♨ EPA Evaluation of the High Volume Collection System (HVCS) for Quantifying Fugitive Organic Vapor Leaks
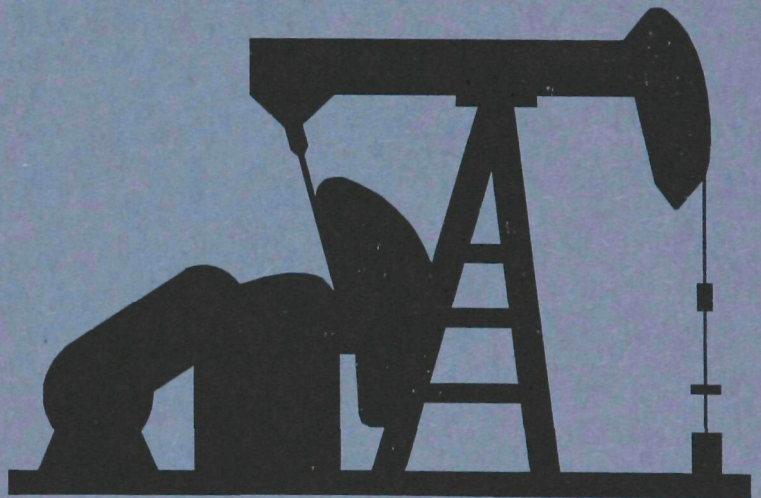
NARSTO

FOREWORD

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

EPA REVIEW NOTICE

Evaluation of the High Volume Collection System (HVCS)
for Quantifying Fugitive Organic Vapor Leaks

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FOREWORD

The North American Research Strategy for Tropospheric Ozone (NARSTO) evolved out of a call by the Clean Air Act Amendments of 1990 [Sec. 185B], in conjunction with the National Academy of Sciences desire to reexamine the role of ozone (O_3) precursors in tropospheric O_3 formation and control. Therefore, the NARSTO study is examining the roles of nitrogen oxide and volatile organic compound emission reductions, and the extent to which these reductions contribute (or are counterproductive) to the achievement of O_3 attainment in different nonattainment areas.

ABSTRACT

Fugitive VOC emissions associated with gas and/or petroleum processing facilities have historically been difficult and expensive to measure accurately. A measurements technique has recently been developed that offers the potential for providing an easy-to-use and cost-effective means to directly measure organic vapor leaks. The method is called the High Volume Collection System (HVCS). The HVCS uses a high volume sampling device and a portable flame ionization detector (FID) for field analysis. The HVCS can obtain direct measurements of mass emission rates without the need for tenting and bagging. This study of HVCS method performance included both field and laboratory testing. Laboratory evaluation of HVCS results closely matched EPA method results with a difference in total measured emissions of only about 3 percent. In one field test, the HVCS matched the EPA estimate of total facility emissions within about 4 percent. In the second field test, the HVCS measured an overall average of 18 percent more emissions than the EPA method. However, the bias was present only in the early part of the test. In the latter part of the test, after efforts were made to identify and correct the source of the bias, HVCS bias was essentially zero. With some physical and procedural enhancements, the HVCS may be offered to EPA for approval as an acceptable alternative to the EPA protocol bagging method with gas chromatographic analysis.

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SECTION 1
INTRODUCTION

Fugitive emissions of methane and other organic vapors from leaking pipelines, valves, flanges, and seals associated with natural gas, petroleum and chemical production and processing facilities are an important source of methane and other organic emissions to the atmosphere. Such emissions have historically been difficult to measure accurately. EPA Reference Method 21 "Determination of Volatile Organic Compound Leaks" describes instruments and procedures that can be used to locate and assess the magnitude of such leaks. This consists of screening components with a portable hydrocarbon analyzer and recording concentration values obtained at the component interface where leaks are detected. Method 21 does not provide a direct measure of the mass emission rate. Mass emission rates for leaking components have traditionally been determined by "tenting and bagging" the leaks. This entails constructing a sampling enclosure around the leaking component, introducing a known flow of diluent gas through the enclosure, and determining the concentration of leaking gas in a sample captured from the enclosure (usually done off-site in a laboratory). The concentration times the total flow rate (diluent and leaking gas) gives the leak rate. This is clearly a laborious and expensive method. A more practical, and less expensive method is desirable to inspect and repair leaking components at a facility.

According to the current EPA protocol (EPA 1993), mass emission rates may be estimated indirectly by one of four methods. (1) Emissions may be estimated by applying published emission factors (EPA 1993) to an inventory of components by type (valves, flanges, etc.) and service (e.g., gas, liquid). (2) More refined emissions estimates may be obtained by identifying leaking components (per Method 21) and applying separate emission factors to leaking and non-leaking components. (3) Still more refined estimates are determined by applying published correlation equations (EPA 1993) to screening values for each component (obtained per Method 21). These emission factors and correlations were developed over the last 15 years based on field studies at petroleum refineries, gas plants, and Synthetic Organic Chemical Manufacturing Industry (SOCMI) plants. (4) Finally, the EPA protocol specifies procedures for developing unit specific correlation equations that may more accurately estimate emissions for a specific facility. This entails obtaining pairs of screening values and direct measurements of mass emissions (by tenting and bagging) at a sufficient number of components so that representative, site specific correlation equations can be developed.

A measurements technique has recently been developed that offers the potential for providing a faster, easy-to-use, and cost-effective means to directly measure organic vapor leaks from gas, oil, and chemical industry sources. The method is known as the High Volume Collection System (HVCS). The HVCS was designed to obtain direct measurements of mass emission rates without the need for tenting and bagging. The HVCS uses a 6 volt battery powered pump to draw ambient air across a leaking component at controlled and metered rates between 10 and 500 standard cubic feet per hour. Figure 1-1 shows a diagram of the HVCS front panel and plumbing (rear view). The flow may be directed through one of three rotameters, which are used to meter the flow. The flow rate is controlled using the needle valves on the smaller rotameters (2-10 and 10-50 scfh), and the ball valve downstream from the larger rotameter (100 to 1000 scfh). A portable Flame Ionization Detector (FID) (Foxboro OVA Model 128) is used to measure the hydrocarbon concentration in the HVCS exhaust.

Exhaust

Control Valve
100 to 1000 scfh

Rotameters

100 to 1000 scfh

10 to 50 scfh

2 to 10 scfh

Vacuum Pump (6V)

Inlet

ON

OFF

Front Panel

Rear View

Pump

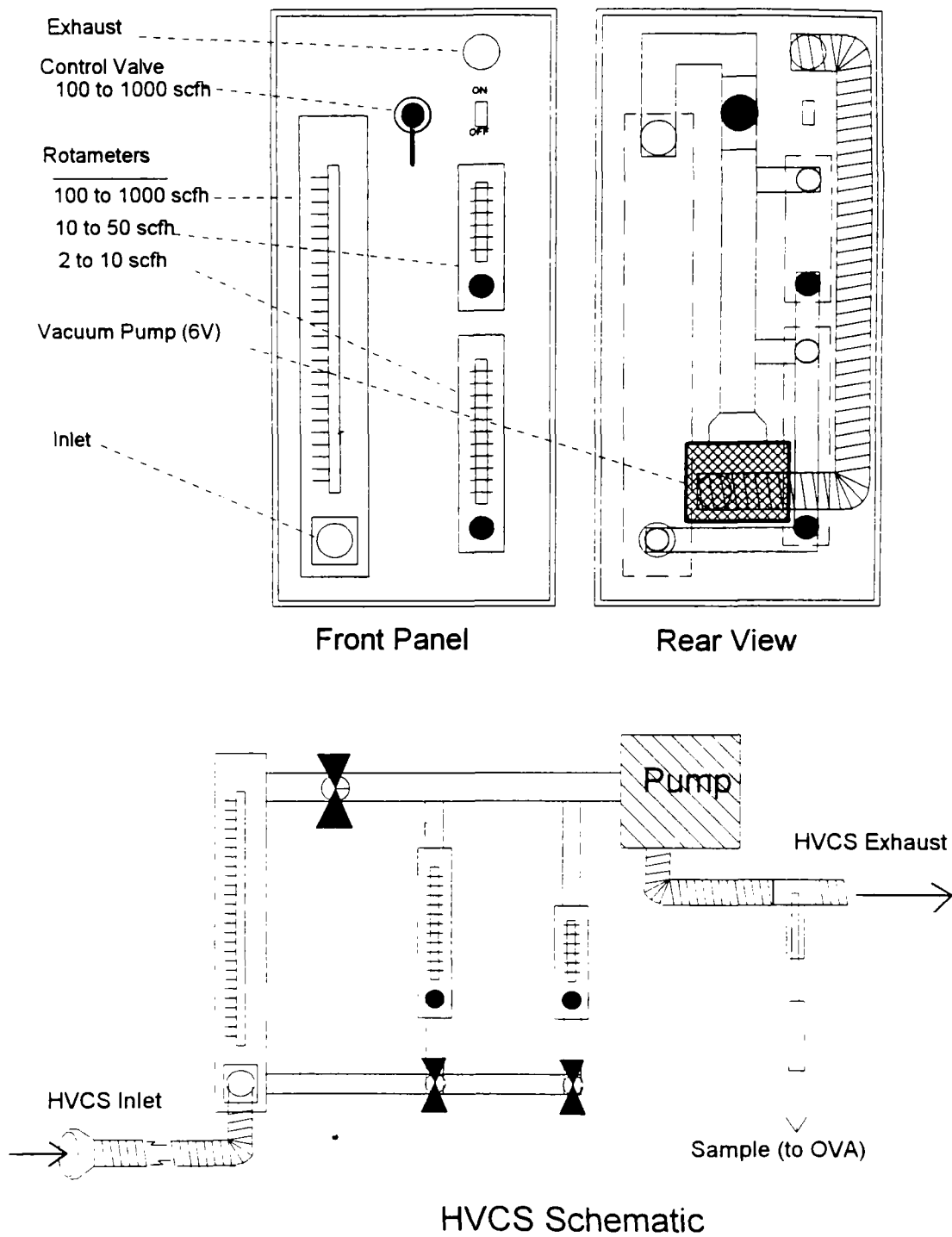HVCS Exhaust

HVCS Inlet

Sample (to OVA)

HVCS Schematic

Figure 1-1. HVCS Diagram and Schematic

The nominal range of the OVA is from 1 to 10,000 ppm. The range can be extended somewhat by directly accessing the voltage output of the OVA. The OVA voltage output is proportional to the logarithm of concentration (in ppm) up to about 5.5 volts, which corresponds to roughly 15,000 ppm (this is somewhat instrument dependent). The OVA was calibrated specific to methane for this study so that the hydrocarbon concentration is reported as methane.

The HVCS mass emission rate is determined as the product of the sample flow rate and the hydrocarbon content in the flow. The success of the method depends on capturing all of the leaking gas from a component in the flow entering the sample inlet. The inlet is constructed to enhance this capture (the inlet is shaped like the mouthpiece of a snorkel). Diffuse leaks from larger components (such as a large flange) are captured by wrapping the component in polyethylene sheeting so that the air flow passes over the entire leaking surface. Prior to this study, limited laboratory and field testing of the HVCS indicated that the system had the potential to provide a practical method for quantifying fugitive hydrocarbon emissions.

1.1   PROJECT OBJECTIVES AND SCOPE

The purpose of this project was to complete a detailed evaluation of HVCS method performance over the wide range of leak sizes, component types and operating conditions characteristic of natural gas production in the United States. The focus of this evaluation is direct comparisons of HVCS results versus controlled leak rates (laboratory) and EPA protocol "tent and bag" method results (field). Consideration is also given to the broader issue of whether the HVCS can be used to accurately determine the total emissions from a facility. In the report, the results are presented from each of these points of view.

The study included both field and laboratory testing. The field testing assessed the accuracy of the HVCS method relative to an EPA protocol emissions measurements method (tenting and bagging). The EPA protocol identifies two methods that can be used to determine mass emission rates: the vacuum method, and the blow through method. The vacuum method was selected for the study based on preliminary laboratory testing (see Appendix A). The goal was to challenge HVCS performance over the range of leak rates, component types and sizes, and operating conditions characteristic of U.S. natural gas production. A major focus of the study was to develop performance criteria for field use of the HVCS method. This included identifying strengths and weaknesses of the prototype HVCS system and making recommendations for improvement, identifying conditions under which best and worst HVCS performance is achieved, and recommending procedures for obtaining optimum results. The laboratory testing was conducted to establish the accuracy and precision of the EPA protocol (bagging) and HVCS methods compared to controlled leak rates. This testing provided necessary support to the field test results by examining the performance of both methods under controlled conditions. In the laboratory, many of the sources of uncertainty associated with field testing were eliminated; the most important of which is that the actual leak rate in the field is not known.

Laboratory testing was completed before the field testing and consisted of EPA and HVCS measurements on constructed leaks representing a range of leak rates and component types typical of natural gas production. Field testing was conducted at two gas production fields; one in south Texas, and one in west Texas. The sites were selected to represent typical facilities where one would expect to find some leaking components; that is, average age of approximately

15 or more years, moderate operating pressure (< 1000 psi), low hydrogen sulfide levels, and with no active leak detection and repair program. The sites also contained a sufficient number of wells, compressor stations, and other installations, in a small enough area, that screening and quantification could be accomplished in a cost effective manner. Leaks were identified with soap solution, and selected leaks were quantified by both the EPA (bagging) and HVCS methods. Gas composition was determined in the field by gas chromatography for each of the bag samples.

A detailed Quality Assurance Project Plan (QAPjP) was prepared, reviewed, and approved prior to beginning any actual testing. This plan was conscientiously adhered to and served as a guide throughout the field testing and final data analysis. Detailed sampling, analytical and QA/QC procedures are described in the QAPjP, which appears as Appendix A to this report.

1.2 SITE DESCRIPTIONS AND LEAK IDENTIFICATION

The south Texas site is a gas production operation consisting of wells, tank batteries, and compressor stations in three separate fields. Testing was completed in two of the three fields. Field number 1 contained 48 wells, 3 tank batteries, and a compressor station with two units. This was an older field operating at relatively low pressure (<100 psi). Field number 2 contained 15 wells, 1 tank battery, and 1 compressor station with a single unit. This was a relatively new field, and was operating at higher pressure (100 to 1000 psi). All sampling in both fields was conducted at the wells.

All components at a total of 44 wells were screened using a Foxboro Organic Vapor Analyzer (OVA) (35 wells in field number 1 and 9 wells in field number 2), for a total of 7628 components. A total of 59 leaks (0.77 percent of screened components) were located using soap solution. Observable soap bubbles are generally not evident with very small leaks (screening values less than 500 ppm). The majority of the leaks identified in this study had screening values of 10,000 ppm or greater. It should be noted, however, that a small leak will produce a screening value in excess of 10,000 ppm. For example, a leak as small as 0.04 slpm (0.08 lb/day as methane), and perhaps smaller (this was the smallest leak constructed in the laboratory studies), produces a Method 21 screening value in excess of 10,000 ppm with calm wind conditions. Most of the emitters were valves (25/59), followed by various types of connectors (15,/59), open ended lines (8/59), and miscellaneous components (11/59). These were generally pressure regulators and gauges.

The west Texas site is a significantly larger operation divided into three separate gas fields feeding a common processing plant. Hydrogen sulfide levels are somewhat higher at this site ranging from a few ppm to over 100 ppm at some wells. H_2S scrubbers are present throughout the field, and H_2S levels at the plant are less than 10 ppm. There are also carbon dioxide stripping facilities located in the fields. Recovered CO_2 is compressed and re-injected into the field at a number of wellheads. Oil wells are interspersed with gas wells at this site. Most of the screening and leak quantification was conducted within the gas plant (51/76 samples). The remaining samples were collected at wellheads (15) and at a propane storage area (10). Operating pressures in the plant are about 890 (inlet) psi down to 30 psi (lowest). Pressure is typically low at the wells (15 to 20 psi). The initial plant stages are about 35 years old. The plant is now in its third phase of development. A total of 13,443 components were screened at 63 locations (plant operating units or well heads). Of these, 98 were identified as leaks (0.73

percent). Most of the leaking components were valves (72/98), followed by threaded connectors (11/98). Table 1-1 summarizes the screening and leak identification results.

Table 1-1. Screened Components and Emitters				
	South Texas		West Texas	
Component	Screened	Leaks	Screened	Leaks
Flanges	889	0	1401	1
Threaded Connectors	3733	12	8010	11
Tube Connectors	931	3	982	0
Valves	1764	25	2890	72
Open End Lines	216	8	55	0
Pressure Relief Valves	21	0	11	7
Miscellaneous	74	11	94	7
Total	7628	59	13443	98

1.3 NOTES ON THE DATA ANALYSIS AND PRESENTATION

These notes are provided to clarify and explain the treatment and presentation of the data in the analysis. The data presentation in sections 2 and 3 is consistent with this reasoning.

The data were validated prior to computing final summary statistics. Validation was necessary since both the EPA and HVCS methods can give spurious results under some circumstances (discussed in some detail throughout this report). Such results are not representative of method performance. Two types of validation were performed: operational and statistical. Operational data validation refers to excluding data where operational problems were noted during sampling or analysis that would compromise data quality. For the EPA method, data were excluded if the total hydrocarbon concentration in the two samples collected from each leak differed by more than 10 percent. EPA method data were also excluded when there were very large leaks. The sampling train used for bag sampling had a maximum flow capacity of about 20 slpm. It was found that if the leak rate exceeded about 8 slpm, the sampling train was unable to capture the leak because the volume of diluent gas was insufficient to promote complete mixing in the bag. HVCS method data were marked suspect if leak capture could not be verified by reproducing the leak rate (within 20 %) at more than one HVCS flow rate. Data were also excluded if there was a known or strongly suspected outside source of bias. In the south Texas results, there were several instances where there was evidence that the leak rate had changed substantially between the EPA method and HVCS quantifications. In the west Texas data, several tests were made in a propane storage area, where the gas composition was primarily propane. Since there is a

known difference in OVA and GC response to propane, these data were also excluded. A statistical validation based on examination of scatter plots with regression analysis was also performed. If a point representing an EPA/HVCS data pair was substantially outside of a 95 percent confidence interval for the regression, it was removed. It is recognized that this type of validation could not be performed for routine HVCS field measurements; however, it is considered that removal of outlying values that significantly skew the results improves the overall representativeness of the HVCS method evaluation.

In this study, the fractional (or percent) difference is used as a measure of overall method performance (independent of leak size). That is, differences between EPA and HVCS results are normalized for the size of the leak (taken as the EPA method result). This measure was chosen because it allows comparison of results over a range of leak sizes, and is simple to grasp intuitively. By its nature, the distribution of the fractional bias is not symmetric. It takes on values from -1 to +∞, with negative biases represented by values between -1 and 0, and positive biases spread from 0 upwards. The logarithm of these values will produce a symmetric distribution. Thus, the underlying distribution for the fractional bias should be described by a 3 parameter lognormal distribution with an offset, τ, of one.

One unfortunate characteristic of log-normally distributed measures, is that the mean and variance of the log transformed data are not the logarithms of the mean and variance of the original, untransformed data. This affects how summary statistics for method performance should be calculated and presented. Since a logarithmic distribution is skewed right (high biases have greater magnitude than low biases), the arithmetic mean computed from the raw data may be biased high. Also, since a logarithmic distribution is not symmetric, confidence intervals do not have the same width on either side of the mean. Unbiased estimators of the mean and variance of log-normally distributed data are available in the literature (e.g., Gilbert 1987). Minimum variance unbiased (MVU) estimators for the mean are used in this report. Summary results are reported as the MVU estimate for the mean, followed by the lower and upper limits for a 95 percent confidence interval in parenthesis. The confidence interval for log-normally distributed data is determined as recommended by Gilbert (1987), and using the tables provided. As it happens, the sampled biases are roughly symmetrically distributed and do not differ greatly from a normal distribution (based on probability plotting). Therefore, the arithmetic mean and confidence interval computed from the "t" distribution is very similar to that computed for the lognormal distribution. The lognormal statistics, however, lend a somewhat greater degree of statistical power to the results. That is, the lognormal confidence intervals are "tighter" Significance tests for differences between means are conducted on the log transformed data using the standard "t" statistic.

Similar to the fractional difference, the leak rates themselves tend to be log-normally distributed. That is, there tend to be a greater number of small leaks, and relatively few very large leaks. This takes on importance in the regression analysis where the results from the two methods are again compared. Again, there is a problem with direct transformation from log space to arithmetic space. To correct for scale bias introduced during the transformation, a scale bias correction factor (SBCF) must be applied. This gives a MVU estimate of the slope of the regression line. The form of the linear regression in log space is given in equation 1-1, where and b are constants determined from the regression.

$$\ln(HVCS) = a + b \cdot \ln(EPA) \qquad \textbf{1-1}$$

$$HVCS = (SBCF) \cdot \exp(a) \cdot EPA^{b} \qquad \textbf{1-2}$$

In arithmetic space, the regression equation should be expressed as in equation 1-2, where the SBCF depends on the mean square error (average of the squared residuals) and the number of data points. It is obtained as the sum of an infinite series (EPA 1993).

Grouped box plots (see Figure 2-3 for an example) are used in this report to illustrate comparisons of segregated data sets. The box plot succinctly illustrates both the central tendency and the distribution of a set of data. The center line in the box represents the median of the data. The upper and lower boundaries of the box represent the 75th and 25th percentiles respectively. The "whiskers" extend vertically above and below the box a distance from the median to the furthest data point within 1.5 times the inter-quartile range (the difference between the 75th and 25th percentiles), or the height of the box. For normal distributions, the whiskers encompass approximately 95 percent of the data. Data lying outside the whiskers are plotted as points. These are often considered outliers. Side by side comparisons of box plots provide a means to make meaningful comparisons that account for how the data are distributed. This helps, for example, to avoid erroneous comparisons of "average" values that may be greatly skewed by outliers, or by non-symmetrical distributions.

SECTION 2
LABORATORY STUDY RESULTS

The EPA vacuum bagging method, as well as the HVCS method, was evaluated in the laboratory studies. Since the EPA method, like any measurement, is subject to imprecision and bias, quantification of these data quality indicators was essential before the EPA method could reliably be used in the field as a measure of HVCS performance. Only limited controlled testing of EPA protocol method performance has been conducted previously (Radian 1980), and this did not include treatment of errors associated with the total sampling system, including the "bag" or component enclosure. The laboratory tests conducted for this study were devised to represent "real world" components and leak types so that overall errors (including total sampling errors) are represented. Actual pipeline components were assembled in such a manner that induced leak rates could be precisely controlled and accurately metered against a primary flow standard. Components tested included a 2 inch gate valve, a 4 inch threaded coupling, a 6 inch pipe flange, and a 1/2 inch pump shaft. These represent component types and sizes that are typically encountered at natural gas production and processing facilities. Details of the laboratory test bench set-up and test matrix are given in the QAPjP (Appendix A). Laboratory test procedures were identical to the field test procedures.

