latch. When the manual engine starting air valve is opened, starting air will be applied through bulkhead no. 5 to the pilot of valve 8-1, causing it to open. This allows supply air to flow to shuttle valve 15-1 and on through flow control valve 13-1 in the unrestricted direction to immediately fill volume chamber 20-1, shifting valve 9-1. Valve 9-1 when shifted vents bulkheads 2 & 4, allowing valve 100-1 to vent the Static-Pac(s) and indicator 19R-1 which returns to the black position. Note that this is a back-up circuit only and that manual disengagement should always be used.

After the engine has been purged, the manual fuel gas valve is opened. This applies gas pressure to the pilot of relay valve 101-1 causing it to open and allow supply air to flow from bulkhead no. 7 back to bulkhead no. 3. This signal will remain while engine is running and through shuttle valve 15-1 will keep signal to pilot valve 100-1 vented, keeping Static-Pac(s) on compressor disengaged.

The engine is now running with the Static-Pac(s) on the compressor disengaged.

When the engine is stopped by closing the manual fuel valve, relay valve 101-1 will close, venting the pressure from bulkhead no. 3. The air trapped in volume chamber 20-1 will be slowly vented through flow control valve 13-1 in the restricted direction and on through shuttle valve 15-1 to bulkhead no. 3. Valve 13-1 is adjusted to provide a time delay (up to two minutes) before valve 9-1 shifts to permit the engine/compressor to come to a full stop before engaging the compressor Static-Pac(s). When the pressure is removed from the pilot of valve 9-1, the valve will return to the normally open position allowing pressure to flow through from bulkhead no. 6 to bulkheads no. 2 & 4 causing valve 100-1 to apply pressure to the Static-Pac(s) and to indicator 19R-1, returning is to the red position "STATIC-PAC(s) ENGAGED".

The Static-Pac control can be operated manually to disengage the compressor Static-Pac(s) for maintenance when the engine/compressor is shut down. Raise the red lever on valve 9-1 to disengage the Static-Pac(s), lower the lever to re-engage. Should the lever be accidently left in the manually disengaged position, it will automatically return to normal after the next start/stop sequence.

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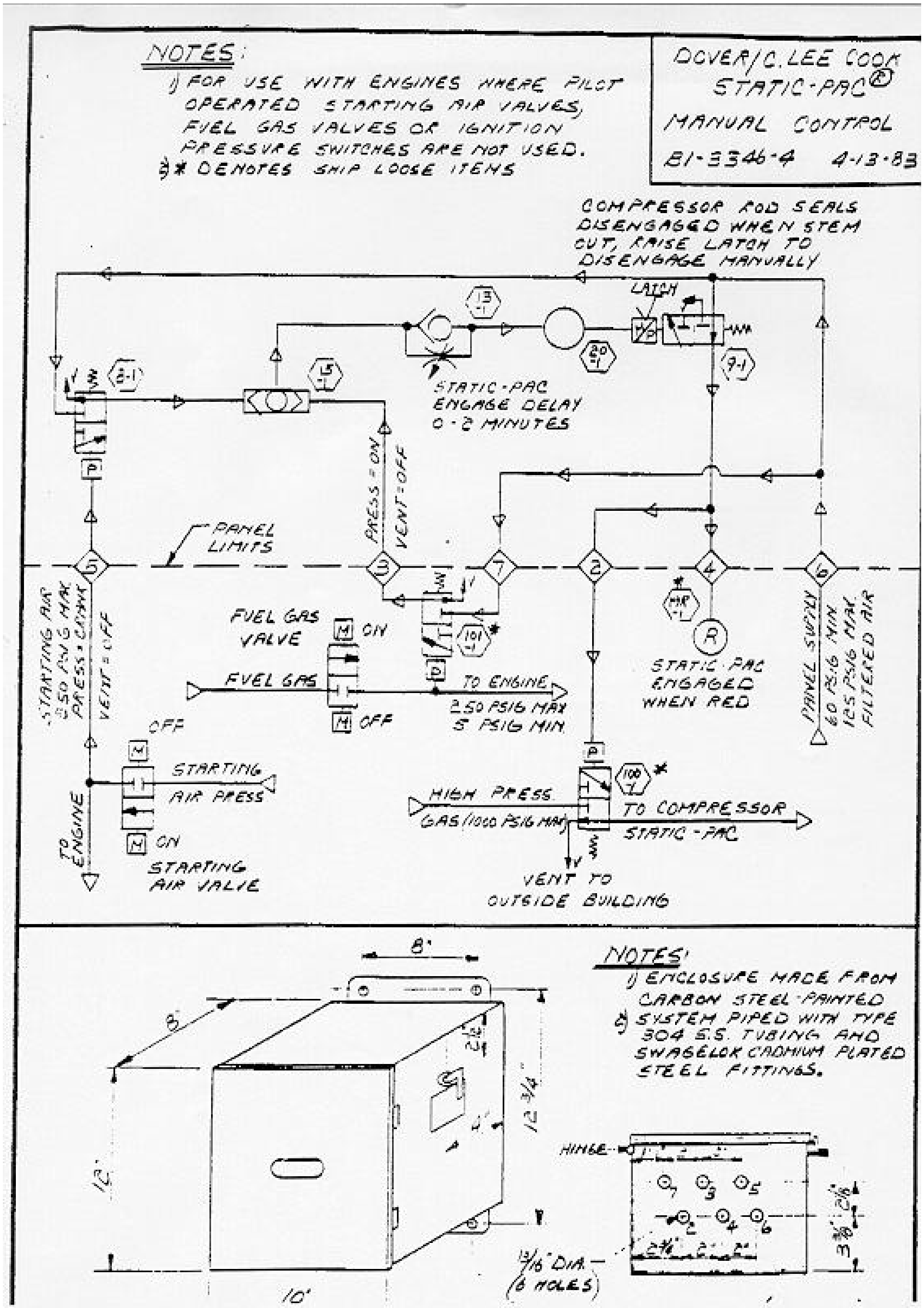
NOTES:
1) FOR USE WITH ENGINES WHERE PILOT OPERATED STARTING AIR VALVES, FUEL GAS VALVES OR IGNITION PRESSURE SWITCHES ARE NOT USED.
2) * DENOTES SHIP LOOSE ITEMS
DOVER/C. LEE COOK
STATIC-PAC®
MANUAL CONTROL
81-3346-4 4-13-83
COMPRESSOR ROD SEALS DISENGAGED WHEN STEM OUT, RAISE LATCH TO DISENGAGE MANUALLY
LATCH
STATIC-PAC ENGAGE DELAY 0-2 MINUTES
PRESS = ON
VENT = OFF
PANEL LIMITS
STARTING AIR 350 PSIG MAX PRESS = CRANK
VENT = OFF
FUEL GAS VALVE
ON
FUEL GAS
OFF
TO ENGINE
250 PSIG MAX
5 PSIG MIN
STATIC-PAC ENGAGED WHEN RED
PANEL SUPPLY 60 PSIG MIN 125 PSIG MAX FILTERED AIR
OFF
STARTING AIR PRESS
TO ENGINE
ON
STARTING AIR VALVE
HIGH PRESS. GAS (1000 PSIG MAX)
TO COMPRESSOR STATIC-PAC
VENT TO OUTSIDE BUILDING
NOTES:
1) ENCLOSURE MADE FROM CARBON STEEL-PAINTED
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8"
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