The EPA protocol vacuum bagging method was selected for the study based on preliminary laboratory testing. Initially, the blow-through method was selected because the required apparatus is less complicated, and because a non-combustible gas such as N_2 can be used as the diluent, eliminating the risk of obtaining explosive mixtures in the sample bags. However, during initial testing, the blow-through method gave unsatisfactory results. Errors were large, and results were inconsistent. One problem is that the blow-through method does not provide for direct determination of the total flow (including the leak flow) through the system, since only the flow of carrier gas is measured. This introduces a direct and significant error when leak flows are large relative to the carrier gas flow. An attempt was made to measure the total flow downstream from the enclosure (bag); however, this requires a completely leak-free enclosure, which is generally impractical to execute. Initial trials with the vacuum method gave good results, so it was adopted for the study.

Leak rates induced in the lab study span 4 orders of magnitude and are representative of the range of leaks likely to be encountered at actual gas and oil production facilities. Induced leak rates ranged from 0.02 to 20 slpm (0.4 to 40 lbs/day as CH_4). This range is representative of essentially all of the emissions and more than half of the emitters (including all of the larger emitters) characterized in recent measurements at on-shore gas and oil production operations (API 1993) at 16 sites where nearly 140,000 components were screened and 4200 emitters identified. A summary of the laboratory test results is given in Table 2-1. Laboratory test results are discussed in detail in the following paragraphs.

Table 2-1. Laboratory Results Summary				
Method Bias	**Mean (MVU)**	**Lower 95% Limit**	**Upper 95 % Limit**	**No.**
EPA Method Bias vs. Induced	-7.4%	-9.7%	-5.0%	55
HVCS Bias	-8.3%	-12.0%	-4.3%	32/55[1]
HVCS Relative Bias	0.3%	-9.0%	8.5%	9/22[1]
HVCS "True" Bias	-7.1%	-15.7%	0.5%	9/22[1]
Difference in Total Emissions	**Leak (slpm)**	**Result (slpm)**	**Diff (%)**	**No.**
EPA Method vs. Induced	96.1	90.4	-5.9%	55
HVCS Method vs. Induced	175.1	164.5	-6.1%	55
EPA vs. HVCS	25.1 (EPA)	24.4 (HVCS)	-2.8%	22

[1]. Summary results are calculated using only data that are unaffected by the probe position bias (see Section 2.2).

2.1 EPA METHOD RESULTS

A total of 59 constructed leaks were measured by the EPA vacuum method. Fifty-five of these were valid measurements. Three tests were invalidated because the concentration analyses for the two bag samples differed by more than 10 percent. One additional test was invalidated based on a regression outlier test (point was outside of a 95 percent confidence interval for the regression in log space, and removal of the point improved the regression fit). The QAPjP data quality objective for the EPA laboratory measurements of 45 valid quantifications was met. Figure 2-1 shows EPA method bias (in chronological order) for the raw and validated data sets.

The total induced leak rate from all components tested was 96.1 slpm (198.9 lb/day). The total leak rate measured by the EPA method was 90.4 slpm (187.1 lb/day) , for an overall difference of -5.9 percent. If the totality of the test results is viewed as a facility, this result can be viewed as the error in the total facility emissions estimate.

The MVU (see Section 1.3) estimator of the mean bias in the EPA method is -7.4 (-9.7 to -5.0) percent, where the range given in parenthesis represents the lower and upper limits for a 95 percent confidence interval for a lognormal distribution (Gilbert 1987). These results are summarized in Table 2-1. Clearly, the EPA method exhibited a negative bias for the laboratory study. This was most likely due to incomplete mixing in the bag. That is, dilution air (atmospheric) may have been taken up by the sampling system directly, without having mixed completely with the leaking gas. This would explain a negative bias. Every effort was made to minimize this artifact. The normal procedure included leak testing sampling enclosures prior to

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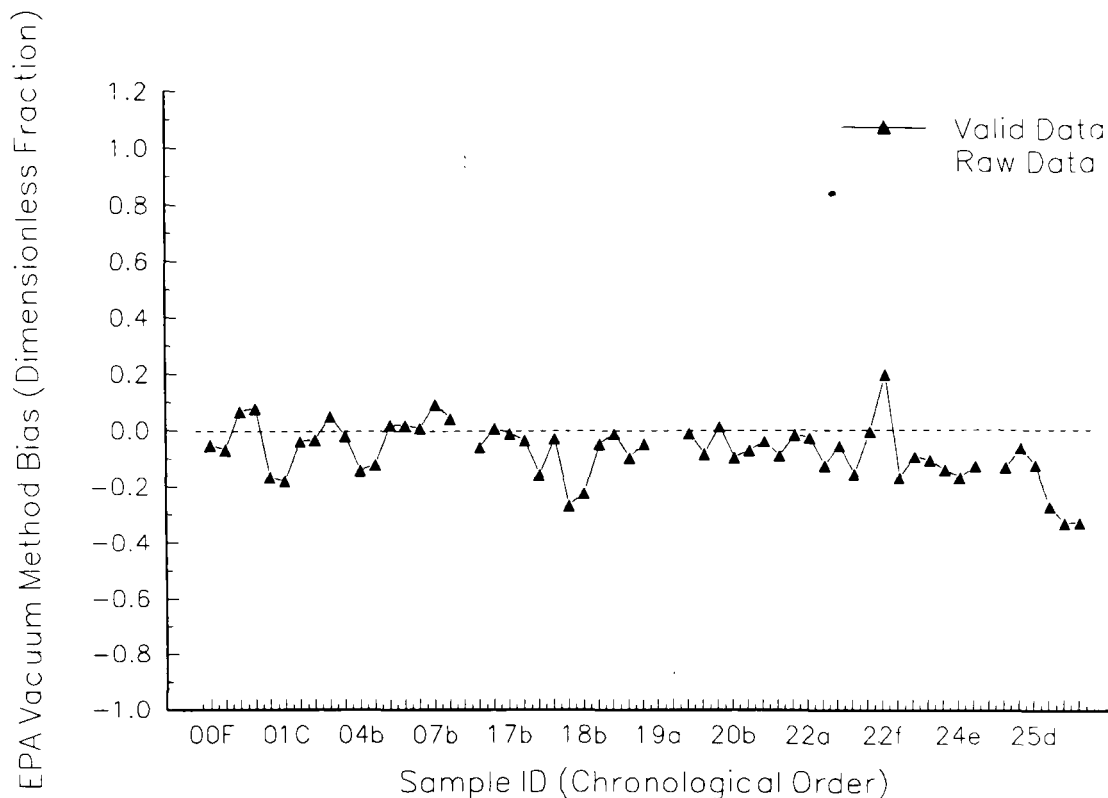
Figure 2-1. EPA Vacuum Method Laboratory Performance - Data Validation

sampling (the bag should collapse over the enclosure when vacuum is applied), and then cutting small air inlets into the bag opposite the leak from the sampling inlet. There is a strong, linear relationship between the EPA results and the induced leak (r^2 = 0.991). The regression is shown in Figure 2-2.

The bias in the EPA method bias is not strongly dependent on leak rate, component type, leak type, or internal pressure. Figure 2-3 shows box plot comparisons. At first, it may appear that the method is more strongly biased for the smaller leaks (< 0.1 slpm); however, this is an artifact of the use of the fractional bias to measure method performance. By its nature, the fractional bias will tend to be larger with smaller leaks simply because a small difference may be a large fraction of a small number. Since the absolute magnitude of these errors is small, it was decided that rigorous statistical tests to infer whether the apparently larger bias for small leaks is significant were unnecessary. From the box plots, there is no observable dependence of method performance on component type, pressure, or leak character.

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EPA = 0.931 * 1.003 * Induced$^{(1.013)}$, r^2 = 0.991

Figure 2-2. EPA Vacuum Method Laboratory Performance - Regression Analysis

Figure 2-3. EPA Vacuum Method Laboratory Performance - Box Plot Comparisons
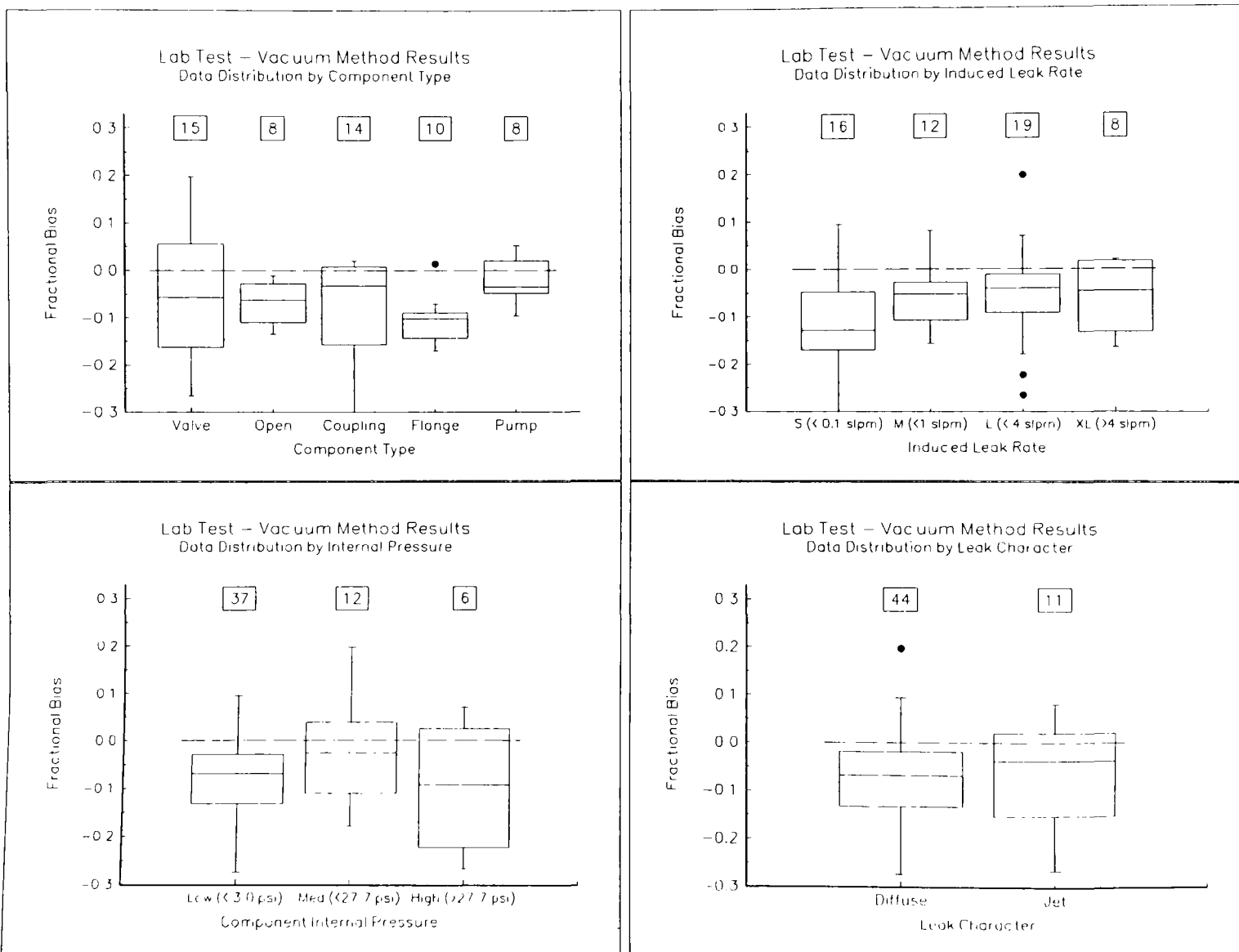
2.2 HVCS METHOD RESULTS

A total of 75 constructed leaks were quantified by the HVCS method. Sixty of these were operationally valid, meaning that the coefficient of variation (ratio of the standard deviation to the mean) for three leak rate determinations at different flows was within 20 percent. Most of the 15 invalid tests were invalidated due to incomplete leak capture at lower HVCS flows. These could have been recovered by simply monitoring the results during testing, and repeating tests until three "good" measurements were obtained. For the field studies, a procedure was developed to identify instances where incomplete leak capture may have occurred and, if possible, recover valid data by omitting these occurrences (see Section 4). Five additional samples were excluded based on regression outlier tests, so that a total of 55 valid tests remained. The QAPjP data quality objective for the HVCS measurements of 45 valid quantifications was met. Figure 2-4 shows HVCS method bias for the raw and validated data sets.
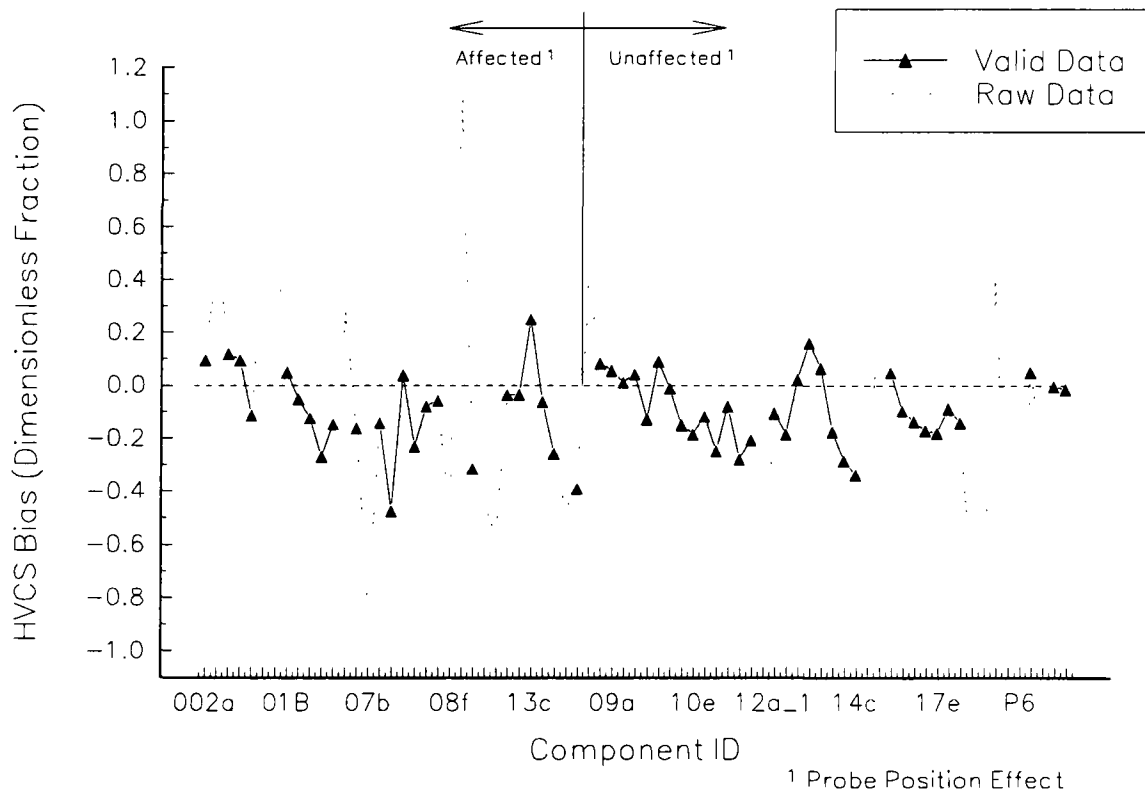
Figure 2-4. HVCS Laboratory Performance - Data Validation

The total induced leak rate from all components tested was 175.1 slpm (84.6 lb/day). The total leak rate measured by the HVCS method was 164.5 slpm (79.5 lb/day) , for an overall difference of -6.1 percent. If the totality of the test results is viewed as a facility, this result can be viewed as the error in the total facility emissions estimate.

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Figure 2-4 also indicates a change in sampling methodology that was initiated when a sampling bias related to the position of the OVA probe in the HVCS exhaust stream was discovered. It was found that when the OVA probe is positioned directly into the HVCS exhaust (probe at 0 degrees to the exhaust flow), a higher concentration reading is obtained than when the probe is positioned at 90 degrees to the exhaust flow. This is due to the increased pressure on the OVA inlet, which increases the sample flow to the detector, and produces a bias. It should be noted, that in earlier work with the HVCS, the OVA probe was positioned directly into the HVCS exhaust. In order to determine the magnitude of the probe position bias, a series of measurements were made with the probe alternately positioned directly into the flow and at 90 degrees to the flow. Results with the probe positioned directly into the flow were consistently higher than those where the probe was positioned at a right angle to the flow. The bias over four series of tests (at leak rates of 0.76, 0.305, 0.045, and 0.0135 slpm, covering the operational concentration range for the OVA, and spanning the effective HVCS flow range) averaged +11.6 ±1.1 percent. It was concluded that the probe should be positioned at a right angle to the HVCS exhaust flow and "T" adapter was constructed that was used in all further laboratory and field testing.
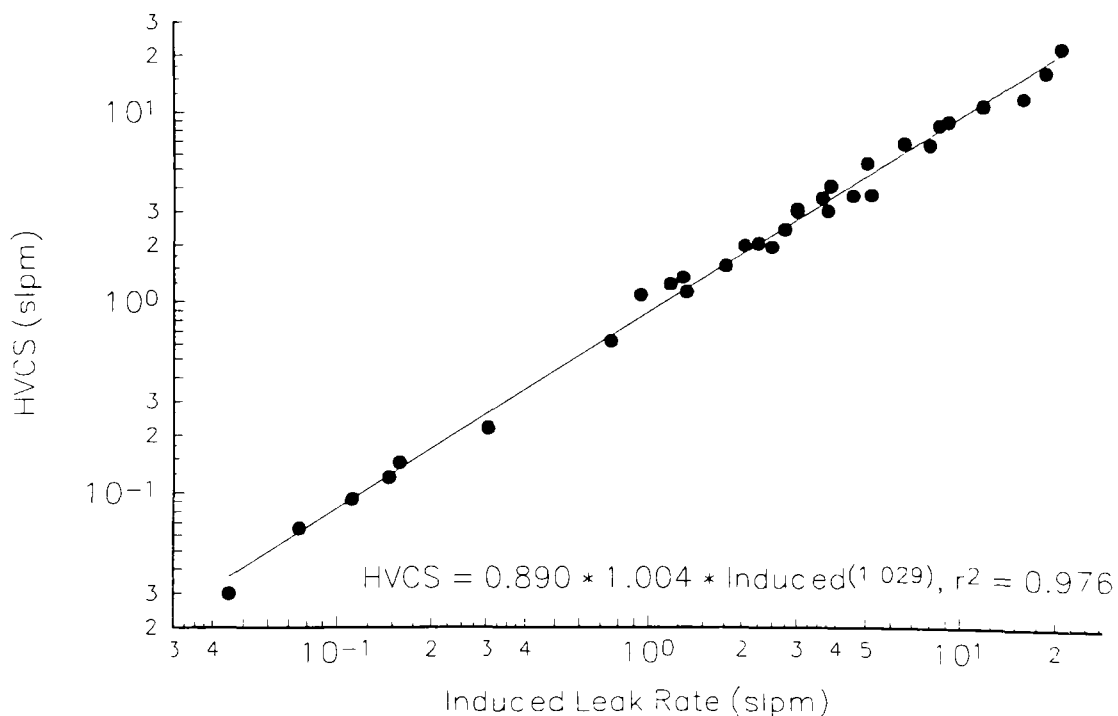
Figure 2-5. HVCS Laboratory Performance - Regression Analysis

A total of 23 of the valid HVCS leak rate measurements were obtained with the OVA before the effect of probe position was noted. While the probe position bias was clearly apparent in the

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special testing described above, it was not possible to distinguish the bias in the overall data set. In many cases, the effect is probably overwhelmed by other sources of bias, such as incomplete leak capture. On this basis, it was decided that applying a "correction" for the bias was not advisable. Conclusions and recommendations made in this report are based on the 32 HVCS measurements that are unaffected by the probe position bias.

For the data unaffected by the probe position bias, the MVU estimate of the mean is -8.3 (-12.0 to -4.3) percent. The HVCS determinations correlate well with the induced leak rates ($r^2=0.992$). The regression is shown in Figure 2-5. The magnitude and direction of the HVCS bias is similar to that for the EPA method; however, there is considerably more variability in the HVCS data. (e.g., compare Figures 2-1 and 2-4). Nonetheless, it is clear that the overall bias is negative. The negative bias is probably due to incomplete leak capture. In the laboratory studies, the HVCS "snorkel" inlet (about 2 inches across) was used alone on the smaller components (e.g., the 2 inch valve, and pump shaft). On larger components (e.g., the 4 inch threaded coupling), a larger snorkel shaped inlet (about 4 inches across) was used, and capture was enhanced by shielding the side of the component opposite the HVCS inlet with Mylar film. On the 6 inch flange, a Mylar shield was wrapped around the component to form a partial enclosure. It is believed that some of the leaking gas was not caught up in the HVCS slip stream, even with the aid of the shields and partial enclosure. Partial enclosures were used much more extensively in the field. In the field, the HVCS inlet was typically attached near the leak interface and the entire interface and inlet were wrapped in light weight polyethylene. A spring coil (toy "Slinky") was used, when necessary, to prevent the wrapping from obstructing the leak and allow unrestricted airflow around the component. This additional wrapping appears to significantly improve leak capture, especially in windy conditions.

The bias in the HVCS method bias is not strongly dependent on leak rate, component type, leak type, or internal pressure. Figure 2-6 shows box plot comparisons for the entire (uncorrected) data set. As with the EPA data, it appears at first that the method is more strongly biased for smaller leaks (< 0.1 slpm), however, this is probably an artifact of the measure used for bias. Once again, since the absolute magnitude of these errors is small, it was decided that rigorous statistical tests to infer whether the apparently larger bias for small leaks is significant were unnecessary. From the box plots, there is no observable dependence of method performance on component type, pressure, or leak character.
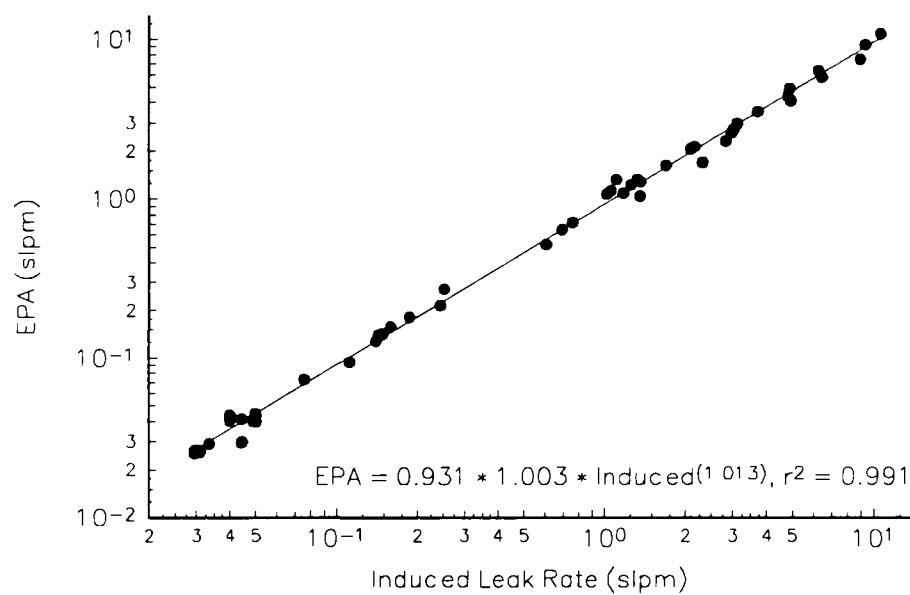
The prototype HVCS demonstrated in the lab tests uses a 6 volt DC vacuum fan motor to draw ambient air at up to 400 scfh across a leaking component. The gas flow is measured by one of 3 rotameters, covering a range from 2 to 1000 scfh. The concentration of hydrocarbon in the gas mixture (air and leaking gas) is measured by a Foxboro OVA 108 with an output scale from 1 to 10,000 ppm and a voltage output that is proportional to the log of concentration from 0.0 up to about 5.5 VDC (for a maximum concentration of about 14,500 ppm with the unit used in the lab study). Above 5.5 VDC, the OVA output is highly non-linear.

HVCS leak measuring capacity is limited by the HVCS flow capacity and/or the concentration range measurable by the OVA. At maximum flow (about 400 scfh), leaks of up to 1.9 slpm (3.8 lbs/day methane) can be measured on the conventional OVA scale (up to 10,000 ppm) and leaks up to about 2.7 slpm (5.4 lbs/day methane) can be measured by extending the OVA scale (up to 5.5 V or about 15,000 ppm) using the voltage output. However, the leak rate should be determined at more than one HVCS flow to verify leak capture. If measurements are to be made

at each of the three HVCS flow scales (100 to 1,000 scfh, 20 to 100 scfh, and 2 to 20 scfh), the maximum measurable leak rate is around 0.07 slpm (assuming a lower flow of 10 scfh). This is among the smallest leak rates measured in the lab studies. As a practical matter, HVCS precision can be determined using several flows on the upper HVCS flow scale (100 to 400 scfm). This gives a maximum directly measurable leak rate of about 0.7 slpm, or 1.4 lb/day (with a lower flow of 100 scfh), a moderate sized leak. To quantify larger leaks, a dilution probe must be used on the OVA, or a hydrocarbon analyzer with greater range must be used.

To cover the range of leaks in the lab tests, HVCS leak measuring capacity was extended using a Geotechnical Instruments GA 90 Infrared (IR) gas analyzer (Model# 601003), which measures the methane concentration from 0.1 to 100 percent. Concentrations below 1 percent (10,000 ppm) were measured by the OVA, and above 1 percent were measured by the IR analyzer. This worked well in the laboratory studies since the leaking gas was nearly 100 percent methane. The response of the IR analyzer to hydrocarbons other than methane was not tested directly. In the field, however, the response of the IR analyzer to the gas mixtures encountered was unpredictable, indicating that the device is not well suited for gas field measurements. Of the 55 valid measurements, 35 were made using the OVA, and 20 were made with the IR analyzer. It should be noted that the IR analyzer did not exhibit the probe position bias that was observed for the OVA. There was no distinct difference in HVCS method bias depending on which analyzer was used. Foxboro's dilution probe was used extensively in the field, with apparently good results. Most dilution factors were on the order of 30 times. Higher dilution ratios should probably be avoided.

2.3   EPA/HVCS COMPARISONS

For 22 tests, both EPA and HVCS measurements were made on exactly the same constructed leak, allowing for direct comparisons. Only 9 of these tests, however, were unaffected by the OVA probe position bias. Summary results for these 9 data pairs are presented here. For this subset, HVCS bias was -8.6 (-17.3 to -1.2) percent. EPA bias was -8.7 (-13.4 to -3.2) percent. These results are consistent with those for the overall data set. HVCS bias relative to the EPA method was +0.3 (-9.0 to +8.5) percent, indicating that the two methods get essentially the same results, though both exhibit small, negative biases. The HVCS and EPA methods correlate very well with each other (r^2 = 0.999).

The total induced leak rate from all components tested by both methods was 26.1 slpm (54.0 lb/day). The total leak rate measured by the EPA method was 25.1 slpm (52.0 lb/day), and the total leak rate measured by the HVCS method was 24.4 slpm (50.5 lb/day). The overall difference between the EPA and HVCS methods was of -2.5 percent. If the totality of the test results is viewed as a facility, this result can be viewed as the difference in total facility emissions estimates that would be obtained by the two methods.

The "true" HVCS bias (*i.e.*, relative to the actual leak rate as opposed to the EPA method result) is calculated from the HVCS and EPA measurements, and the measured bias in the EPA method (EPA$_E$, as determined in the laboratory) using equation 2-1, which is derived in the QAPjP For the laboratory comparisons, "true" HVCS bias is found to be -7 1 (-15.7 to +0.5) percent, using the -7.4 percent bias determined for the EPA method. This calculated "true" HVCS bias of -7 1 percent is reasonably consistent with the directly measured HVCS bias of -8.3 percent. The

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Figure 2-6. HVCS Laboratory Performance - Box Plot Comparisons

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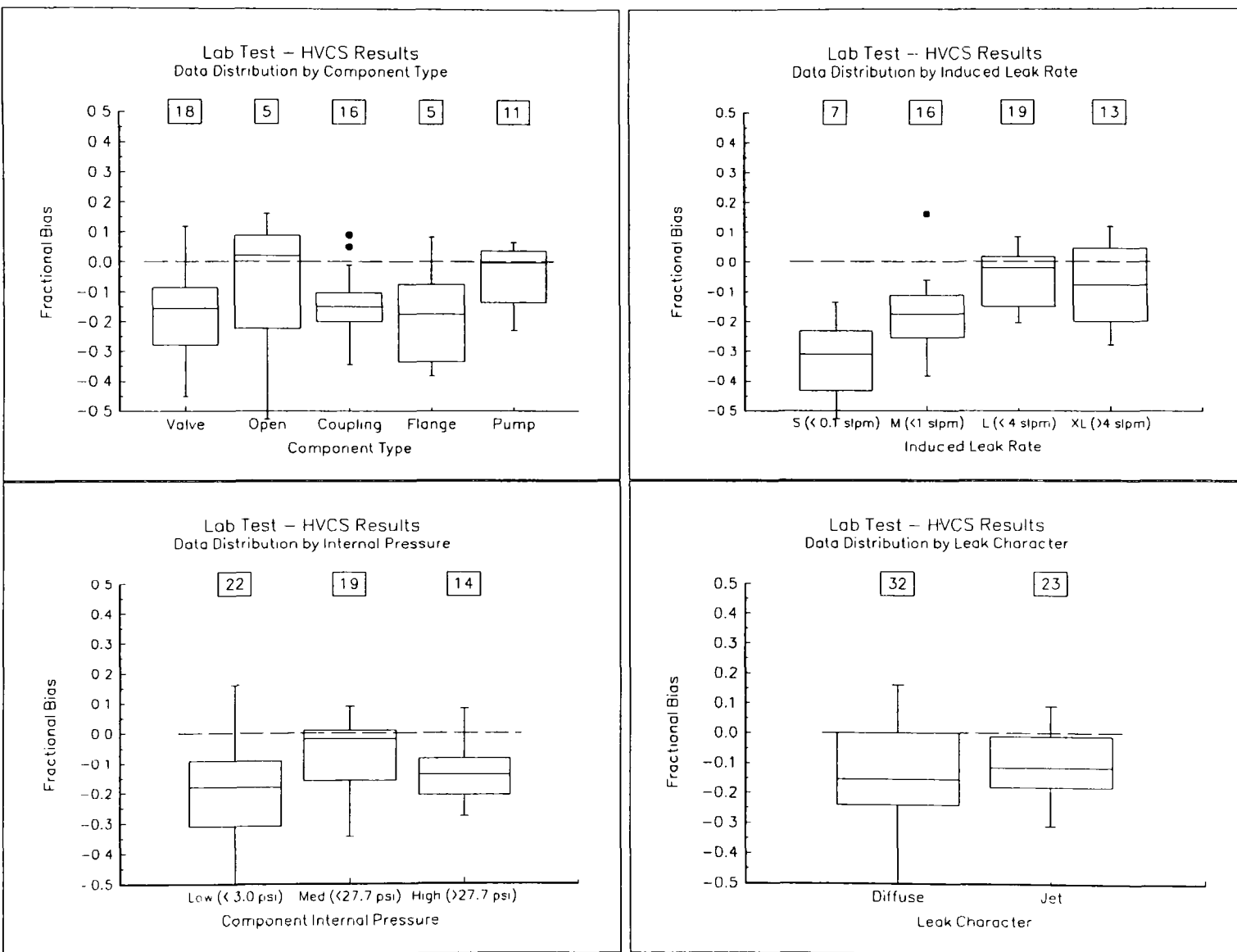
"true" bias is an important measure for the field performance of the HVCS, since the true leak rate will not be known absolutely, but must be inferred from the EPA method results.

$$True\ Bias = \frac{HVCS - EPA + EPA_E\ HVCS}{EPA}$$

where,

HVCS is the leak rate determined by the HVCS (slpm),

EPA is the leak rate determined by the EPA method,

EPA_E is the laboratory measured bias for the EPA method

2-1

2.4   SUMMARY OF LABORATORY STUDY FINDINGS

The primary goal of the laboratory study was to determine the precision and accuracy of the EPA method under controlled conditions. This was essential to the study since the EPA method is used in the field as the point of comparison for determining HVCS method performance, and representative test data were not available from other sources. The laboratory study yielded reliable estimates of EPA vacuum method precision and accuracy representative of a wide range of leak rates, and component types and sizes. The EPA method exhibited a small, but significant negative bias, averaging about -7.4 percent, which was quite consistent with a 95 percent confidence interval of about ±2.4 percent. The cause of the bias is most likely incomplete mixing within the sampling enclosure, which occurs even when reasonable measures are taken to promote mixing. Perhaps some modification to the method would improve performance; however, such a determination was beyond the scope of this project.

The second goal of the laboratory study was to examine HVCS performance under controlled conditions to determine its operating characteristics and optimum operating conditions. Several important findings were made.

■   The HVCS compared well with the EPA method in direct comparisons. Overall, the HVCS exhibited a negative bias of nearly the same magnitude as the bias in the EPA method. The cause of the HVCS bias was incomplete leak capture. The cause of the EPA method bias was incomplete mixing in the bag.

■   Both methods gave accurate determinations of "total facility emissions", viewed as the sum of emissions from all tested components.

■   The analyzer probe should be positioned perpendicular to the HVCS exhaust flow to avoid a positive sampling bias on the order of 10%.

■   The prototype HVCS unit used with the Foxboro OVA 108 is not adequate for measuring larger leaks (more than about 1 slpm) without the use of a dilution probe or an alternate analyzer with greater range. In some tests, the HVCS exhaust contained methane concentrations as high as 15 percent by volume.

■   In general, the flow capacity of the prototype HVCS is not generally sufficient to effect complete leak capture unless an enclosure is constructed around the leaking component.

Finally, "true" HVCS bias based on comparisons of HVCS results with bias corrected EPA method results closely matches the HVCS bias determined from actual comparisons to known leak rates.

SECTION 3
FIELD STUDY RESULTS

The overall goal for the field study was to obtain 125 valid pairs of HVCS and EPA method leak quantifications. A total of 135 pairs of operationally valid measurements were obtained. Of these, 114 pairs were used in the final data analysis. To locate leaks for the study, over 21,000 components were screened at two gas production facilities located in separate areas (south Texas and west Texas). A more detailed description of the two facilities and of the numbers and types of components screened and emitters found is given in Section 1.2. Table 3-1 gives a summary of the field study results. Note that, for the west Texas study, results are presented for the overall study and as segregated before and after September 26 (1994). This was done because the apparent HVCS bias changed dramatically after this date. Sources of bias, and possible reasons for the improvement in results are discussed in section 3.3.

Table 3-1. Field Study Results Summary				
Method Bias	**Mean (MVU)**	**Lower 95% Limit**	**Upper 95 % Limit**	**No.**
South Texas HVCS Relative Bias	15.2%	4.1%	29.8%	48
South Texas HVCS "True" Bias	6.6%	-3.6%	20.2%	48
West Texas HVCS Relative Bias Overall	44.5%	34.3%	56.7%	66
West Texas HVCS "True" Bias - Overall	33.8%	24.4%	45.1%	66
West Texas HVCS Relative Bias *On and Before September 26*	67.0%	56.5%	84.8%	40
West Texas HVCS "True" Bias *On and Before September 26*	54.7%	44.9%	71.1%	40
West Texas HVCS Relative Bias *After September 26*	5.7%	-0.4%	18.6%	26
West Texas HVCS "True" Bias *After September 26*	0.0%	-7.3%	9.8%	26
Difference in Total Emissions	**EPA (slpm)**	**HVCS (slpm)**	**Diff. (%)**	**No.**
South Texas	55.8	58.2	+4.3%	48
West Texas - Overall	79.2	93.9	+18.6%	66
West Texas - *On and Before September 26*	32.7	48.1	+47.1%	40
West Texas - *After September 26*	46.5	45.8	-1.5%	26

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3.1   SOUTH TEXAS RESULTS

At the south Texas site, 56 operationally valid data pairs were obtained, and 48 of these were retained in the final data analysis. Four pairs were eliminated as outliers (regression test). Two pairs were eliminated because there were very large absolute differences in the leak rates determined by the two methods. These "leaks" were probably, in actual fact, pressure releases due to a compressor failure that occurred downstream, so that the emission rate changed substantially in the interval between the two measurements. Two additional pairs were eliminated due to unusually high percentage differences in the two measurements. Figure 3-1 shows a time plot of the raw and validated data from the south Texas site.

Figure 3-1. South Texas Results - Data Validation

Leak rates measured at the south Texas site ranged from less than 0.01 to more than 9 slpm as measured by the EPA method. Some larger leaks were not measurable by the EPA method. The HVCS method measured leak rates up to 13 slpm. The average leak rate was about 1.2 slpm, with a median of 0.25 slpm. Total measured emissions (EPA method) were about 70 slpm, or about 140 lb/day, representing most of the leaks in two of three gas fields served by the facility.
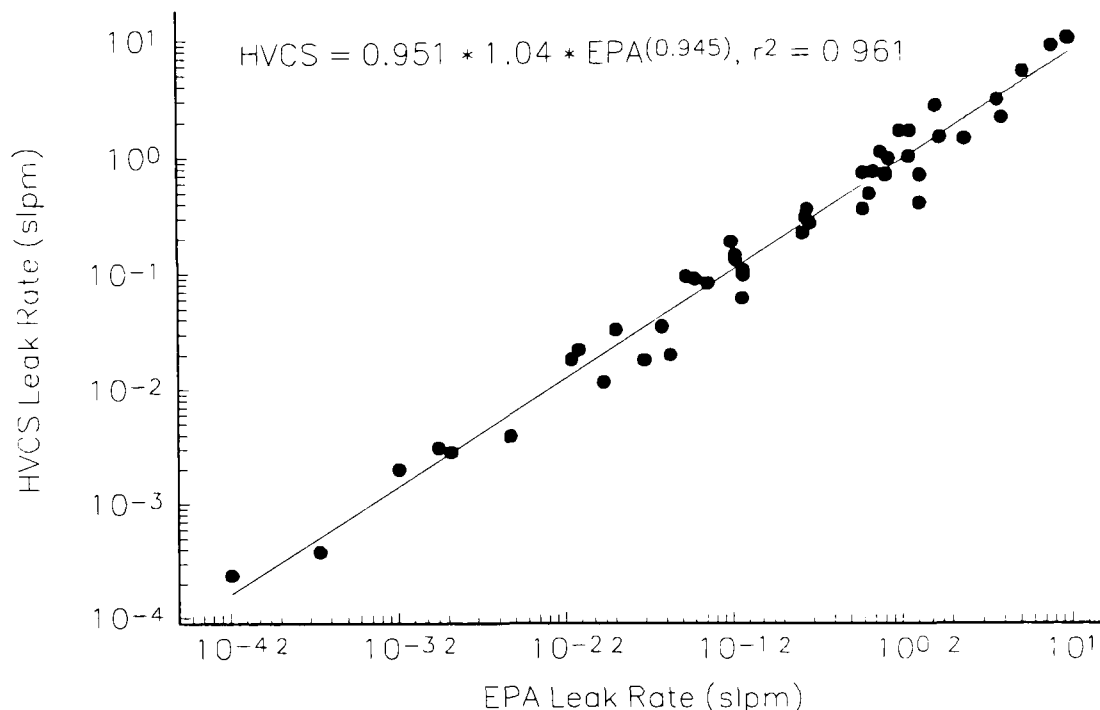
Figure 3-2. South Texas Results - Regression Analysis

HVCS bias was +15.2 (4.1 to 29.8) percent relative to the EPA method, and "true" HVCS bias was +6.6 (-3.6 to 20.2) percent. There is a significant degree of imprecision in these results due to the high degree of variability in the data (the standard error of the mean is about 45 percent of the mean value). This yields wide confidence intervals. There appears to be a positive bias in the field data compared to the laboratory results; however a statistical comparison gives a probability that the means are different of only 65 to 75 percent. That is, given the variability in the data, the average laboratory study and south Texas field study results cannot be distinguished with a very high level of statistical significance. Nonetheless, it is reasonable to suspect that there is some positive HVCS bias in the south Texas results. The negative bias observed in the laboratory studies was probably eliminated by the additional component wrapping (see section 2.2) that was routinely performed in the field. The source of the additional positive bias has not been definitively determined, but may be an analytical bias caused by differences in OVA and GC response to the same samples. This is discussed in detail below (see Section 3.3).

Despite the differences, the HVCS and EPA measurements correlate very well (r^2 = 0.96). A regression plot and equation is shown in Figure 3-2. Segregation of the data by leak size (see Figure 3-3) shows that the HVCS bias is larger for smaller leaks. As previously noted, this is typical of the use of a relative bias, or percent difference as a measure of method performance.

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In terms of an overall inventory, the relative bias overstates the difference between the two methods. Overall measured emissions (final validated data only), are 58.2 slpm (about 120 lb/day) for the HVCS method and 55.8 slpm (about 115 lbs/day) for the EPA method, an overall difference of only about 4 percent. SRI also investigated possible dependence of the HVCS bias on the delay time between the EPA and HVCS measurements, component type, and use of the dilution probe (6 tests). None of these factors had an observable influence on HVCS bias. For south Texas, delay times were often significant (up to several days); however, this did not appear to have a significant impact on the data. The delay time problems in South Texas were caused by excessive time required to locate leaks, since the gas well Jocations were widely scattered. There were no problems with delay time in the West Texas study, where most of the leaks were located within a gas plant.
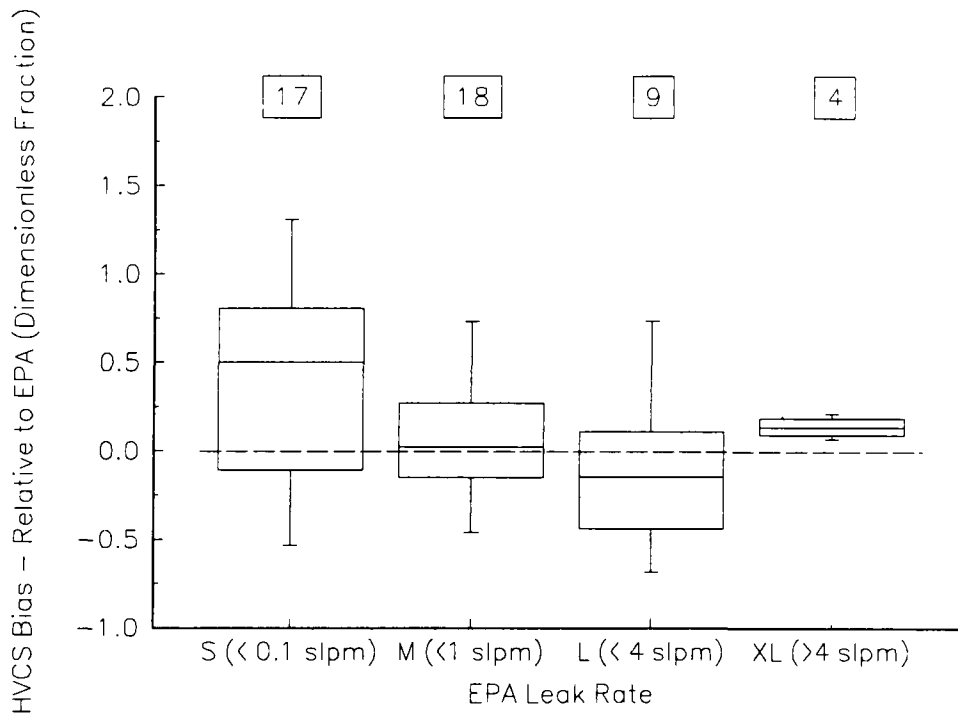
Figure 3-3. South Texas - Bias Dependence on Leak Rate

3.2   WEST TEXAS RESULTS

At the west Texas site, 79 operationally valid data pairs were obtained, and 66 pairs were retained in the final data analysis. Two pairs were eliminated as outliers (regression test). Five pairs were eliminated due to very high absolute differences in the leak rate. These were very large leaks (> 8 slpm) where the EPA method may have been ineffective since the maximum vacuum flow that could be attained with the apparatus used in the study was about 20 slpm. In addition, 6 pairs were excluded because the gas composition was primarily propane, and the OVA response to propane is less than half of the GC response. Figure 3-4 shows a time plot of the raw and validated data from the west Texas site. The improvement in the HVCS bias after September 26 (just before ID71) is readily apparent in the Figure. This improvement is discussed in section 3.3.
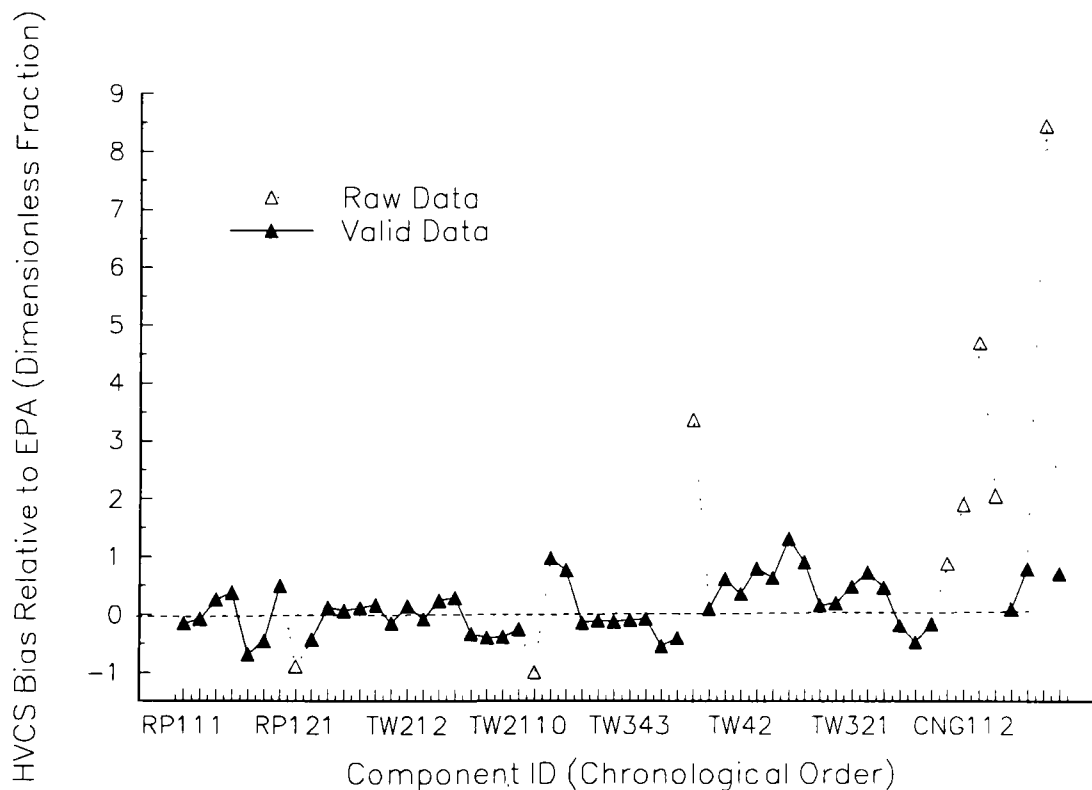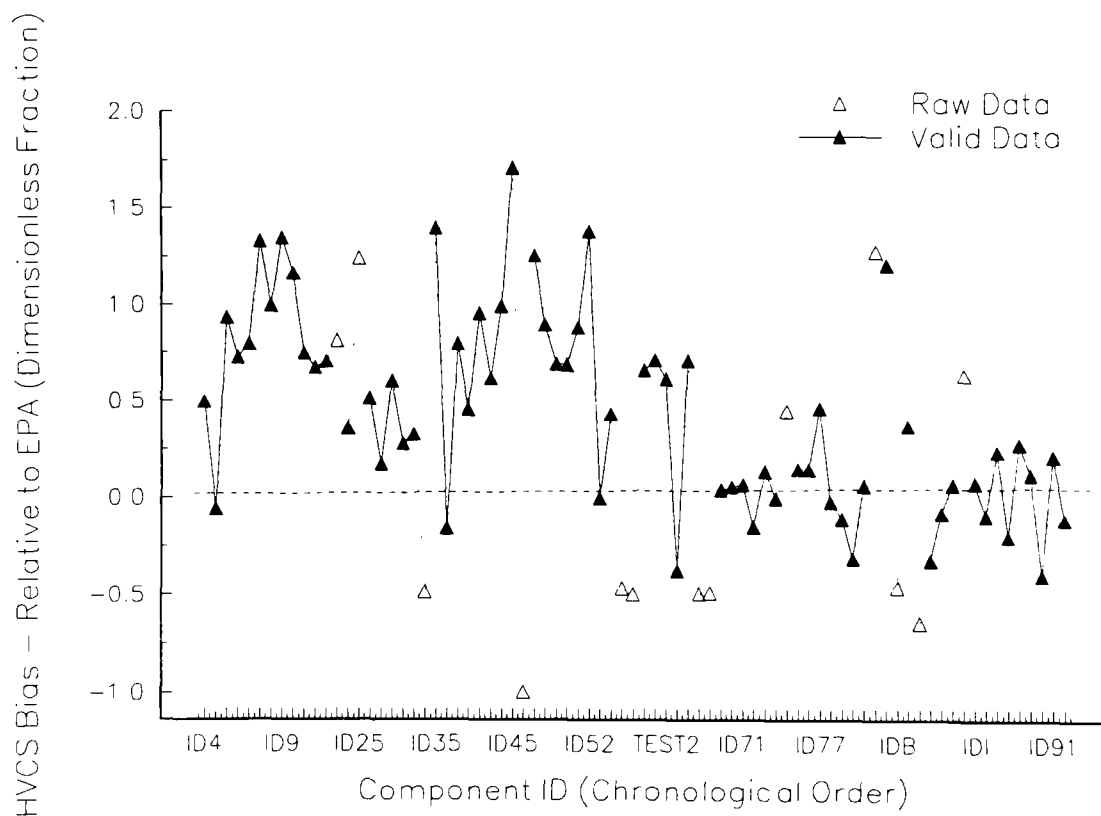

Figure 3-4. West Texas Results - Data Validation

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Leak rates measured at the west Texas site ranged from less than 0.01 to more than 20 slpm. The average leak rate was about 1.2 slpm, with a median of 0.7 slpm. Total measured emissions (EPA method) amounted to about 130 slpm (about 260 lb/day). The majority of the measurements were obtained in the gas plant (51/79). The remainder were collected at well heads, and in a propane storage area.

Average HVCS bias relative to the EPA method was +44.5 (34.2 to 56.7) percent. HVCS "true" bias was +33.8 (24.4 to 45.1) percent. As in south Texas, there is a significant degree of variability in the results; however, it is clear that there is a very significant positive HVCS bias in the overall results. The probability that the mean bias in the west Texas results is the same as in the laboratory studies is very small (0.4 percent). The probability that the mean west Texas bias is the same as in the south Texas data is also small (0.9 percent). The most highly biased results are concentrated in the early part of the study (before September 26). This is significant,
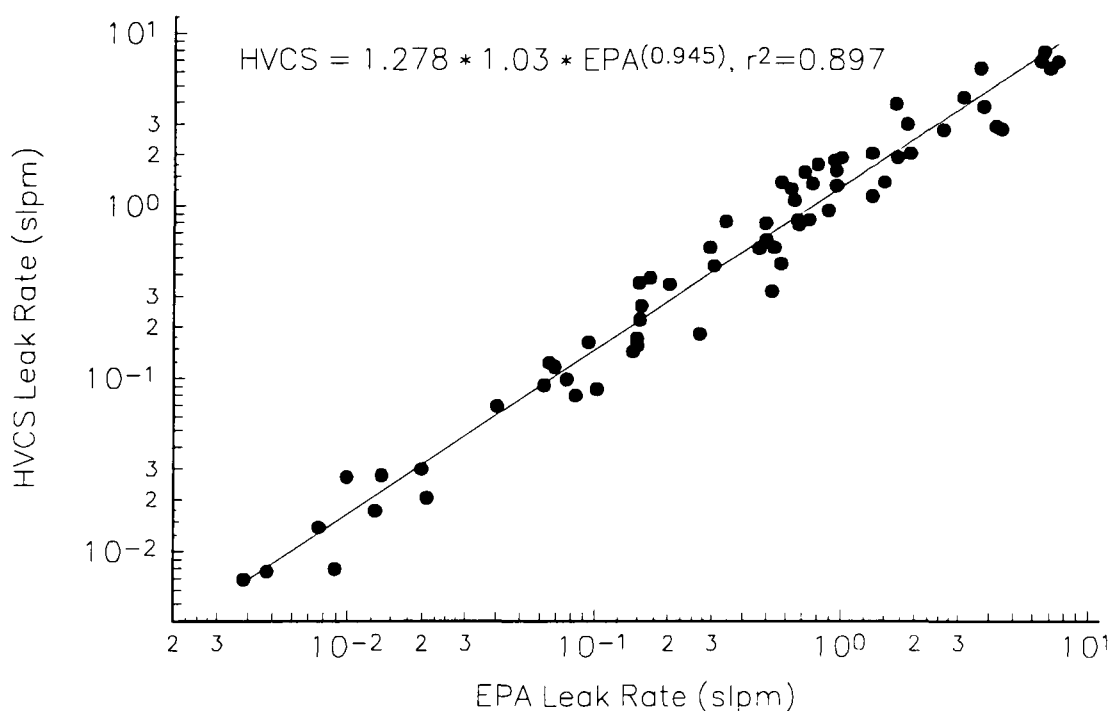
Figure 3-5. West Texas Results - Regression Analysis

as there were some operational and procedural changes that were made in the field after that date in an attempt to improve results (see section 3.3). Data collected on and before September 26 show an average HVCS bias of +67.0 (56.5 to 84.8) percent, while data collected after that date show an average bias of only +5.7 (-0.4 to 18.6) percent.

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For the validated data, the HVCS method measured a total of 93.9 slpm (194 lb/day), while the EPA method came up with only 79.2 slpm (164 lb/day). As seen before, the HVCS bias is larger for small leaks, but the difference in the total emissions for the overall study is still significant at 18.6 percent. Most of this bias was seen in the early part of the study. Before September 26, the difference in total emissions was 47 1 percent, and after this date the difference was essentially zero (-1.5 percent).

Despite the differences, the overall HVCS and EPA results correlate well (r^2 = 0.897). A regression plot and equation are shown in Figure 3-5. Bias as a function of leak rate is illustrated in Figure 3-6. Aside from the relationship with leak size, no other operational relationships were observed in the west Texas data. Delay times were minimal (most less than 2 hours), and there was no dependence on component type or the use of a dilution probe. In west Texas, the dilution probe was used for 27 of the 66 valid measurements. A more detailed discussion of the sources of the HVCS bias in the field study data is given below (Section 3.3).
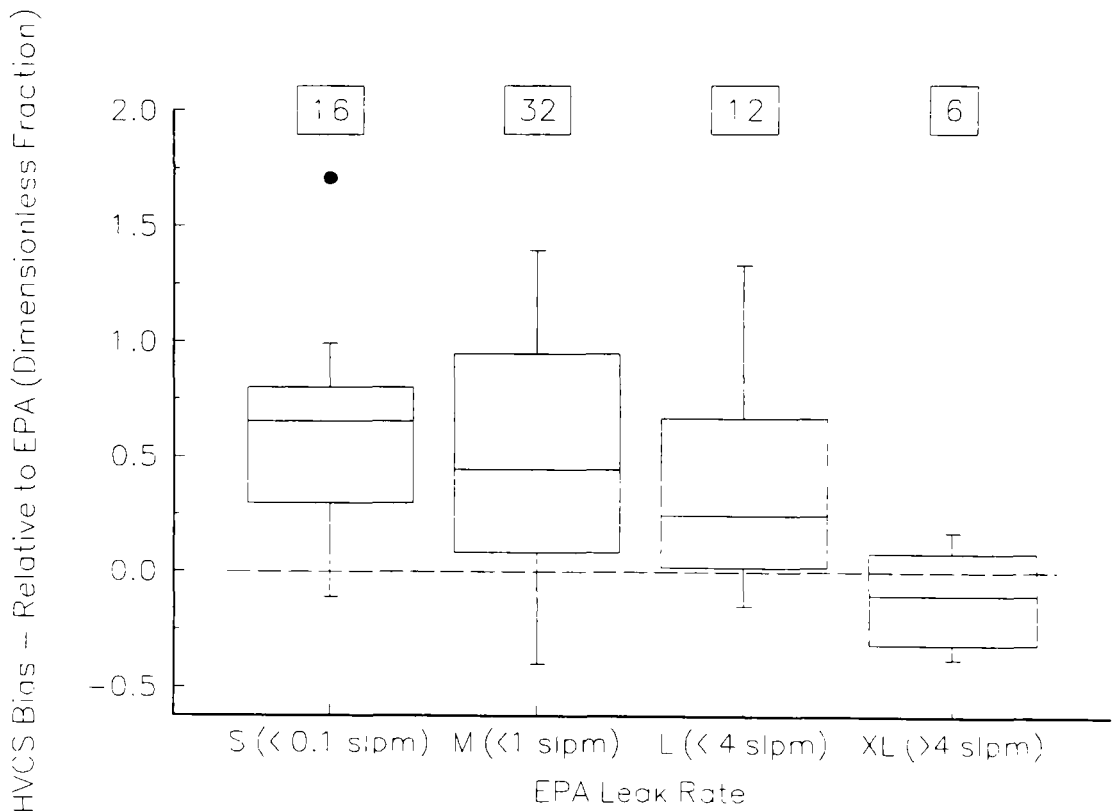
Figure 3-6. West Texas - Bias Dependence on Leak Rate

3.3   SOURCES OF HVCS BIAS

Preliminary analysis of the south Texas data suggested the presence of a positive HVCS bias. (6.6 percent "true" bias); however, the magnitude of the bias was not considered strongly significant given the variability in the results, and the fact that the difference in total emissions determined by the two methods was small. At the west Texas site, the HVCS bias was much larger (33.8 percent "true" bias). This was noted immediately in the field. The field crew conducted numerous quality control and operational checks, to determine the source of the bias. The HVCS and bag sampling apparatus were carefully leak checked, and additional flow calibrations were performed. The OVA was calibrated before and after each HVCS quantification using the same methane standards as were used to calibrate the GC. Controlled leak tests, and other special tests were also conducted in an attempt to isolate the source of the bias.

After efforts in the early part of the study failed to eliminate the bias, a concentrated effort was made on September 26 to isolate and eliminate the bias, if possible. This included controlled leak tests, equipment checks and cleaning, and minor changes in operating procedures. Early in the day, a set of two controlled leak tests were conducted using the same equipment used in the laboratory studies. These were "blind" tests, i.e., the HVCS and EPA method operators did not know the actual leak rate produced. The known leak rates were 0.168 slpm (test 1) and 3.27 slpm (test 2). The HVCS results were 0.163 slpm (-3.0 percent) and 3.026 slpm (-7.5 percent), respectively. The EPA method results were 0.095 slpm (-43.2 percent) and 1.879 slpm (-42.5 percent), respectively. These results focused attention on a possible *negative* bias in the EPA method as the source of the apparent positive bias in the HVCS system.

In the EPA sampling system, samples were withdrawn from the main flow using a small secondary sampling pump connected at a "tee" located about 3.5 inches upstream from the main pump exhaust. The main pump was typically operated at 15 slpm and the smaller pump was operated at about 1.5 to 2 slpm. Both pumps were diaphragm type. A hypothesis to explain a negative bias in the EPA system was that the secondary pump may have been able to pull in ambient air over a short distance against the main flow; especially if the exhaust pressure from the main pump was weakened due to a defective or obstructed reed valve.

To test this hypothesis, sample concentrations were measured with and without a length of tubing added to the exhaust. This test was based on the assumption that dilution air could not enter the sample over the longer distance. An initial test was conducted in the field at a propane leak using the OVA to obtain concentration measurements at the outlet of the EPA sample line. This test showed an approximate twofold increase in sample concentration when the extension tube was added. This effect was magnified at lower sample flows in the EPA system. After this test, it was decided to clean the main pump to clear any possible obstruction. This was accomplished by flushing a small quantity of water through the pump. The team then conducted similar tests in the field laboratory using a controlled leak rate of pure methane. Sample concentrations were measured directly with the OVA. In consecutive tests at the same leak rate conducted with and without the extension tube, sample concentrations (read by the OVA) were consistent (5404 and 5143 ppm, respectively). This suggests that the extension tube alone was not responsible for the results seen in the field. However, as a precautionary measure, an extension tube was used during the remainder of the study. A third controlled leak test was then conducted. In this test, the HVCS and EPA results agreed very well. The HVCS result was 0.156 slpm, and the EPA result (without the extension tube) was 0.151 slpm, for an HVCS bias of +3.3 percent. A second

EPA method quantification using the extension tube on the same controlled leak gave a slightly lower result of 0.13 slpm.

The proper conclusion to be reached from this set of tests is confounded somewhat by the differences in sample gas (propane in the field vs. methane in the laboratory) and by the fact that the pump was cleaned before the laboratory tests were conducted. The extension tube had no effect in the laboratory tests using methane and after the pump was cleaned, but appeared to have some effect before the pump was cleaned and when the sample consisted primarily of propane. The agreement between the HVCS and EPA results in the controlled leak tests improved in the test conducted after the pump was cleaned compared to the tests conducted earlier on the same day. This appears to suggest that cleaning the pump improved EPA method performance; however, the mechanism for this improvement was not determined.

The effect of contamination in a diaphragm pump would be to prevent the reed valve from sealing completely on the pump downstroke. Significant pump contamination or a leaking reed valve would prevent the pump from functioning properly, and there would be no flow, or significantly reduced flow. This has been noted in other studies using the same model of pump. However, flows of 20 lpm (which was the maximum effective system flow) were achieved before the pump was cleaned. In addition, at normal flows of 15 slpm, it is difficult to conceive how the secondary pump, operating at less than 2 slpm could pull in sufficient dilution air against the main flow to produce the magnitude of bias observed. In many cases, this would require that one half or more of the total sample consisted of dilution air. Thus, the explanation that cleaning the pump eliminated a negative bias in the EPA method is not completely satisfactory.

Two additional possibilities that could explain the apparent HVCS bias were identified: (1) high background hydrocarbon levels, and (2) analytical bias of the OVA versus the GC. Background hydrocarbon concentrations can produce a positive HVCS bias since the background concentration is multiplied by the higher HVCS flow rate to obtain the emission rate. That is, the HVCS result is more strongly influenced by background levels than the EPA vacuum method, even though both use the air surrounding the leaking component as dilution gas. Although both the GC and the OVA use flame ionization detection (FID), an analytical bias could result from differences in instrument design that make the OVA response sensitive to sample contaminants, sample gas composition, and possibly environmental effects such as pressure. These possibilities are discussed in more detail below (see sections 3.3.1, and 3.3.2, respectively).

In addition to the possible effect of operational changes that were implemented after September 26 (the pump was cleaned, and an extension tube was added to the EPA apparatus), the improvement in HVCS results after September 26 may be related to a combination of two other factors. First, as part of efforts to determine and eliminate the source of the bias, measuring in areas with high background levels was avoided after that date. Earlier in the study, most of the measurements were obtained from dense clusters of leaking components where there were potentially high background levels. At the south Texas site, background levels were minimal (samples were obtained in remote, open areas and wind speeds were very high). Second, the average leak rate after September 26 (1.8 slpm) is larger than the average leak rate before that date (1.2). This would reduce an HVCS bias related to background hydrocarbon since such a bias is less significant for larger leaks.

3.3.1 High Background Levels

Measured background levels averaged about 30 ppm in the plant area and levels as high as 1500 to 1750 ppm were detected in several instances. Near the well heads, in the gas fields, background levels averaged 5 to 10 ppm. One can calculate the background level required to produce the biases observed in the west Texas data. At the high end of HVCS flows typically used in the study (about 125 slpm) a background concentration of 3,600 ppm would be required to produce an HVCS bias of +45 percent at a leak rate of about 1.0 slpm (using an EPA flow of 15 slpm). These are typical values for the early part of the study. At lower HVCS flows, significantly higher background levels would be required. Only for the smaller leaks (less than 0.1 slpm) were measured background levels high enough to produce the biases observed. In addition, it can be demonstrated that results obtained at different HVCS flow rates (at the same leak rate) do not generally differ by as much as would be expected if background interferences were significantly affecting the results. Based on this, it is unlikely that high background levels contributed significantly to the overall bias observed in the data for this study.

However, the issue of background interferences with the HVCS quantification is important. Sufficiently high background hydrocarbon concentrations will interfere with HVCS leak rate quantifications, producing a positive bias relative to "low flow" methods, or methods that use hydrocarbon free dilution gas. This situation may not be avoidable in some circumstances, such as when leaks are densely clustered, or are located near an emissions source. Methods should be adopted for use in accounting and correcting for such interferences.

The simplest approach is to directly measure background levels using the OVA, and correct for these concentrations in the HVCS sample flow. However, in this study it was found that this is not always straightforward. Background measurements taken using the OVA during HVCS quantifications often fluctuated wildly (especially in windy conditions, which predominated), and it was not possible to obtain a representative reading. An alternative means for determining the background level from the HVCS results themselves has also been proposed. The method depends on the fact that the HVCS can conveniently measure the leak rate at more than one flow. As the HVCS flow rate increases, the fraction of total hydrocarbon in the HVCS exhaust due to the fugitive leak decreases. If the HVCS flow could be increased infinitely, the contribution of the fugitive leak would be zero, but the contribution of the background concentration would remain constant. The background concentration can be found by plotting a line from several HVCS leak rate determinations where the x-axis is the reciprocal of HVCS flow and the y-axis is the HVCS outlet concentration (in ppm). If this line is extended to zero, the intercept represents concentration at infinite flow. A positive intercept is correctly interpreted as the background concentration.

This method could produce a background level that is representative of actual background hydrocarbon taken in during HVCS sampling, even under conditions where ambient concentrations could not be reliably quantified by direct measurement. However, for the method to give true results, one must be certain that changes in HVCS outlet concentration are due solely to changes in HVCS flow, that is, that total leak capture is attained at all HVCS flows. When there is incomplete leak capture, increases in the HVCS outlet concentration do not keep pace with the decreases in HVCS flow. If this method is applied to such data, there will be an apparent background concentration (positive intercept) that is really just an artifact of incomplete leak capture.

The prototype HVCS device used in this study was not generally able to maintain complete leak capture at any but the highest flows (see laboratory study results). If this correction is applied to data where there was not complete leak capture at all flows, a negative bias will be introduced. For example, the method appears to correct for much of the positive bias in the west Texas data; however, if the same method is applied to the south Texas data, a negative bias appears. Because of such inconsistency, it was decided that this method could not be consistently applied to correct the evaluation study results. However, the method might be successfully applied in future work with an improved HVCS with greater flow capacity.

3.3.2 Analytical Bias

During the west Texas study, the field crew conducted a number of special tests designed to identify the source of the HVCS bias. One set of special tests (conducted on September 24) provided evidence of an analytical bias between the OVA response and the GC response to the same samples. First, the concentration in an EPA method bag sample was measured directly by the OVA and by GC. The OVA recorded 8828 ppm, and the GC recorded 6433 ppm, a +37 percent OVA bias. Second, a bag sample was collected from the HVCS exhaust. The OVA recorded 10,372 ppm and the GC recorded 8229 ppm, a +26 percent OVA bias. Although both the OVA and the GC use Flame Ionization Detection (FID), there are two major differences in instrument design that might be responsible for the observed bias.

First, the OVA uses sample air to supply oxygen to the FID flame, whereas the GC FID has an independent air supply that provides a steadier, more controlled flame. FID response is very sensitive to flame characteristics (e.g., temperature, fuel/air ratio). Contaminants in the sample air or differences in sample gas composition could produce a bias in the OVA results. Second, all of the components in the sample gas mixture are presented to the OVA FID simultaneously, and the OVA response is to the total hydrocarbon present in the mixture. In the GC, the sample is separated into its components by the GC column before reaching the detector, and the total hydrocarbon concentration is arrived at by summing the FID response for each gas. If a compound were present in the sample that was not detected in the GC run (e.g., because the run was not long enough for the compound to elute from the column), a bias would be introduced. However, since natural gas is made up primarily of light hydrocarbons (C1-C5), and these were detected in the GC runs (see Section 3.4 - Gas Composition), the "excess" compound could be present only at low concentration, and would have to elicit a very large OVA FID response (relative to methane) in order to produce a significant bias.

After the field study, it was determined that there was a need for additional laboratory testing to further investigate the source of bias in the west Texas results. Five gas samples were obtained in pressurized stainless steel sample canisters from the west Texas plant. The samples were collected progressively through the gas processing stages and represent the areas in the gas plant where leak quantifications were made. In addition, the same OVA used in the study was obtained for comparative tests with the GC. The laboratory testing was designed to identify a contaminant in the gas samples, or an unidentified compound that could produce the observed bias.

One possible contaminant that could produce a positive OVA bias is hydrogen gas (H_2). There is potential for excess H_2 in the west Texas sample gas occurring as a byproduct of H_2S removal. A simple laboratory test was conducted to determine whether this could explain the bias in the

west Texas results. Hydrogen gas was introduced incrementally into steady flows containing approximately 100 and 1000 ppm methane. This test showed that it would take an H_2 concentration of more than 5 percent (50,000 ppm) to cause a significant change in OVA response (more than a few percent). GC analysis of pure gas samples from the field showed that H_2 levels do not begin to approach such high values, so this explanation can be eliminated. While it is possible that some other contaminant might act to alter OVA FID response, none has been identified.

The second set of tests consisted of conducting long GC runs on each of the 5 pure gas samples to allow time for any heavier hydrocarbons to elute. Also, since these tests were conducted on undiluted samples, there is a greater likelihood of detecting "trace" compounds that could go undetected in the diluted field samples collected using the EPA bag sampling method. The pure gas samples showed roughly the same proportions of light hydrocarbons as the field samples. While a few unidentified compounds were noted on the chromatograms for the pure gas samples, FID response to these compounds was not significant relative to the response to the known light hydrocarbons.

Finally, the pure gas samples were diluted to approximately 1000 ppm in room air, and the diluted samples were analyzed directly by GC and by the OVA. The relative proportions of light hydrocarbons in the diluted samples were nearly the same as in the pure gas samples, indicating that the diluted samples were thoroughly mixed. These tests failed to reproduce the positive bias noted in similar tests conducted in the field. In fact, the OVA gave negatively biased results in the laboratory tests (this was traced to poor OVA response to higher molecular weight hydrocarbons).

In summary, no evidence was found in the laboratory tests to confirm a positive analytical bias of the OVA versus the GC. In addition, no contaminants or excess compounds were identified that could have produced such an analytical bias. The only identified factors that were not investigated in these tests are environmental factors, such as the difference in atmospheric pressure due to the high altitude of the west Texas site (about 3500 feet above mean sea level compared to near sea level elevations for the laboratory and south Texas studies). While the OVA response is known to be sensitive to sample inlet pressure, this should not affect the results since the OVA was calibrated at the pressure at which it was used.

3.4   GAS COMPOSITION

Gas composition (C1 through C6 alkanes and alkenes, carbon dioxide, oxygen, and nitrogen) was determined for each bag sample. Two samples were analyzed for each component tested. The percentage difference between the two bags averaged 0.24 ±0.07 percent for the TCD, and 0.33 ±0.03 percent for the FID (west and south Texas combined). Only methane, ethane, propane, butene, butane, pentene, and pentene were detected in more than trace amounts. Results are summarized in Table 3-2. In the Table, results are given as percentages of total hydrocarbon, where the total hydrocarbon is simply the sum of GC response to each compound, calibrated as methane. In most cases, methane makes up more than 85 percent of total hydrocarbon. Ethane is second, and propane is third. A few samples collected in a propane storage area at the west Texas site are predominately propane. In most cases only trace amounts of C4 and heavier

hydrocarbons were present in leaking gas. This is consistent with the species composition of emissions from the gas and oil industry as identified by EPA (EPA 1988).

Table 3-2. Summary of Gas Composition (percent)							
	Methane	**Ethane**	**Propane**	**Butane**	**Butene**	**Pentane**	**Pentene**
South Texas							
Average	88.1	5.7	4.2	0.7	0.7	0.2	0.3
Max	97.7	8.5	87	2	2	0.8	2.3
Min	7.6	2	0	0	0	0	0
West Texas							
Average	84.2	5	10.4	0.2	0.2	0	0
Max	97.8	15	92.2	2.3	1.3	1.2	0.6
Min	0.3	1.7	0	0	0	0	0

3.5 COMPARISON OF DIRECT MEASUREMENT RESULTS WITH EPA EMISSION FACTORS

It is interesting to compare the directly measured leak rates at each field site with the emissions computed using the EPA protocol emission factors. The EPA protocol gives several methods for estimating emissions from equipment leaks including average emission factors that are applied to each component inventoried, and leak/no leak emission factors that are applied separately to non-leaking and leaking components as designated using Method 21. In the field studies, most of the components identified as leaking (using soap solution) had screening values of 10,000 ppm or more. For the purposes of this exercise, all leaking components are considered to have screening values of at least 10,000 ppm, which is the definition of a leak for purposes of applying the leak/no leak emission factors. Table 3-3 summarizes total emissions for directly measured (EPA and HVCS methods), EPA average emissions factors, and EPA leak/no leak emission factors. The EPA protocol correlation approach is not applicable here since direct screening values were not obtained for small leaks that did not produce observable soap bubbles, and those leaks with observable bubbles generally "pegged" the OVA at 10,000 ppmv. EPA has recently published interim emission factors and correlation equations for gas and oil production (EPA 1995). These new values are acceptable for immediate use for estimating emissions from leaking equipment; but may change based on additional input from industry and state and local air pollution control agencies. Table 3-4 also includes emissions calculated using these new factors. It is apparent that the use of the original EPA protocol average emission factors can yield a dramatic overestimate of actual emissions. The 1993 protocol leak/no leak emission factors improve the estimate, but are still quite conservative. The new interim leak/no leak emission factors appear to yield very reasonable emissions estimates, compared to measured values.

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Table 3-4. Comparison of Emissions Estimates by Different Methods

Screening Information

Component Type	South Texas			West Texas		
	Screened	No Leak	Leak	Screened	No Leak	Leak
Flange	889	889	0	1,401	1,400	1
Connector	4,664	4,647	17	8,992	8,985	7
Valve	1,764	1,741	23	2,897	2,833	64
Open Line	216	208	8	55	55	0
Pressure Relief	21	21	0	4	3	1
Misc.	74	66	8	94	88	6
Total	7,628	7,572	56	13,443	13,364	79

Direct Measured Emissions

Component Type	South Texas			West Texas		
		EPA Em. (kg/hr)	HVCS Em.(kg/hr)		EPA Em. (kg/hr)	HVCS Em.(kg/hr)
Flange		0.00	0.00		0.02	0.02
Connector		0.83	0.88		0.09	0.13
Valve		1.11	1.22		4.28	5 79
Open Line		0.06	0.13		0.00	0.00
Pressure Relief		0.00	0.00		0.17	0.12
Misc.		0.75	1.05		0.64	0.81
Total (kg/hr)		2.75	3.28		5.20	6.87
Total (lb/day)		145.05	173.37		274 32	362.72

1993 Protocol Average Emissions Factors

Component Type	South Texas			West Texas		
	Factor (kg/hr)		Em. (kg/hr)	Factor (kg/hr)		Em. (kg/hr)
Flange	0.0011		0.98	0.0011		1.54
Connector	0.0011		5.13	0.0011		9.89
Valve	0.0200		35.28	0.0200		57.94
Open Line	0.0220		4.75	0.0220		1.21
Pressure Relief	0.1880		3.95	0.1880		0.75
Misc. (as Valve)	0.0200		1.48	0.0200		1.88
Total (kg/hr)			51.57			73.21
Total (lb/day)			2722.81			3865.72

1993 Protocol Leak/No Leak Emissions

Component Type	South Texas			West Texas		
	No Leak EF (kg/hr)	Leak EF (kg/hr)	Em. (kg/hr)	No Leak EF (kg/hr)	Leak EF (kg/hr)	Em. (kg/hr)
Flange	6.0E-05	0.03360	0.05	6.0E-05	0.03360	0.12
Connector	6.0E-05	0.03360	0.85	6.0E-05	0.03360	0.77
Valve	2.9E-03	0.09800	7.30	2.9E-03	0.09800	14.49
Open Line	1.5E-03	0.17400	1.70	1.5E-03	0.17400	0.08
Pressure Relief	4.5E-02	0.86300	0.94	4.5E-02	0.86300	1.00
Misc. (as Valve)	2.9E-03	0.09800	0.98	2.9E-03	0.09800	0.84
Total (kg/hr)			11.82			17.30
Total (lb/day)			624 33			913.57

1995 Interim Leak/No Leak Emission Factors

Component Type	South Texas			West Texas		
	No Leak EF (kg/hr)	Leak (EF (kg/hr)	Em. (kg/hr)	No Leak EF (kg/hr)	Leak (EF (kg/hr)	Em. (kg/hr)
Flange	3.1E-07	0.08500	0.00	3.1E-07	0.08500	0.09
Connector	7.5E-06	0.02800	0.51	7.5E-06	0.02800	0.26
Valve	7.8E-06	0.06400	1.49	7 8E-06	0.06400	4.12
Open Line	2.0E-06	0.03000	0.24	2.0E-06	0.03000	0.00
Pressure Relief	4.0E-06	0.07300	0.00	4.0E-06	0 07300	0.07
Misc.	4.0E-06	0.07300	0.58	4.0E-06	0.07300	0.44
Total (kg/hr)			2.82			4.98
Total (lb/day)			148.97			262.86

1995 Interim Correlation Emission Factors

Component Type	South Texas			West Texas		
	Default Zero (kg/hr)	Corr. EF (kg/hr)*	Em. (kg/hr)	Default Zero (kg/hr)	Corr. EF (kg/hr)*	Em. (kg/hr)
Flange	3.1E-07	0.00290	0.00	3.1E-07	0.00290	0 00
Connector	7.5E-06	0.00130	0.06	7.5E-06	0.00130	0.08
Valve	7.8E-06	0.00220	0.06	7.8E-06	0.00220	0.16
Open Line	2.0E-06	0.00130	0.01	2.0E-06	0.00130	0.00
Pressure Relief	4.0E-06	0.00300	0.00	4.0E-06	0.00300	0.00
Misc.	4.0E-06	0.00300	0.02	4.0E-06	0.00300	0.02
Total (kg/hr)			0.16			0.26
Total (lb/day)			8.45			13.95

Notes:
*All Screening Values Taken as 10,000 ppmv.
Assume Wt. Fraction VOC is 100 percent (incl. methane)
Direct Measured Emissions Given for Operationally Valid Measurements Only

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SECTION 4
DATA QUALITY

Sampling, analytical, and quality control procedures were carried out as specified in the QAPjP that was prepared and approved for this AEERL QA Category III project. Overall data quality was very high with precision and accuracy for all primary measurements remaining within data quality objectives throughout the study. Data capture and representativeness are discussed in detail in Sections 2 and 3 of this report. Overall precision and accuracy for the EPA and HVCS methods was determined from the laboratory studies and is discussed in detail in Section 2. Controlled leak tests were also conducted in the field; however, the laboratory results give a much better representation of overall data quality for the two methods since a much larger number of measurements are available. In the west Texas study, replicate HVCS quantifications were made for 16 leaks. The average difference in the repeat measurements was -4.5 ±7.7 percent.

Table 4-1 summarizes precision and accuracy for the concentration measurements (OVA and GC) as determined from calibration data. Precision and accuracy for the OVA are calculated as the arithmetic mean and standard deviation of the percentage differences between consecutive calibrations. The OVA was calibrated before and after each HVCS quantification, so drift was minimized. Precision and accuracy for the GC is presented for each detector, per Method 18, as the average and standard deviation of percent differences between upscale calibration points and linear fit. Injection precision was also calculated as the standard deviation of percentage differences between duplicate injections for each sample. For the laboratory study, injection precision was 0.81% (TCD) and 0.26% (FID). For the field studies (combined), injection precision was 0.21% (TCD), and 0.08% (FID).

Table 4-1. Concentration Measurements - Data Quality				
Measurement	**Precision (%)**		**Accuracy (%)**	
	DQO	**Actual**	**DQO**	**Actual**
Portable HC Analyzer OVA - Lab	15	5.6	15	0.1
Portable HC Analyzer OVA - South Texas	15	10.3	15	0.2
Portable HC Analyzer OVA - West Texas	15	11.6	15	-1.2
Gas Chromatography - Lab	5	1.78 (TCD) 1.30 (FID)	10	+0.11 (TCD) -0.21 (FID)
Gas Chromatography South Texas	5	1.80 (TCD) 3.60 (FID)	10	0.22 (TCD) -0.19 (FID)
Gas Chromatography West Texas	5	3.60 (TCD) 2.20 (FID)	10	-0.71 (TCD) -0.62 (FID)

The rotameters used to determine flows for the EPA vacuum bag method and the HVCS were calibrated at the start of the laboratory study and checked during the south and west Texas field studies. The large HVCS rotameters were calibrated during the laboratory study against an EPA primary standard spirometer. In the field, the large HVCS rotameters were checked against a dry gas meter traceable to the EPA spirometer. The HVCS small rotameter and the EPA vacuum bag rotameter were calibrated against a primary standard bubble meter. Good linearity ($r^2 > 0.95$) was obtained for all rotameter calibrations. Actual calibration slopes and intercepts were used to determine the correct flow rates from the direct rotameter readings. The average and standard deviation of differences from the regression value (curve fit) at calibration set points can be used as an indicator of the accuracy and precision of the rotameter flows. For the bag cart rotameter (2-20 slpm), the accuracy was +0.38 percent and the precision was 5.28 percent. The QAPjP data quality objectives were 10 percent for precision and 10 percent for accuracy. For the large HVCS rotameter (50 to 500 slpm), the accuracy was -0.02 percent, and the precision was 1.40 percent. For the medium HVCS rotameter (5 to 25 slpm), the accuracy was +0.53 percent, and the precision was 0.09 percent. For the small HVCS rotameter (1 to 10 slpm), the accuracy was +0.09 percent, and the precision was 2.80 percent. HVCS flows were always read from a single rotameter. The data quality objectives for the HVCS flows were 5 percent for precision and 5 percent for accuracy. On-site temperature and pressure obtained at the time of the measurements were used to correct flows to standard conditions. This was important in south Texas as ambient temperatures were very high (as high as 114 °F, or 46 °C), and in west Texas which was at a high elevation (ambient pressures of about 680 mm Hg, or 90.65 kPa).

No external audits were planned or performed for this study.

As discussed earlier, the prototype HVCS was generally unable to maintain complete leak capture, except at the highest flows. Typically, the measured leak rate would begin to fall off after the first or second determination at decreasing HVCS flow rates. Ideally, the average of 3 HVCS quantifications at different flows should be used to determine the leak rate. Since this was not always possible, it was necessary to adopt a procedure to recover useful data in instances where marginal leak capture occurred at lower flows. A decision procedure was developed and applied to the field study results in cases where incomplete leak capture may have occurred. The procedure used is as follows.

At least three HVCS leak quantifications were made for each component. The three measurements corresponding to the highest HVCS flows were used as initial inputs to a spreadsheet that was used to automate repetitive calculations. At this point, one of two tests was applied depending on the apparent size of the leak (average of the three measurements). For leaks larger than 0.15 slpm (about 0.3 lb/day), the maximum percentage difference relative to the mean of the 3 measurements had to be within ±20 percent. For leaks smaller than 0.15 slpm, the maximum absolute difference from the mean had to be smaller than 0.03 slpm. If the test was passed, the average of the three determinations was taken as the valid HVCS result.

If the test was failed, the leak determination corresponding to the highest flow was substituted for the determination that gave results furthest from the mean (generally the lowest HVCS flow). That is, the leak determination corresponding to the highest HVCS flow was used twice in the average, weighting the average to the highest flow and greatest leak capture. HVCS results where this occurred were flagged, but considered valid. If the test was failed again, the highest HVCS flow alone was used to obtain the HVCS result. Such results were flagged as suspect

because, since only a single point was used, there was no verification of leak capture. The dual test was necessary to avoid excluding data for small leaks where absolute differences were small, but percentage differences were large.

It should be emphasized that this procedure was used only as a means to recover data in instances where the flow capacity of the prototype HVCS was insufficient to fully capture the leak. The flow capacity of the HVCS system should be improved before the system is used in future work. The cut-off value of 0.03 slpm was chosen as a minimum leak rate of interest, since previous testing has shown that essentially 100 percent of emissions are due to much larger leaks (API 1993). The 20 percent test criteria was adopted, based on the laboratory study findings, as a practical value that could generally be attained by the prototype HVCS, but would still yield useful results. While these test criteria were reasonable for the test data set with the prototype HVCS, more stringent criteria should be applied in future work with an improved system.

SECTION 5
CONCLUSIONS

As demonstrated in the laboratory study and field study results, the HVCS is capable of accurately quantifying fugitive leaks over a wide range of leak sizes, and component types and sizes.

- Laboratory evaluation of HVCS performance was very favorable. The HVCS results closely matched EPA method results with a difference in total measured emissions of only about 3 percent. The HVCS also reproduced a wide range of known leak rates with an average bias of -8.3 percent. The negative bias is probably due to incomplete leak capture. In the laboratory tests, HVCS leak capture depended solely on the ability of the HVCS to capture all of the leaking gas in the slip stream of dilution air entering the HVCS inlet. No enclosures were constructed to shield components and direct gas into the HVCS inlet.

- The HVCS also performed very well in the south Texas field study. The HVCS matched the EPA estimate of total facility emissions within about 4 percent, similar performance to that obtained in the laboratory studies. In the field, enclosures were constructed to shield components from wind and assist in directing leaking gas into the HVCS inlet.

- During the early part of the west Texas study, an apparent positive bias was observed in the HVCS results. On and before September 26 (about midway through the study), the HVCS measured 47.1 percent more total emissions than the EPA method. After this date, no appreciable bias was observed. Over the entire study, the HVCS measured 18.6 percent more emissions from the facility than the EPA method. The source of the bias in the early part of the study is unclear; however, the results suggest that there may have been some operational problem that was overcome as a result of efforts undertaken in the field. Other factors that may have contributed to the change in results include; (1) efforts that were made to avoid sampling in areas with potentially high background concentrations that could cause a positive bias in the HVCS results, and (2) the fact that average leak rates were higher in the later part of the study, which would tend to lessen the effect of background interference on the HVCS quantifications (see section 3.3).

Overall, these results are within acceptable limits for field emissions measurements. With some physical and procedural enhancements, the HVCS should offer an acceptable alternative to the EPA protocol bagging method with GC analysis.

- Special precautions must be taken to obtain accurate HVCS quantifications in areas where they may be elevated background concentrations, such as in confined areas, or where there are dense clusters of leaking components or very large leaks. The simplest approach is to attempt to quantify background levels with the OVA, and apply an appropriate correction to the results. This must be done very carefully since background levels in such areas have been observed to range widely in small areas and change very rapidly. An alternative method for determining the background level has been suggested that, in some instances, could provide a useable correction, even when background levels cannot be practically measured (see Section 3.3). The limitation of this method is that one

must be certain that changes in HVCS outlet concentration are due solely to changes in HVCS flow. That is, that total leak capture must be attained at all HVCS flows. A third, though more difficult to execute, alternative would be to supply the HVCS with hydrocarbon free dilution air.

■ Improved HVCS flow capacity, control, and metering are needed to enhance leak capture and provide greater reliability and ease of use in the field. With the current rotameter set-up, the capacity could be doubled by simply increasing pump capacity. Power requirements would also be increased, but the unit could still be battery operated (a 12 V pump could reach near 1000 scfh, or about 470 slpm). Much larger flows would require more power, decreasing portability, and the metering system would also have to be modified substantially to handle the higher flows. Increased flow capacity would also increase the size of leaks that could be quantified without the need for a dilution probe, or other alternative to extend the range of the portable hydrocarbon monitor. Enhanced leak capture might also make it possible to measure leaks from larger components without the need for auxiliary bagging. This could decrease the time required for each measurement.

■ Increased range and enhanced stability of the portable hydrocarbon monitoring device used with the HVCS are also needed. The portable hydrocarbon monitor used with the HVCS needs greater range and reliability than the Foxboro OVA Model 108 that is currently used. The OVA's upper range is at 10,000 ppm, or 1 percent. This can be extended to perhaps 15,000 ppm using the direct voltage output from the OVA; however, precision rapidly deteriorates at this upper end. In the field, Foxboro's dilution probe was used to extend the quantification range, with generally good results; however, the use of the dilution probe adds a degree of complexity. The OVA is also very sensitive to sampling conditions, contaminants, battery levels, and other factors. The OVA requires frequent calibration, which adds significantly to the expense and level of uncertainty associated with its use in quantitative applications. The OVA is very sensitive to sample gas composition since the detector is exposed to the entire sample stream at once and uses sample stream air as combustion air for the FID. The OVA exhibits varying responses to different hydrocarbons, and sometimes radical responses to "contaminants" (water, dust, and presence of gases, *e.g.*, excess hydrogen, that affect the response of the FID). Some research is needed to identify and test alternative analyzers with greater range and stability than the OVA. This might include infrared devices and electrochemical sensors. In addition, there has been some preliminary development of a catalytic combustor that would determine HC concentration by stoichiometry, using measurements of O_2 and CO_2 at the entrance and exit from the combustor.

The HVCS may have a very significant role to play in applications where rapid, cost effective, on-site leak quantifications are important.

■ With the HVCS, a single operator can quantify approximately 30 leaks per day. With the EPA bagging method, approximately 10 leaks can be sampled per day with additional time and expense required for GC analysis.

■ The HVCS could be very useful in evaluating the effectiveness of different inspection and maintenance programs, and determining the most cost effective approach for maintaining emissions below a given level.

■ The HVCS would also be useful for emissions inventory and compliance testing activities related to Federal and State air permit requirements.

■ In addition, the HVCS may be valuable in evaluating the performance of optical sensing based techniques for determining fugitive emission rates under real world conditions. Such methods are currently under development at EPA, and may soon be tested under actual site conditions. For these tests, there will be a need to independently determine leak rates from multiple fugitive sources as a basis for evaluating the performance of the optical sensing based methods.

SECTION 6
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SECTION 7
DATA TABLES

Laboratory Study Data

Method	ID	Date	Component	Leak Configuration	Leak Character	Pressure (psi)	LeakRate	Result	Flag	Bias
HVCS	01B	07/01	2" Gate Valve	loose body nut	2 pin leaks	10.90	0.25	0.26	Suspect	4.83%
HVCS	002a	07/05	2" Gate Valve	loose body nut	diffuse	23.20	2.772	3.04	Valid	9.59%
HVCS	003a	07/05	Pump Body	back plat loose	NA	8.30	1.667	1.87	Valid	12.00%
HVCS	003b	07/06	Pump Body	back plat loose	diffuse	5.95	1.007	1.10	Valid	9.40%
HVCS	003c	07/06	Pump Body	back plat loose	diffuse	1.60	0.186	0.16	Valid	-11.25%
HVCS	04a	07/06	4" Threaded Coupling	no sealant on threads	diffuse	29.80	1.317	1.25	Valid	-5.32%
HVCS	04b	07/06	4" Threaded Coupling	no sealant on threads	diffuse	11.75	0.599	0.52	Valid	-12.47%
HVCS	04c	07/06	4" Threaded Coupling	no sealant on threads	diffuse	4.00	0.242	0.18	Valid	-26.88%
HVCS	05a	07/07	4" Threaded Coupling	no sealant on threads	multiple jets - high pressur	94.15	6.068	5.18	Suspect	-14.57%
HVCS	07a	07/08	4" Threaded Coupling	hand tight	low flow, low pressure	0.00	0.04	0.03	Valid	-16.16%
HVCS	07c	07/08	Pump Body	loose back plate	low flow, low pressure	0.00	0.041	0.03	Valid	-14.09%
HVCS	07d	07/08	2" Open Ended Line	NA	low flow, low pressure	0.00	0.042	0.02	Valid	-47.38%
HVCS	07e	07/08	2" Open Ended Line	NA	low flow	0.00	0.751	0.78	Valid	3.83%
HVCS	08a	07/11	6" Pipe Flange	cut gasket	jet	0.00	0.042	0.03	Valid	-22.98%
HVCS	08b	07/11	6" Pipe Flange	cut gasket	jet	7.90	0.748	0.69	Valid	-7.77%
HVCS	08c	07/11	6" Pipe Flange	cut gasket	jet	26.75	2.012	1.89	Valid	-5.91%
HVCS	08e	07/11	6" Pipe Flange	gasket damaged - groove	jet	51.70	3.864	4.18	Valid	8.27%
HVCS	08h	07/12	6" Pipe Flange	loose bolts	broad, diffuse	0.00	0.107	0.07	Valid	-31.38%
HVCS	09a	07/12	Pump Body	damaged shaft seal	broad leak around shaft	20.35	6.628	7.00	Valid	5.56%
HVCS	09b	07/12	Pump Body	damaged shaft seal	broad leak around shaft	24.55	8.579	8.67	Valid	1.02%
HVCS	09c	07/12	Pump Body	damaged shaft seal	broad jets -	42.25	20.856	21.71	Valid	4.12%
HVCS	10a	07/12	4" Threaded coupling	no sealant	several point sources	39.00	18.633	16.27	Valid	-12.68%
HVCS	10b	07/12	4" Threaded coupling	no sealant	multiple point sources	10.45	5.065	5.52	Valid	8.92%
HVCS	10c	07/12	4" Threaded coupling	no sealant	several jet leaks	19.30	9.166	9.06	Valid	-1.14%
HVCS	10d	07/12	4" Threaded coupling	no sealant	multiple pin leaks	45.20	8.016	6.83	Valid	-14.79%
HVCS	10e	07/12	4" Threaded coupling	no sealant	multiple pinhole leaks	23.40	3.79	3.10	Valid	-18.27%
HVCS	10f	07/12	4" Threaded coupling	no sealant	multiple pin leaks	12.00	1.79	1.58	Valid	-11.57%
HVCS	11a	07/13	2" Gate Valve	loose body nut	broad & diffuse	40.40	15.833	11.92	Valid	-24.72%
HVCS	11b	07/13	2" Gate Valve	loose body nut	broad & diffuse	47.10	11.777	10.86	Valid	-7.77%
HVCS	11c	07/13	2" Gate Valve	loose body nut	broad & diffuse	43.20	5.221	3.77	Valid	-27.81%
HVCS	11d	07/13	2" Gate Valve	loose body nut	narrow jet, high velocity	46.75	2.514	2.00	Valid	-20.59%
HVCS	12a_1	07/13	2" Gate Valve	loose body nut	narrow jet, high velocity	47.05	2.761	2.47	Valid	-10.45%
HVCS	14a	07/13	2" Gate Valve	loose body nut	NA	0.00	0.761	0.63	Valid	-17.37%
HVCS	14a_1	07/13	2" Gate Valve	loose body nut	NA	0.00	0.761	0.57	Valid	-25.72%
HVCS	14b	07/13	2" Gate Valve	loose body nut	NA	0.00	0.305	0.22	Valid	-28.38%
HVCS	14c	07/13	2" Gate Valve	loose body nut	NA	0.00	0.045	0.03	Valid	-33.65%
HVCS	14c_1	07/13	2" Gate Valve	loose body nut	NA	0.00	0.045	0.03	Valid	-38.90%
HVCS	13a	07/14	2" Gate Valve	loose body nut	broad, low velocity	0.00	0.73	0.70	Valid	-3.63%
HVCS	13b	07/14	2" Gate Valve	loose body nut	broad, low velocity	36.85	0.466	0.45	Valid	-3.60%
HVCS	13c	07/14	2" Gate Valve	loose body nut	broad, low velocity	0.10	4.557	5.69	Valid	24.90%
HVCS	13c_1	07/14	2" Gate Valve	loose body nut	broad, low velocity	0.10	4.557	3.72	Valid	-18.32%
HVCS	13d	07/14	Pump Body	damaged shaft seal	broad, low velocity	6.50	1.183	1.11	Valid	-6.08%
HVCS	13e	07/14	2" Open Ended Line	open line beyond gate valv	low velocity	0.00	3.023	3.08	Valid	2.02%
HVCS	13e_1	07/14	2" Open Ended Line	open line beyond gate valv	low velocity	0.00	3.023	3.18	Valid	5.06%
HVCS	13f	07/14	2" Open Ended Line	open line beyond gate valv	low velocity	0.10	0.953	1.11	Valid	16.01%
HVCS	13g	07/14	Pump Body	damaged shaft seal	broad	6.95	1.185	1.26	Valid	6.56%

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Laboratory Study Data

Method	ID	Date	Component	Leak Configuration	Leak Character	Pressure (psi)	LeakRate	Result	Flag	Bias
HVCS	17a	07/19	4" Threaded Coupling	no thread sealant	diffuse	8.80	1.304	1.37	Valid	4.92%
HVCS	17b	07/19	4" Threaded Coupling	no thread sealant	diffuse	1.00	0.158	0.14	Valid	-9.43%
HVCS	17c	07/19	4" Threaded Coupling	no thread sealant	diffuse	0.40	0.076	0.07	Valid	-13.61%
HVCS	17d	07/19	4" Threaded Coupling	no thread sealant	diffuse	0.75	0.112	0.09	Valid	-17.04%
HVCS	17e	07/19	4" Threaded Coupling	no thread sealant	diffuse	0.80	0.147	0.12	Valid	-17.77%
HVCS	18a	07/20	2" Gate Valve	loose body nut	jet	60.05	2.275	2.08	Valid	-8.69%
HVCS	18b	07/20	2" Gate Valve	loose body nut	jet	39.05	1.336	1.15	Valid	-13.91%
HVCS	18c_1	07/20	Pump Body	damaged shaft seal	jet	17.20	3.634	3.62	Valid	-0.33%
HVCS	18d_1	07/20	Pump Body	damaged shaft seal	jet	15.05	2.054	2.03	Valid	-1.33%
EPA	00C	06/28	2" Gate Valve	Loose Body Nut	Diffuse	0.00	0.687	0.64	Suspect	-6.84%
EPA	00F	06/28	2" Gate Valve	Loose Body Nut	Diffuse	0.00	3.048	2.89	Valid	-5.16%
EPA	00G	06/29	2" Gate Valve	Loose Body Nut	2 small jets on opposite sid	98.60	1.044	1.12	Valid	6.91%
EPA	01A	07/01	2" Gate Valve	Loose Body Nut	2 pin leaks at 10 & 2 o'cloc	10.90	0.25	0.27	Valid	8.13%
EPA	002b	07/05	2" Gate Valve	Loose Body Nut	2 pin holes, 10 and 2 o:clo	32.00	4.807	4.01	Valid	-16.48%
EPA	01C	07/05	2" Gate Valve	Loose Body Nut	Diffuse	23.20	2.772	2.27	Valid	-17.98%
EPA	003a	07/05	Pump Body	Back Plat Loose	NA	8.30	1.667	1.60	Valid	-3.78%
EPA	003b	07/06	Pump Body	Back Plat Loose	Diffuse	5.95	1.007	1.06	Valid	5.37%
EPA	003c	07/06	Pump Body	Back Plat Loose	Diffuse	1.60	0.186	0.18	Suspect	-3.23%
EPA	04a	07/06	4" Threaded Coupling	No sealant on threads	Diffuse	29.80	1.317	1.29	Valid	-1.88%
EPA	04b	07/06	4" Threaded Coupling	No sealant on threads	Diffuse	11.75	0.599	0.52	Valid	-14.02%
EPA	04c	07/06	4" Threaded Coupling	No sealant on threads	Diffuse	4.00	0.242	0.21	Valid	-11.91%
EPA	05a	07/07	4" Threaded Coupling	No sealant on threads	Multiple Jets - High Pressu	94.15	6.068	6.19	Valid	2.09%
EPA	06a	07/07	4" Threaded Coupling	Hand Tight	NA	17.20	10.278	10.47	Valid	1.89%
EPA	07a	07/08	4" Threaded Coupling	Hand Tight	low flow, low pressure	0.00	0.04	0.04	Suspect	0.85%
EPA	07b	07/08	2" Gate Valve	Loose Body Nut	low flow, low pressure	0.00	0.04	0.04	Valid	9.51%
EPA	07c	07/08	Pump Body	Loose Back Plate	low flow, low pressure	0.00	0.041	0.04	Valid	3.00%
EPA	07e	07/08	2" Open Ended Line	NA	low flow	0.00	0.751	0.71	Valid	-5.82%
EPA	17a	07/19	4" Threaded Coupling	No Thread Sealant	Diffuse	8.80	1.304	1.31	Valid	0.76%
EPA	17b	07/19	4" Threaded Coupling	No Thread Sealant	Diffuse	1.00	0.158	0.16	Valid	-0.92%
EPA	17c	07/19	4" Threaded Coupling	No Thread Sealant	Diffuse	0.40	0.076	0.07	Valid	-4.08%
EPA	17d	07/19	4" Threaded Coupling	No Thread Sealant	Diffuse	0.75	0.112	0.09	Suspect	-16.07%
EPA	17e	07/19	4" Threaded Coupling	No Thread Sealant	Diffuse	0.80	0.147	0.14	Valid	-3.16%
EPA	18a	07/20	2" Gate Valve	Loose Body Nut	Jet	60.05	2.275	1.67	Valid	-26.62%
EPA	18b	07/20	2" Gate Valve	Loose Body Nut	Jet	39.05	1.336	1.04	Valid	-22.39%
EPA	18c	07/20	Pump Body	Damaged shaft seal	Jet	17.20	3.634	3.46	Valid	-4.89%
EPA	18d	07/20	Pump Body	Damaged shaft seal	Jet	15.05	2.054	2.03	Valid	-1.21%
EPA	18e	07/21	Pump BOdy	Damaged shaft seal	Jet	11.40	6.254	5.64	Valid	-9.74%
EPA	18f	07/21	Pump Body	Damaged shaft seal	Diffuse	0.95	0.149	0.14	Valid	-4.99%
EPA	19c	07/22	2" open end line		Diffuse	0.00	2.122	2.10	Valid	-1.16%
EPA	19d	07/22	2" open end line		Diffuse	0.00	4.692	4.29	Valid	-8.52%
EPA	20a	07/26	6" Flange	cut gasket	Diffuse	0.00	4.756	4.82	Valid	1.34%
EPA	20b	07/26	6" Flange	cut gasket	Diffuse	0.00	2.959	2.67	Valid	-9.68%
EPA	20c	07/26	6" Flange	cut gasket	Diffuse	0.00	1.161	1.08	Valid	-7.11%
EPA	21b	07/27	2" open end line		diffuse	0.00	3.044	2.92	Valid	-4.09%
EPA	20d	07/27	6" Flange	cut gasket	Diffuse	0.00	0.14	0.13	Suspect	-9.29%

Laboratory Study Data

Method	ID	Date	Component	Leak Configuration	Leak Character	Pressure (psi)	LeakRate	Result	Flag	Bias
EPA	21a	07/27	2" open end line		Diffuse	0 00	1.24	1.22	Valid	-1.84%
EPA	22a	07/27	2" inch gate valve	loose body nut	diffuse	0.00	0.143	0.14	Valid	-2.85%
EPA	22c	07/27	2" inch gate valve	loose body nut	diffuse	0 00	2.909	2.54	Valid	-12.70%
EPA	22b	07/27	2" inch gate valve	loose body nut	diffuse	0 00	1.341	1.26	Valid	-5 76%
EPA	22d	07/29	2" inch gate valve	loose body nut	diffuse	0.40	8.641	7.28	Valid	-15.81%
EPA	22e	08/01	2" inch gate valve	loose body nut	diffuse	0.30	9.031	8.97	Valid	-0.71%
EPA	22f	08/01	2" inch gate valve	loose body nut	diffuse	24 20	1.092	1.31	Valid	19.72%
EPA	24a	08/09	6" Flange	Cut Gasket	diffuse	0 00	0.049	0.04	Valid	-17.52%
EPA	24b	08/09	6" Flange	Cut Gasket	diffuse	0 00	0.05	0.04	Valid	-10 26%
EPA	24c	08/09	6" Flange	Cut Gasket	diffuse	0.00	0.03	0.03	Suspect	-12.27%
EPA	24d	08/09	6" Flange	Cut Gasket	diffuse	0 00	0.029	0.03	Valid	-12.93%
EPA	24e	08/09	6" Flange	Cut Gasket	diffuse	0 00	0.031	0.03	Valid	-17 29%
EPA	24f	08/09	6" Flange	Cut Gasket	diffuse	0.00	0.03	0.03	Valid	-11.84%
EPA	25b	08/10	2" Open Line		diffuse	0 00	0.033	0.03	Valid	-12 31%
EPA	25c	08/10	2" Open Line		diffuse	0 00	0.044	0.04	Suspect	-5 96%
EPA	25d	08/10	2" Open Line		diffuse	0 00	0.05	0.04	Valid	-12.82%
EPA	26a	08/10	4" threaded coupling	no sealant	diffuse	0.00	0.05	0.04	Valid	-27.51%
EPA	26b	08/10	4" threaded coupling	no sealant	diffuse	0 00	0.044	0.03	Valid	-33.07%
EPA	26c	08/10	4" threaded coupling	no sealant	diffuse	0.00	0.044	0.03	Valid	-32.54%

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South Texas Data							
ID	Date	Component Type	HVCS (slpm)	EPA (slpm)	Absolute Bias (slpm)	Relative Bias (%)	True Bias (%)
RP111	08/23	CN	0.0944	0.1116	-0.0172	-15.4%	-0.22
RP111A	08/23	CN	0.1035	0.1116	-0 0081	-7.3%	-0 14
RP112	08/23	VL	0.1279	0.1010	0.0269	26.6%	0.17
RP112A	08/23	VL	0.1397	0.1010	0.0387	38.3%	0.28
RP113	08/23	CN	0.3854	1.2167	-0 8313	-68.3%	-0.71
RP113A	08/23	CN	0.6711	1.2167	-0.5456	-44.8%	-0.49
TEST1	08/23	OL	0.0870	0.0581	0.0289	49 8%	0.39
RP121A	08/23	CT	2.0862	3.6759	-1 5897	-43.2%	-0.47
RP161	08/23	CT	0.2920	0.2606	0.0313	12.0%	0.04
EB161	08/24	CN	5.2570	4.9158	0.3412	6.9%	-0.01
EB162	08/24	VL	10.2516	9.1666	1.0850	11 8%	0.04
EB163	08/24	VL	0.9309	0.7982	0.1326	16.6%	0.08
TW211	08/24	VL	0.2136	0.2513	-0.0377	-15.0%	-0.21
TW212	08/24	VL	10.4233	9.0375	1.3857	15 3%	0.07
TW213	08/24	OL	0.0341	0.0370	-0.0029	-7 8%	-0 15
TW214	08/25	OL	0.7030	0.5651	0 1378	24 4%	0.15
TW215	08/25	OL	0.3456	0.2670	0.0786	29 4%	0.20
TW216	08/25	CN	0.0113	0.0168	-0.0055	-32.6%	-0 38
TW217	08/25	VL	0.0176	0.0292	-0.0116	-39.8%	-0.44
TW218	08/25	VL	1.3658	2.2238	-0.8580	-38 6%	-0.43
TW2110	08/25	VL	0.4611	0.6171	-0.1560	-25.3%	-0.31
TW31	08/25	OL	0.0020	0.0010	0.0010	97.6%	0.83
TW32	08/25	OL	0.0031	0.0017	0.0013	76.9%	0.64
TW341	08/26	VL	0.6631	0.7672	-0.1041	-13.6%	-0.20
TW341A	08/26	VL	0.6926	0.7672	-0.0746	-9.7%	-0.16
TW342	08/26	VL	1.4156	1.5955	-0.1799	-11.3%	-0 18
TW343	08/26	VL	0.9648	1.0518	-0.0870	-8.3%	-0.15
TW344	08/26	VL	0.2606	0.2777	-0.0171	-6 2%	-0.13
TW345	08/26	VL	0.0194	0.0416	-0.0223	-53.5%	-0.57
TW346	08/26	VL	0.3408	0.5682	-0.2274	-40.0%	-0.44
TW162	08/26	MS	0.7242	0.6542	0.0700	10.7%	0.03
TW41	08/26	VL	0.0320	0.0198	0.0122	61.9%	0.50
TW42	08/26	CT	0.0028	0.0021	0.0007	36.0%	0.26
TW43	08/27	MS	0.0216	0.0119	0.0096	80.7%	0.67
TW81	08/27	CN	0.0177	0.0108	0.0069	63.9%	0.52
TW271	08/27	VL	0.0002	0.0001	0.0001	130.8%	1.14
TW301	08/27	VL	0.1820	0.0951	0.0869	91.4%	0.77
EC22	08/27	VL	0.0806	0.0688	0.0119	17.2%	0.09
CNG471	08/29	MS	8.8271	7.2788	1.5483	21.3%	0.12
TW321	08/29	CT	1.5959	1.0677	0.5283	49.5%	0.38
CNG641	08/29	CT	2.6064	1.5027	1.1037	73.4%	0.61
CNG621	08/29	MS	1.0553	0.7145	0.3408	47.7%	0.37
CNG622	08/29	CB	0.0038	0.0047	-0 0008	-17 9%	-0.24
CNG611	08/29	MS	0.0593	0.1100	-0.0507	-46.1%	-0.50
CNG461	08/30	MS	2.9543	3.4697	-0.5154	-14.9%	-0.21
RP122	08/30	CN	0.0004	0.0003	0.0000	10.1%	0.02
TEST2	08/31	OL	0.0923	0.0512	0.0411	80.4%	0.67
TW321A	08/31	CT	1.5959	0.9236	0 6723	72.8%	0.60

West Texas Data						
ID	Date	Component Type	HVCS (slpm)	EPA (slpm)	Absolute Bias (slpm)	Relative Bias (%)	True Bias (%)
ID4	09/21	CN	0.0298	0.0200	0.0099	49 5%	38.5%
ID5	09/21	VL	0.0798	0 0845	-0 0047	-5 6%	-12 6%
ID6	09/21	CN	0 5777	0.2985	0 2792	93 5%	79.2%
ID7	09/21	CN	0.3524	0.2038	0 1486	72.9%	60 1%
ID3	09/21	VL	0 0138	0 0077	0 0061	79 9%	66 6%
ID1	09/21	VL	3.9422	1.6919	2.2503	133 0%	115.8%
ID2	09/21	VL	1 2705	0.6363	0 6342	99.7%	84 9%
ID9	09/21	VL	0.3604	0.1536	0 2068	134 6%	117 3%
ID10	09/21	VL	1 7620	0.8151	0.9469	116.2%	100 2%
ID12	09/22	CN	1.3587	0.7767	0 5820	74 9%	62 0%
ID13	09/22	VL	1.6213	0.9676	0.6537	67.6%	55 2%
ID15	09/22	VL	0.0691	0.0405	0.0286	70 7%	58 0%
ID21	09/22	VL	4 3116	3.1760	1 1356	35 8%	25.7%
ID24	09/22	VL	2.0488	1.3544	0 6944	51 3%	40 1%
ID26	09/22	VL	7.8876	6.7354	1 1521	17 1%	8 4%
ID30	09/23	VL	0.8039	0.5014	0.3024	60.3%	48 4%
ID31	09/23	VL	0.0992	0.0777	0 0216	27 8%	18 3%
ID34	09/23	VL	0 0172	0 0130	0 0042	32.8%	23 0%
ID35	09/23	MS	1 3897	0.5803	0.8094	139 5%	121 8%
ID36	09/23	CN	0.0869	0.1032	-0 0163	-15 8%	-22 0%
ID42	09/23	VL	0.0069	0.0038	0.0031	80 0%	66 6%
ID37	09/23	VL	0.4509	0.3099	0.1410	45 5%	34 7%
ID38	09/23	VL	1 8613	0.9521	0.9092	95.5%	81.0%
ID43	09/23	VL	0 0077	0 0048	0.0029	61 7%	49 7%
ID44	09/23	VL	0.0274	0.0138	0.0136	99.0%	84 3%
ID45	09/23	VL	0 0269	0 0099	0.0170	170.7%	150 7%
ID40	09/24	VL	0.3831	0.1702	0.2130	125.2%	108.5%
ID46	09/24	VL	1.9290	1.0186	0.9105	89.4%	75 4%
ID49	09/24	VL	0.2647	0.1566	0.1080	69 0%	56.5%
ID50	09/24	VL	0.1168	0.0693	0.0475	68.6%	56 1%
ID51	09/24	VL	0 1241	0.0660	0 0581	88.0%	74 0%
ID52	09/24	VL	0.8201	0.3448	0.4752	137 8%	120.2%
ID56S	09/24	VL	0.1442	0.1447	-0.0005	-0 3%	-7 7%
ID57	09/24	VL	0.2204	0.1542	0 0663	43 0%	32 4%
ID60	09/24	VL	1.0875	0.6568	0.4308	65 6%	53 3%
TEST1	09/26	VL	0.1633	0.0954	0.0679	71 1%	58.5%
TEST2	09/26	VL	3 0263	1 8791	1.1472	61.0%	49 1%
ID61	09/26	VL	2.8341	4.5508	-1 7167	-37 7%	-42 3%
ID62	09/26	VL	6.3681	3.7301	2.6380	70 7%	58 1%
TEST3	09/27	VL	0.1562	0.1505	0.0057	3 8%	-3 9%
ID70	09/27	VL	2.0472	1.9435	0.1037	5.3%	-2 5%
ID71	09/27	VL	2.8108	2.6418	0.1690	6 4%	-1 5%
ID73	09/27	VL	1 1530	1.3602	-0 2072	-15.2%	-21.5%
ID72	09/27	VL	1.9447	1.7184	0.2263	13 2%	4 8%
ID47	09/27	VL	3 8225	3.8435	-0.0210	-0.5%	-7 9%
ID75	09/27	VL	0.1718	0.1501	0.0216	14 4%	5 9%
ID76	09/27	CN	0.7859	0 6883	0 0977	14 2%	5 7%
ID77	09/27	VL	0.0915	0.0627	0 0288	45 8%	35 0%
ID78	09/27	VL	0.0204	0.0209	-0.0005	-2 4%	-9 6%
ID79	09/27	VL	0.0079	0 0089	-0 0010	-11 0%	-17 6%
ID1 R1	09/28	PR	2.9474	4.3063	-1 3588	-31 6%	-36 6%
ID12 R1	09/28	VL	0 9535	0.9016	0 0518	5 7%	-2 1%
ID46 R1	09/28	VL	1 5865	0 7210	0 8655	120 0%	103 8%
IDF	09/28	VL	1.3279	0.9726	0 3553	36 5%	26 4%
ID84	09/28	CN	0 1828	0.2703	-0 0875	-32 4%	-37 4%
ID85	09/28	MS	1 3955	1.5214	-0 1259	-8 3%	-15 1%
ID87	09/28	CF	0.5777	0.5449	0 0329	6 0%	-1 8%
IDI	09/28	VL	6.9937	6 5334	0 4604	7 0%	-0 9%
ID88	09/28	VL	6 9424	7 6512	-0.7089	-9 3%	-16 0%
ID89	09/28	VL	0.8320	0.6747	0 1574	23 3%	14 2%
ID95	09/29	VL	0 4644	0 5827	-0 1184	-20 3%	-26 2%
ID96	09/29	VL	0.6434	0.5062	0 1372	27 1%	17 7%
ID92	09/29	VL	0.8397	0 7532	0 0865	11.5%	3 2%
ID93	09/29	VL	0.3208	0 5350	-0 2142	-40.0%	-44 5%
ID91	09/29	VL	0.5719	0 4740	0 0979	20 7%	11 7%
ID90	09/29	VL	6 3306	7 1402	-0 8096	-11 3%	-17 9%

APPENDIX A

MEASUREMENT OF FUGITIVE ORGANIC VAPOR LEAKS

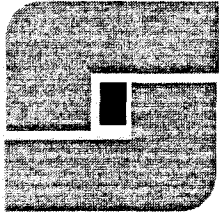Quality Assurance Project Plan

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Prepared for:

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MEMORANDUM

To: Charles C. Masser
From: Eric Ringler
Date: June 29, 1994
Subject: Response to Comments on QA Plan for the HVCS Evaluation Study

This memorandum constitutes SRI's response to the comments of the reviewers of the Quality Assurance Project Plan for the HVCS Evaluation Study. We appreciate the careful and constructive review of the plan, and especially the very favorable response to the section on Data Quality Objectives. The responses follow the order in which the comments are given in the review dated June 3, 1994. We feel that these responses adequately address the concerns of the reviewers. We understand that the plan is approved with consideration of the comments and have no plans to revise the plan itself at this time. A revised version of the plan can be prepared at your request. The comments and these responses should be provided to those who may have received copies of the plan and should accompany any future distribution.

Since the draft plan was submitted, we have come up with some criticisms of our own that the reviewers did not address. Changes to procedures that address these issues are included after the responses to the reviewers comments. Please let us know if you have any questions or further comments.

cc: Ashley Williamson
       Stephen Piccot

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Response to Reviewers Comments

GENERAL
- As recommended, text in section 1 should be amended to read: *EPA Method 21 is not included in the laboratory testing because it is intended to locate and classify leaks only, and is not intended to be used as a direct measure of mass emission rates (40 CFR 60, Appendix A, Method 21, Paragraph 1.2).*

  It should be noted; however, that method 21 procedures will be used for obtaining screening values before and after each measurement of mass emissions on the laboratory test components, just as will be done in the field. However, the laboratory testing is not intended to evaluate the performance of method 21.

- The unexplained asterisk in Table 2-2 should refer to the following comment: Estimated precision and accuracy objectives for HVCS. Determining the true precision and accuracy of the HVCS measurements is the purpose of the study.

LABORATORY MEASUREMENTS TEST MATRIX
- The precision of the flow measurements required for the laboratory testing will be established based on comparisons with a primary standard bubble flow meter. These comparisons will be performed immediately before and after each measurement. It is not necessary to repeat the HVCS or bagging procedures to establish the precision of the flow measurements.

DATA QUALITY OBJECTIVES
- This comment describes the careful treatment given to DQO's in the plan. We are grateful for the reviewers appreciation of this section.

- It would be desirable to randomize the order in which HVCS and EPA protocol measurements are performed in the field to minimize the impact of possible changes in leak rate with time. It is expected that the two types of measurements will not always be performed in the same order; however, as a practical matter, it is likely that efficient use of time and manpower will be the deciding factor. As the reviewers stated, screening values will be obtained before and after each emissions measurement, and these will be used to determine if a change has occurred. A data quality objective of 20 percent is given for the repeatability of the screening measurements. Thus, a change in screening value of less than 20 percent would not be considered significant. If there is a significant change in screening value, the effect would be to invalidate the comparison. The simplest remedy is to repeat either the HVCS or EPA protocol measurement (as appropriate) as soon as possible.

SCREENING MEASUREMENTS

■ Each OVA will be leak checked daily and the sample flow rate will be checked during the daily calibrations - 3 times per day. Screening values will be obtained per EPA protocol procedures; with the probe at the surface of the leak interface when there are no moving parts, and 1 cm from the interface when there are moving parts. The 1 cm distance will be gauged by eye. No spacer will be used. No glass wool will be used in the probe. The test plan specifies multipoint calibrations 3 times per day using a centrally located certified gas supply. A Mylar bag containing 1,000 or 10,000 ppm methane (from the certified gas supply) can be obtained and carried with the operator if needed due to difficulty in returning to the central gas supply or if frequent flameouts are expected (the calibration should be checked after each flameout).

SCREENING QA/QC PROCEDURES

■ Certified calibration gases that have been quantitatively analyzed after mixing will be obtained from a commercial specialty gas vendor. The analytical accuracy of the gas certification is guaranteed by the vendor to be within ±2 percent. In addition, SRI will cross check the gas concentrations against other certified gas standards and verify the gas composition by FTIR spectroscopy.

■ After analysis, each bag will be purged with room air 3 times. Before sampling, each bag will be purged with sample gas 3 times. SRI has direct experience to show it is not necessary to take extraordinary measures in order to minimize carryover when reusing sample bags that have been used to sample natural gas (primarily methane and other light hydrocarbons). Purging, as described above, is sufficient. It is not necessary to segregate high concentration bags from low concentration bags.

QA/QC FOR BAG SAMPLING

■ For natural gas sampling, purging as described above, is sufficient to minimize carryover. It is not necessary to check hydrocarbon concentrations in the purge air in every case. However, it is a reasonable precaution to check purge air for several bags collected from different areas at the start of the study. If carryover is found to be a problem, then purge air would be checked on every bag. Alternatively, it may be more cost effective to simply destroy the bags and make new ones, reusing only the valve. SRI will have the capability to make heat sealed sample bags in the field.

CONTROLLED LEAK TEST QA/QC

■ For the controlled leak tests, the flow will be metered as in the laboratory studies. SRI has modified this approach since the draft Plan was submitted. The new approach to controlling and metering the leak rate in a simulated component is described below.

AUDITS
- SRI has adopted careful measures to ensure the quality of the calibration standards that will be used (see above). Use of independent audit gases is not necessary to meet Category III requirements.

PROJECT ORGANIZATION
- The controlled leak rates will not be revealed to the operators (STAR and SRI) of the HVCS and bagging apparatus during the blind leak tests. The apparatus that will be used (see below) will be arranged so that the* leak rate cannot be read by the operator. The leak rates will be set and controlled by the SRI field coordinator. STAR will follow all QA/QC procedures in the QAPP. Field review of STAR activities and data will be conducted by the SRI field coordinator.

Further Modifications to Procedures
SRI has adopted changes to the EPA protocol emissions sampling and laboratory test procedures since the draft QAPP was submitted for review.

First, SRI noted that the "Blow-Through" tent/bag protocol does not adequately account for the total gas flow when testing large leaks. Specifically, the volume of the leaking gas is not directly measured. If this volume is large compared the carrier gas volume, then a significant underestimate of the total flow (and the leak rate) will result. This error is equal to the ratio of the leak flow to the carrier flow. SRI initially decided to modify the "Blow-Through" method so that the total flow exiting the bag is measured. However, during initial testing, it proved to be impractical to consistently construct a sufficiently leak tight enclosure so that the exit flow could be accurately measured. Therefore, it was decided to evaluate the vacuum bag method, especially for use with larger leak rates. The vacuum method is not as sensitive to enclosure leaks since the total gas flow is measured directly, including any air that may infiltrate the bag. The vacuum method is slightly more complex to execute in the field and there is a small potential that an explosive gas mixture could be sampled. However, the performance advantages of the vacuum method outweigh these disadvantages. Based on this evaluation, SRI has now decided to use the vacuum bag protocol in the field. The laboratory testing will include a limited number of comparisons of the vacuum and blow through method; however, it is beyond the scope of the current work to fully evaluate differences in performance between the two methods.

Second, since the draft QAPP was submitted, SRI has developed an improved method for controlling and metering the leak rates in the laboratory test components (and in the field leak rate tests). The method specified in the QAPP called for developing a "family" of calibration curves for each rotameter over a range of back pressures. In practice, it turned out to be difficult to maintain constant pressure over a range of flow rates so that these curves could be generated. In addition, the effect of back pressure increases on rotameter readings was such that a large number of calibration curves would be needed to adequately cover the pressure range from 0 to 100 psig. Each 1 psi increase in back-

pressure decreases the rotameter reading by about 2.5 to 4 percent (the relationship is not linear). This means that a family of 10 to 20 calibration curves would be needed to bracket the 0 to 100 psi pressure range so that no flow measurement in this range was more than 10 percent away from a calibration curve. This was not anticipated when the draft QAPP was prepared.

In initial testing, it was also shown that the usual formula used to correct for back pressure on a rotameter based on the square root of the ratio of the pressures leads to significant underestimates (as much as 30 percent) of the true flow rate with pressures as high as 90 psig. In addition, this formula underpredicts systematically by different amounts at different flow rates (the underpredicition is more severe at lower flows). This is a consequence of the fact that the ratio of the pressures does not fully account for rotameter behavior, especially at elevated back pressures. A full treatment of rotameter mechanics is given in the student manual for EPA's APTI Course 435, Atmospheric Sampling.

The modified leak metering and control procedure is not subject to these difficulties and is simple to execute. In this procedure, the leak rate is induced at a desired back pressure by manipulating the downstream component and a flow metering valve (upstream from the rotameter). Pressure is metered directly upstream from the component using a sensitive pressure transducer (0.5 torr resolution). The rotameter reading and back pressure are recorded. A 3-way valve is then actuated so that the flow from the rotameter is directed through a needle valve and then to a bubble flowmeter. The needle valve is used to re-create the exact back-pressure condition on the rotameter that was used in establishing the component leak. The actual flow (at room conditions) is then measured by the bubble meter. The flow is then returned to the component and pressure and rotameter readings are checked to ensure that they have not changed. The flow measured by the bubble meter is the leak rate. The leak rate is verified after each mass emissions measurement by the same method. If a change of more than 5 percent has occurred, the measurement is repeated.

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SECTION 1
PROJECT DESCRIPTION

1.1   INTRODUCTION

Fugitive emissions of methane and other organic vapors from leaking pipelines, valves, flanges, and seals associated with natural gas, petroleum and chemical production and processing facilities are an important source of methane and other organic emissions to the atmosphere. Such emissions have historically been difficult to measure accurately. EPA Reference Method 21 "Determination of Volatile Organic Compound Leaks" describes instruments and procedures that can be used to locate and assess the magnitude of such leaks. This consists of screening components with a portable hydrocarbon analyzer and recording concentration values obtained at the component interface where leaks are detected. Method 21 does not provide a direct measure of the mass emission rate. Mass emission rates for leaking components have traditionally been determined by "tenting and bagging" the leaks. This entails constructing a sampling enclosure around the leaking component, introducing a known flow of diluent gas through the enclosure, and determining the concentration of leaking gas in a sample captured from the enclosure (usually done off-site in a laboratory). The concentration times the total flow rate (diluent and leaking gas) gives the leak rate. This is clearly, a laborious and expensive method that is not generally practical to apply for each leaking component at a facility.

According to the current EPA protocol (EPA 1993), mass emission rates may be estimated indirectly by one of four methods. (1) Emissions may be estimated by applying published emission factors (EPA 1993) to an inventory of components by type (valves, flanges, etc.) and service (e.g., gas, liquid). (2) More refined emissions estimates may be obtained by identifying leaking components (per Method 21) and applying separate emission factors to leaking and non-leaking components. (3) Still more refined estimates are determined by applylying published correlation equations (EPA 1993) to screening values for each component (obtained per Method 21). These emission factors and correlations were developed over the last 15 years based on field studies at petroleum refineries, gas plants, and Synthetic Organic Chemical Manufacturing Industry (SOCMI) plants. (4) Finally, the EPA protocol specifies procedures for developing unit specific correlation equations that may more accurately estimate emissions for a specific facility. This entails obtaining pairs of screening values and direct measurements of mass emissions (by tenting and bagging) at a sufficient number of components so that representative, site specific correlation equations can be developed.

A new measurements technique has recently been developed as a result of work sponsored by the Gas Research Institute (GRI) (GRI 1994). The method is known as the High Volume Collection System (HVCS). The HVCS was designed to obtain direct measurements of mass emission rates without the need for tenting and bagging, and offers the potential for providing an easy to use, and cost effective means to measure organic vapor leaks from gas, oil, and chemical industry sources. The HVCS uses a battery powered pump to draw ambient air across a leaking component at controlled and metered rates between 10 and 500 standard cubic feet per hour. A portable Flame Ionization Detector (FID) is used to measure the hydrocarbon concentration in

the HVCS exhaust. The mass emission rate is determined as the product of the sample flow rate and the hydrocarbon content in the flow. The success of the method depends on capturing all of the leaking gas from a component in the flow entering the sample inlet. The inlet is constructed to enhance this capture (the inlet is shaped like the mouthpiece of a snorkel). Diffuse leaks from larger components (such as a large flange) are captured by wrapping the component in polyethylene sheeting so that the air flow passes over the entire leaking surface. Prior to this study, limited laboratory and field testing of the HVCS indicated that the system had the potential to provide a practical method for quantifying fugitive hydrocarbon emissions (GRI 1994).

1.2   PROJECT OBJECTIVES

The purpose of this project is to complete a study of HVCS method performance. The study will consist of both field and laboratory testing. The field testing will assess the accuracy of the HVCS method relative to an EPA protocol emissions measurements method. The performance of the HVCS method will be evaluated specific to the range of component types, operating conditions and leak rates encountered during the field testing. The goal is to challenge system performance under the range of conditions representative of natural gas production. A major focus of the study is to develop performance criteria for field use of the HVCS method. These criteria will identify conditions under which best and worst HVCS performance is achieved and recommend procedures for obtaining optimum results.

Laboratory testing is needed to establish the accuracy and precision of the EPA protocol (bagging) and HVCS methods compared to controlled leak rates. This testing will strengthen and support the field test results by associating the methods with test results under controlled conditions. The laboratory tests are devised to represent "real world" components and leak types so that overall errors (including sampling errors) are represented. Laboratory test procedures will mirror the field test procedures. Laboratory testing will be completed prior to the field tests. Field testing will be completed during the summer of 1994.

1.3   TEST SITE SELECTION

Field testing for this study will be conducted at natural gas production fields. The sites will be selected by EPA in cooperation with GRI and API. The sites should be representative of a geographic region associated with significant gas production. The sites should provide a reasonably large number and high density of components so that a sufficient number and type of leaking components can be identified without undue effort. The sites should be of "average" age for U.S gas production sites (15 ± 5 years). The sites should be operating at moderate pressure (200 to 600 psi). Few leaks are expected at very high pressure (2000 to 3000 psi) sites since these sites must be highly maintained. More leaks might be expected at low pressure sites (30 to 100 psi); however, expected leak rates would be small. Sites where the gas contains large amounts of hydrogen sulfide (H_2S) would not be considered because of the obvious safety hazards and because very few leaks would be expected at these sites.

Gas production areas meeting these criteria can be found in south and west Texas. In these regions, it is expected that a sufficient number of components can be found among 4 to 8 gas production fields grouped around one or two gas processing plants. Sites in these areas are being surveyed by API to identify industry participants for the study.

1.4   STUDY DESIGN OVERVIEW

This section presents an overview of the test plan for all field and laboratory measurements. The test matrix proposed for field and laboratory measurements is presented in this section and identifies the type and number of measurements to be completed. This includes primary measurements that will be used directly to assess the performance of the HVCS method, and additional measurements and calibrations necessary for quality assurance and quality control purposes. This section also discusses how field activities will be coordinated to achieve the project objectives.

1.4.1   Field Measurements

The first step in conducting the field study will be to identify and classify leaking components. SRI will screen a sufficient number of components (up to 25,000) to allow selection of a representative set of components for comparative analysis of the HVCS and bagging measurements. This screening will be conducted according to EPA Reference Method 21 using a Foxboro Model 108 organic vapor analyzer (OVA) calibrated specific to methane to obtain instrument screening values (ISV's). The screening value, component identification number, type, location, and operating parameters will be recorded for all components where readings over 10 ppmv (above background) are obtained. Leaking components will be further classified by equipment type, type of service, and process location. Non-emitting components (ISV less than 10 ppmv) will simply be inventoried.

Experience from recent measurements at gas production fields in the Eastern United States (conducted by STAR Environmental for GRI) indicates that screening 25,000 components can be expected to yield 400 to 600 small leaks (ISV less than 1000 ppm), 300 to 400 medium leaks (ISV less than 10,000 ppm), 200 to 300 large leaks (ISV greater than 10,000 ppm) and perhaps 20 very large leaks (ISV greater than 100,000 ppm) (GRI 1994). Recent measurements at Western gas production fields indicates that 25,000 components can be expected to yield about 250 small leaks, 200 medium leaks, 200 large leaks and as many as 150 very large leaks (API, 1993). It appears that Eastern fields contain an overall larger number of leaking components, while Western fields contain more larger leaks. This is probably related to the relative age of Eastern and Western fields, as well as the average operating pressure. Western fields tend to be newer and operate at higher pressure than Eastern fields.

A subset of at least 200 of the leaking components will be selected from the screened components for emissions measurements using the HVCS (see section 4.2). The total number will depend on how much screening is necessary to find leaking components. HVCS measurements will be made at three flow settings for each component. If the HVCS is functioning properly and captures all of the gas leaking from the component, the leak rates at each flow

setting should agree. The selected components should include most of the largest leaks, and enough medium and small leaks to make up the balance. The goal is to fully characterize the largest leaks and select enough medium and small leaks that a representative range of leak rates, component types, and operating conditions is encountered and the system performance is challenged under a wide range of conditions. SRI will review the screening data on a continuous basis in the field, and coordinate measurement activities to achieve this goal.

The emission rates for at least 125 of the leaking components measured by the HVCS will also be measured using a mass emissions sampling protocol published by EPA (see sections 4.3 and 4.4). The EPA protocol methods involve isolating a component leak, introducing a known flow rate of a carrier gas, and measuring the concentration of the leaking gas to determine the emission rate. The 125 components will characterize the largest leaks and should also represent the range of leak types, sizes and operating conditions encountered. The bagged samples for all of the 125 components will be analyzed for methane and total hydrocarbon content by gas chromatography (GC) following EPA's Reference Method 18.

Further analysis will be conducted on about 50 of the 125 bag samples to determine speciation. This will also be done following EPA Reference Method 18 (see section 4.4). The speciation will be specific to methane, ethane, propane, and n-butane. According to EPA's SPECIATE database for fugitive emissions from gas and oil production, these four compounds should make up more than 80 percent of total fugitive hydrocarbon released from valves and fittings in gas service, and more than 60 percent of fugitive emissions from valves and fittings in liquid service. Methane made up more than 90 percent of the gas composition in a small number of samples (8) recently obtained from gas production facilities (GRI, 1994).

In this study, the speciation information will be used to assess the response of the portable FID to gases other than the calibration gas (methane) that are present. Ethane, propane and n-butane all have FID response factors for the OVA of less than 1 (0.57 for ethane, 0.88 for propane, and 0.38 for n-butane). That is, more of these gases will be present than indicated by the OVA. Speciation will be performed on samples selected to represent groups of tested components where differences in chemical composition may exist.

SRI anticipates that about 24 days of field testing will be needed to complete the field evaluation. This time will be distributed over 2 to 3 trips, depending on the number and location of sites selected. A brief pre-survey trip (2 to 3 days) is also planned. During the pre-survey, SRI will survey the site(s), obtain equipment inventories and process diagrams, consult with plant engineers and management, and make scheduling and logistical arrangements. Field activities will consist of component screening, HVCS measurements, tenting and bagging, GC operation, and field coordination. The field crew will consist of a total of up to 6 personnel: 2 screening, 1 HVCS, 1 tent/bag, 1 GC operator and 1 coordinator. The activities of these personnel will be coordinated so that the required number of measurements of each type are completed in an efficient manner. The role of the coordinator is to monitor screening and other data collection activities in the field, select an appropriate number and type of leaking components for HVCS, bagging, and speciation analysis, and direct field activities. The coordinator will also ensure that QA/QC procedures are followed, and initiate corrective actions as necessary.

SRI anticipates that the full crew of 6 will not be needed at all times in the field. For example, the screening crew might arrive on site a few days before the rest of the crew to get a head start on identifying leaking components and then leave a few days early. In addition, the screening crew could be supplemented with HVCS and tent/bag personnel until a sufficient number of leaking components are identified. Measurement activities will be sequenced so that initial screening will be followed as closely as possible by HVCS and bagging measurements. In accordance with the EPA protocol, all components measured by HVCS and bagging will be re-screened immediately before and after the measurement to verify screening values.

Table 1-1 presents the test matrix for the field measurements. In the table, the 4 primary measurement types: (1) Method 21 screening, (2) HVCS emissions measurements, (3) EPA protocol emissions measurements, and (4) speciated measurements are grouped together with the associated calibration and quality control measurements that will be used to assess data quality. Measurement frequencies are based on study requirements and quality control needs. Numbers of measurements are based on program and quality control requirements and on the anticipated number of trips and days in the field needed to complete the measurements.

1.4.2 Laboratory Measurements

In this study, the primary means of establishing the performance of the HVCS will be through comparisons of HVCS measurements with results from the EPA protocol emissions sampling method. Thus, it is important that the precision and accuracy of the bagging method is carefully determined.

Quality assurance testing of the bagging method was conducted in a previous study (EPA 1980c). In this study, the overall sampling and analytical precision of the bagging method (vacuum bag protocol) was found to be about 17 percent based on tests involving introduction of a known amount of gas into the sampling apparatus. It should be noted, however, that these tests did not account for any sampling errors associated with the leak enclosure. For example, errors resulting from constructing an imperfect enclosure around a component that leaks excessively or prevents adequate mixing of the dilution air with the leaking gas would not have been reflected in the tests. Other tests involving repeat measurements of the leak rate from the same component yielded an overall precision of about 40 percent. The researchers concluded that this apparent imprecision was due to actual changes in the leak rate of the component over time.

The EPA protocol describes two mass emission sampling methods, referred to as the vacuum-bag and blow-through methods, and allows for variation in sampling and analytical technique. Because of this variation, it is important that the accuracy of the method, as actually applied, be established on a case by case basis. The protocol recommends that the accuracy of the sampling/analytical method be verified by performing leak rate checks. According to the protocol, this can be accomplished simply by introducing a known flow of a known gas into a sampling bag, measuring the gas concentration, and calculating the leak rate. The calculated leak rate should agree with the induced leak rate. EPA recommends that these checks be conducted in the laboratory to verify the performance of equipment and procedures, and repeated periodically in the field. These leak rate checks do not test the accuracy of the bagging procedures as they

would actually be applied in the field since they do not address the total sampling error (*i.e.*, the enclosure is left out of the sampling system).

The tenting and bagging procedure is fairly complex and there are numerous ways in which sampling and analytical errors might occur. Since, in this study, the bag sampling data will be used as the reference against which the field performance of the HVCS method will be measured, the precision and accuracy of the data acquired with the bagging method must be evaluated under controlled conditions that closely simulate field conditions. To accomplish this, SRI will construct controllable leaks in a number of representative components (see section 4.5). The leak rate will be controlled by varying the pressure delivered to the component, and/or by physically altering the size of the leak (See Section 4.5). A representative range of leak rates will be established and measured for each component. In the EPA emission factors for gas plants (EPA Protocol, June 1993), leak rates (as methane) range from 0.002 to 1.1 liters per minute (lpm) for small leaks (defined as yielding an ISV less than 10,000 ppm) and 0.8 to 20 lpm for large leaks (ISV more than 10,000 ppm), depending on the type of component. Leak rates between 0.0002 and 1.3 lpm (with one leak as high as 25 lpm) have recently been measured at gas production operations in the Gulf and Appalachian regions (GRI, 1994). Based on this, and considering that larger leaks are of greater importance for this study, SRI will induce leak rates in the test components in the range of 0.1 to 20 l/min. This range covers most of the largest leaks and all but the smallest of the smaller leaks.

In these laboratory studies, emissions from the controlled leaks will also be measured using the HVCS method. These tests will establish the accuracy and comparability of the HVCS and bagging techniques under controlled conditions before testing under field conditions. The tests will also serve to identify and evaluate any problems with HVCS performance before field testing. One of the key areas of uncertainty in the HVCS method is the ability of the sampler to capture all of the leaking gas, especially for larger leak rates and larger component sizes. Table 1-2 presents a test matrix for the laboratory measurements. The actual test matrix executed may differ somewhat from Table 1-2 depending on the range of leak rates and pressures that can actually be achieved in the test components.

Controlled leak rate tests will be repeated periodically in the field using a suitable component (see section 4.5). The performance of both the HVCS and bagging methods will be assessed in the field leak rate tests. The field leak rate tests will also be used as "blind" audits to test operator proficiency.

1.4.3   Data Analysis and Reporting

Upon the conclusion of field measurements, data screening, and data analysis activities, a report will be prepared that describes the study findings and documents how these findings were arrived at. The report will assess the overall performance of the HVCS and identify factors that affect its performance. HVCS performance will also be assessed for different component types, leak rates, and operating conditions (*e.g.*, pressure). HVCS performance will also be evaluated under varying operating conditions of the HVCS (*e.g.*, flow rate, and concentration range). Appropriate descriptive statistics and significance tests will be used to represent the data and interpret the results (see sections 2, 3 and 5).

If sufficient data are available, the report will also present a comparison of emissions estimates based on HVCS, tenting/bagging, and EPA protocol emission factor and correlation approaches. It is important that such comparisons are carried out over representative groups of components as the EPA emission factor and correlation approaches are properly applied only to relatively large sets of components. Finally, the report will include an assessment of data quality based on data quality indicators (as described in section 3), and on consideration of any operational or methodological problems that may occur. The report will also contain summary tables of data collected for the study.

Table 1-1 Field Measurements Test Matrix					
Measurement Type	**Method or Device**	**Quantity**	**Frequency**	**Number**	**Data Use**
Method 21 Screening	Foxboro OVA 108	Screening Value	900 to 1800 per day	up to 25,000	(1) Identify leaking components, (2) provide screening values for emissions estimates
OVA Calibrations	Cylinder Gases	Concentration	Daily Pre/Post Test	42 (per OVA)	Analytical P&A
HVCS Emissions Measurements	STAR HVCS	Leak Rate	approx. 15/day	200	Evaluation of HVCS Performance
Flow	Rotameters	Flow	approx. 15/day	200	Input to leak rate calculation
Concentration	Foxboro OVA 108	Concentration	approx. 15/day	200	Input to leak rate calculation
Pre/Post Screening	Foxboro OVA 108	Screening Value	Each measurement	400	Verification of screening value
Field Leak Rate Test	Controlled leak	Flow	Three per field test	9	Field P&A , operator bias
OVA Calibrations	Cylinder Gases	Concentration	Daily Pre/Post Test	36	Analytical P&A
Flow Calibrations	Dry Gas Meter	Flow	Pre/post field test	6	Verify HVCS flow system accuracy
EPA Protocol Emissions Measurements	Tent/Bag	Leak Rate	5 to 10/day	125	Evaluation of HVCS Performance
Flow	Rotameter	Flow	5 to 10/day	125	Input to leak rate calculation
Concentration	GC/FID/TCD HP5890	THC Concentration	5 to 10/day	125	Input to leak rate calculation
Pre/Post Screening	Foxboro OVA 108	Screening Value	Each measurement	250	Verification of screening value
Field Leak Rate Test	Bubble Flowmeter & Cylinder Gas	Flow	Three per field test	9	Flow/Concentration P&A
GC Calibrations	Cylinder Gases	Methane Concentration	Daily Pre/Post test	48	Analytical P&A
Speciated Measurements	GC/FID/TCD HP5890	Methane, Ethane, Propane, n-Butane	2 to 4 per day	50	Evaluation of FID response to gas mixture
GC Calibrations	Cylinder Gases	Concentration	Daily Pre/Post test	36	Analytical P&A

Table 1-2 Laboratory Measurements Test Matrix					
Measurement Type	Method or Device	Quantity	Frequency	Number	Data Use
Laboratory Controlled Leak Testing					
Release Rate	Calculated	Leak Rate	5 components, 3 leak rates, 3 pressures	45	Reference leak rate
Flow	Bubble Flowmeter	Flow	5 components, 3 leak rates, 3 pressures	45	Input to leak rate calculation
Concentration	Cylinder Gas	Concentration	5 components, 3 leak rates, 3 pressures	45	Input to leak rate calculation
Method 21 Screening •	Foxboro OVA 108	Screening Value	5 components, 3 leak rates, 3 pressures	45	Associate Method 21 screening values with laboratory tests
OVA Calibrations	Cylinder Gases	Concentration	Daily Pre/Post Test	10	Analytical P&A
EPA Protocol Emissions Measurements	Tent/Bag	Leak Rate	5 components, 3 leak rates, 3 pressures	45	Overall Sampling/Analytical P&A for Method
Flow	Bubble Flowmeter	Flow	5 components, 3 leak rates, 3 pressures	45	Input to leak rate calculation
Concentration	GC/FID/TCD HP5890	Concentration	5 components, 3 leak rates, 3 pressures	45	Input to leak rate calculation
GC Calibrations	Cylinder Gas	Methane Concentration	Daily Pre and Post Test	10	Analytical P&A
HVCS Emissions Measurements	STAR HVCS	Leak Rate	5 components at 3 flow rates, 3 leak rates, 3 pressures	135	Overall Sampling/Analytical P&A for Method
Flow	Rotameters	Flow	5 components at 3 flow rates, 3 leak rates, 3 pressures	135	Input to leak rate calculation
Concentration	Foxboro OVA 108	Concentration	5 components at 3 flow rates, 3 leak rates, 3 pressures	135	Input to leak rate calculation
OVA Calibrations	Cylinder Gas (3)	Concentration	Daily Pre and Post Test	10	Analytical P&A
Flow Calibrations	Dry Gas Meter	Flow	Pre and Post Test	2	HVCS Flow System Accuracy

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SECTION 2
DATA QUALITY OBJECTIVES

In this section, data quality objectives are developed which state the values of key data quality indicators that must be achieved to draw conclusions from the study with the desired level of confidence. This section lays out the criteria for the overall experimental design. First, overall data quality requirements are determined by starting with the study objective and applying appropriate statistical procedures to determine the level of data quality needed to meet that objective at a pre-determined level of significance. Then, these errors are propagated to the level of the direct measurements required to conduct the study. This process yields practical and defensible data quality objectives. Data meeting these objectives can be used to draw conclusions from the study with a known level of confidence. The following section (Section 3) describes how values for the data quality indicators are established for each measurement.

2.1   DETERMINING DATA QUALITY REQUIREMENTS

As stated earlier, the primary goal of the study is to assess the field performance of the HVCS emissions measurement method. Ideally, this assessment would be based on comparisons of the HVCS leak rate measurements with the true leak rate for a wide variety of components, leak rates and operating parameters. These comparisons could be expressed as

$$D = \frac{H - T}{T} \tag{1}$$

where, H is the HVCS measured leak rate, T is the true leak rate, and D is the difference relative to the true leak rate. If the HVCS measurement is unbiased, this difference will be zero. However, after a number of such comparisons have been made, one would expect some variability in D due to systematic and random errors in measurement. Data quality objectives can be developed by considering how much variability in D can be tolerated while detecting a given bias in the HVCS measurement at a given level of significance. This is accomplished using an appropriate statistical test of significance. This "allowable" error is then propagated down to the individual measurements that make up the difference.

The first step is to consider the frequency distribution of D. This will be done using normal probability plots (Gilbert, 1987). If the distribution is approximately normal (*i.e.*, symmetric about the mean and relatively free from outliers), then standard "t" procedures for paired comparisons can be used. However, the value of D as defined in equation 1 is restricted between -1 and $+\infty$. Thus, if H is positively biased as often as negatively biased, the distribution of D will be right skewed and may be lognormal. In this case, the "t" procedures would be applied to the log transformed differences (ln D) (Griffiths, 1986). In either case, the form of the test is as follows.

The null hypothesis is that the mean difference is zero ($H_o : \mu_0 = 0$). The alternative hypothesis is that the mean difference is not zero ($H_a : \mu \neq 0$). The t statistic is then given by:

$$t = \frac{\overline{D} - 0}{s_D / \sqrt{n}} \qquad (2)$$

where $\overline{D}$ is the average of the measured differences, s_D is the standard deviation of the differences, n is the number of data pairs, and the true mean (μ) difference is assumed to be zero. This is a 2-sided test, so when the absolute value of t exceeds a critical value for the given level of significance, H_0 must be rejected, meaning that the measurement is biased. Alternatively if |t| does not exceed the critical value, H_0 cannot be rejected, meaning that the measurement is unbiased. That is,

$$if \quad | \, t \, | > t_\alpha^*(n-1), \quad must\ reject\ H_0, \quad \mu \neq 0$$

$$if \quad | \, t \, | \leq t_\alpha^*(n-1), \quad cannot\ reject\ H_0, \quad \mu = 0 \qquad (3)$$

where $t_\alpha^*(n-1)$ is the critical value for the t distribution with n-1 degrees of freedom. For a 95 percent significance level, $\alpha = 0.025$.

In analyzing the data from this study, we will draw conclusions from sets of comparisons representing different component types, leak rates and operating parameters. These sets may be represented by different numbers of data pairs. In general, increasing the number of data pairs, will increase the level of variability that can be tolerated in detecting a given level of bias. As an example, a "worst case" of 15 data pairs will be considered. This is likely to be the minimum number of pairs from which conclusions will be drawn. Critical values are found using standard statistical tables. For example,

$$t_\alpha^* (15-1) = 2.145 \qquad \textbf{(4)}$$

To arrive at criteria for data quality, equations 2 and 3 are combined and the critical values in (4) are substituted as follows.

$$| \, t \, | = \frac{| \, \overline{D} \, | - 0}{s_D / \sqrt{15}} > t_\alpha^*(15-1) \quad 2.145 \qquad (5)$$

This expression is then evaluated to find the coefficient of variation (CV).

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$$CV = \frac{s_D}{|\overline{D}|} < 1.8 \qquad (6)$$

Equations 5 and 6 state that, for 15 data pairs, when the CV is less than 1.8, the critical t-value is exceeded: meaning that the HVCS measurements are biased at the 95 percent significance level. Similarly, when the CV is greater than or equal to 1.8, the HVCS measurements are unbiased.

The level of precision needed to detect a given level of bias can easily be determined from equation 6. For example, a 10 percent average difference between the HVCS measurement and the true value (D = 0.1) can be detected with precision as high as 18 percent (s = 0.18). Similarly, precision of 8.5 percent would be required to detect a bias of 5 percent. These results are consistent with the logic that more precise measurements are needed to distinguish results that are not far apart, and less precision can be tolerated when looking for larger differences.

2.2   DATA QUALITY REQUIREMENTS FOR HVCS AND BAGGING METHODS

The discussion above compares the HVCS measurements to a true, and unbiased, leak rate. In the field, however, the true leak rate will not be known. Instead, an EPA protocol bagging method will be used as the reference against which the quality of the HVCS data are to be assessed. The EPA protocol methods have wide acceptance; however, they are subject to some bias and variability. Error in the bagging measurements must be addressed explicitly. Laboratory testing using controlled representative leaks (see section 4.5) will be used to determine the magnitude and variability of the error in the bagging technique. The fractional error (bias) in the bagging data, B_E, can be expressed as:

$$B_E = \frac{B - T}{T} \qquad (7)$$

where, B is the bagging measurement and T is the true leak rate. Equations 1 and 7 can then be combined so that the difference between the HVCS measurement and the true value is expressed in terms of the value of the bagging measurement and its associated error, B_E.

$$D = \frac{H - T}{T} = \frac{H - B + B_E H}{B} \qquad (8)$$

The precision of the overall difference, s_D, is then propagated downward to obtain the precision required for the HVCS (H) and bagging (B) measurements. This is done by applying the standard formula for the propagation of errors (equation 9) where the result R is a function of N variables x_i (Clifford et. al., 1973) to equation 8.

$$\sigma_R^2 \quad \sum_{i=1}^{N} \left(\frac{\partial R}{\partial x_i}\right)^2 \sigma_{x_i}^2 \qquad (9)$$

This yields the following expression

$$\sigma_D \quad \frac{[(B_E + 1)^2 \sigma_H^2 + \left(\frac{B_E + 1}{B}\right)^2 H^2 \sigma_B^2 + H^2 \sigma_{B_E}^2]^{1/2}}{B} \qquad (10)$$

relating the precision of the difference between the HVCS and the true leak rate, σ_D, to the precision of the HVCS and bagging measurements, and the error in the bagging measurements (σ_H, σ_B, and σ_{BE}). It can be shown, however, that the relatively simple expression given by

$$\sigma_D \cong \left[\frac{\sigma_H^2}{H^2} + \frac{\sigma_B^2}{B^2}\right]^{1/2} \qquad (11)$$

closely approximates equation 10 so long as the variance of B_E is small, and H is of about the same magnitude as B. The approximation is valid even when the bias in the bagging measurements is fairly large (e.g., 20%).

Table 2-1 gives values for the precision of the HVCS and bagging measurements that must be attained to detect a 5, 10, and 15 percent bias in the HVCS measurement (with 95 percent significance). Values are given for comparisons with 125, 30, and 15 data pairs. The Table also gives the corresponding values for σ_D. The Table assumes that the bagging and HVCS measurements have the same precision ($\sigma_H = \sigma_B$); however, any combination of values for σ_H and σ_B that satisfies equation 11 will work.

Table 2-1 may be used to select objectives for the precision of the HVCS and bagging measurements that meet project objectives and are consistent with realistic measurement capabilities. Based on preliminary studies conducted by STAR environmental, the HVCS measurements should be repeatable to within at least ±20 percent. Based on previous studies, (EPA 1980d) the bagging measurement should also be repeatable to within about ±20 percent. At this general level of precision, and at a 95 percent significance level, a 5 percent bias in the HVCS measurement would be detectable for overall comparisons using 125 data pairs, a 10 percent bias would be detectable for comparisons using 30 data pairs (e.g., for a particular component type), and a 15 percent bias would be detectable for comparisons using 15 data pairs (e.g., for a particular component type and leak type). During the data analysis, the formulas given in this section will be used to calculate the detectable level of bias in the HVCS measurement (i.e., the sensitivity of the comparison) given actual measurement precision (determined from the laboratory testing) and the number of data pairs considered in the actual comparisons.

Table 2-1. Precision Requirements		
To Detect 5 Percent HVCS Bias		
Number of Data Pairs	Required HVCS/Bagging Precision (σ_H and σ_B)	Precision of Difference (σ_D)
125	**19.9 %**	28.2 %
30	9.5 %	13.4 %
15	6.4 %	9.0 %
To Detect 10 Percent HVCS Bias		
Number of Data Pairs	Required HVCS/Bagging Precision (σ_H and σ_B)	Precision of Difference (σ_D)
125	39.8 %	56.5 %
30	**19.0 %**	26.8 %
15	12.8%	18.1 %
To Detect 15 Percent HVCS Bias		
Number of Data Pairs	HVCS/Bagging Precision (σ_H and σ_B)	Precision of Difference (σ_D)
125	59.7 %	84.8 %
30	28.5 %	40.2 %
15	**19.2 %**	27.1 %

2.3   DATA QUALITY OBJECTIVES FOR DIRECT MEASUREMENTS

This section completes the discussion of data quality objectives by specifying objectives for each of the direct measurements that will be made in the field study. The reasons for the selection of the data quality objectives are discussed in each case. In the case of the flow and concentration measurements that make up the HVCS and bagging results, data quality objectives are developed using a formal propagation of errors. In other cases, the justification relies simply on consideration of data quality requirements in light of study goals. Data quality objectives for the overall sampling/analytical methods and for the direct measurements are summarized in Table 2-2.

2.3.1 HVCS and Bagging Emissions Measurements

The HVCS and bagging results are calculated from flow rate and concentration measurements. For the HVCS measurement, flow is measured by rotameters and concentration is measured by a portable FID (Foxboro OVA 108). For the bagging measurements, flow will be measured by a bubble flowmeter and concentration will be measured by GC analysis. The leak rate is equal to the product of flow rate and concentration. By applying the standard formula for propagating errors (see equation 9), the standard error in the leak rate can be expressed in terms of the error in the flow and concentration measurements as follows:

$$L = FC, \qquad \frac{\sigma_L}{L} = \left[\frac{\sigma_F^2}{F^2} + \frac{\sigma_C^2}{C^2} \right]^{1/2} \tag{12}$$

where, L is the leak rate, F is the flow rate, and C is the concentration. That is, the fractional error in the leak rate is proportional to the square root of the sum of the squares of the fractional errors in the flow and concentration measurements. If bias in the flow and concentration measurements is expressed simply as the ratio of the measured value to the true value, then the fractional bias in the overall leak rate L_E is given simply as the product of the bias in the flow and concentration measurements, F_E and C_E minus one.

$$if \; F_E \; \frac{F}{F_T}, \; and \; C_E = \frac{C}{C_T}$$

$$L_E = \frac{L \;\; L_T}{L_T} \quad \frac{L}{L_T} \quad 1 \quad \frac{FC}{F_T C_T} \quad 1 \quad F_E C_E - 1 \tag{13}$$

For the bagging measurements, the bubble meter flow determinations are accurate and repeatable within at least 1.0 percent (according to manufacturer specifications). Allowing for flow measurement error due to differences in the sampling set up and potential leakage, flow measurements are still expected to be accurate and repeatable within 10 percent. Total hydrocarbon concentrations (as methane) measured with the GC should be accurate to within 10 percent and repeatable within 5 percent (according to Method 18). Applying equation 12, precision for the overall bagging measurement is expected to be within about 12 percent. This is well within the level of precision required for the study (see section 2.2). Applying equation 13, bias in the bagging measurements should be within 20 percent. If proper sampling technique is used, the bagging method is expected to capture all of the leaking gas. As discussed above (section 2.2), this amount of bias in the bagging measurements can be easily tolerated so long as it is quantified and remains fairly consistent. The actual precision and bias for the bagging measurements will be determined in the laboratory studies.

In a key study assessing the emissions from petroleum refining conducted in the late 1970's, (EPA, 1980c) a quality assurance program was implemented to assess the analytical and overall precision and accuracy of the bagging method. In this case, the vacuum bag apparatus was

used. The apparatus was challenged with standard gases in a well defined QA protocol of sample recovery tests. The precision of the sampling and analytical systems (standard deviation for sampling and analysis of standard gases) was about 17 percent with no significant bias. A precision of about 2.4 percent was achieved by the analytical system (GC) alone. It is important to note that these tests involved only introducing standard gases into the sampling apparatus and they do not reflect any variability or bias associated with the sampling enclosure. It is also noteworthy that the 17 percent precision achieved in these studies is comparable to (but higher than) the 12 percent expected precision based on the calculations presented above. In the same study, repeat analyses of the same components were also conducted. This yielded a precision of only about 40 percent. Much of the difference was attributed to short term variations in leak rates for the sampled components with some of the variation being attributed to operator effects.

Since evaluating the precision and accuracy of the HVCS measurement is the purpose of the study it may seem out of place to specify data quality objectives for the HVCS. However, it is possible to estimate part of the expected error in the HVCS measurement by the same means used above. For the HVCS measurements, the rotameter flows are accurate and repeatable to within at least 5 percent according to manufacturer's specifications (2 percent or better) and including expected human reading error. The OVA concentration measurements should be accurate and repeatable within at least 15 percent. While the portable analyzers are known to drift by more than 15 percent under some conditions, accuracy and precision of 15 percent or better can reliably be maintained in the field if frequent calibration checks are implemented. For the HVCS measurements, calibrations will be repeated before and after each set of measurements. Applying equation 12, precision for the HVCS leak rate determinations should be within 16 percent. Similarly, the bias in the HVCS measurements should remain within about 20 percent (equation 13). Note that this does not account for sampling error that would occur when the HVCS fails to capture the entire leak.

A total of about 125 bagging measurements are planned for the study. Since it is important that a representative sample of HVCS/bagging data pairs are collected, a completeness criteria of 95 percent will be the objective. A total of 200 HVCS measurements are planned, but only 125 of these same components will also be selected for bagging. The excess HVCS measurements are to allow flexibility in selecting a representative sample of components for the HVCS/bagging comparisons. A data quality objective of 90 percent valid HVCS measurements (for a total of 180) should be sufficient to meet the study objectives.

2.3.2 Screening Measurements

The screening measurements will serve two purposes for the study. The first, and primary purpose of the screening data is to identify leaking components and classify the components in terms of their leak rate (based on the instrument screening value, or ISV). The secondary use of the screening data is to develop emission rates based on EPA protocol emission factors and correlation equations. The EPA protocol emission rate will later be compared to the emission rate measured directly by the HVCS and bagging methods. These purposes will be served if the precision and accuracy of the screening measurements are maintained within ±20 percent. Based on experience, it is reasonable to expect these objectives will be met in the field. Actual

precision and accuracy during field measurements will be documented based on frequent calibrations and quality checks (see section 3 and 4.1). If proper procedures are followed, it should be possible to obtain valid screening values for more than 90 percent of screened components.

2.3.3 Gas Chromatography

Measurement of the concentrations of the major constituents of the gas samples will be used to characterize the gas streams encountered during the study. EPA's Reference Method 18, *Measurement of Gaseous Organic Compound Emissions by Gas Chromatography* will be the guideline for conducting the speciated measurements. According to Reference Method 18, precision of 5 percent and accuracy of 10 percent should be achievable by a skilled GC operator. A total of 50 valid speciation profiles will be obtained for 100 percent data capture. Additional samples will be analyzed to make up for any samples that are invalidated.

Table 2-2. Data Quality Objectives					
Measurement Type	Method or Device	Number	Completeness	Precision	Accuracy
Method 21 Screening	Foxboro OVA 108	up to 25,000	90 %	20 %	20 %
HVCS Emissions Measurements	STAR HVCS	200	90 %	(16 %)*	(20 %)*
Flow	Rotameters	200	90 %	5 %	5 %
Concentration	Foxboro OVA 108	200	90 %	15 %	15 %
EPA Protocol Emissions Measurements	Tent/Bag	125	95 %	12 %	20 %
Flow	Rotameter	125	95 %	10 %	10%
Concentration	GC/FID/TCD HP5890	125	95 %	5 %	10 %
Speciated Measurements	GC/FID/TCD HP5890	50	100 %	5 %	10 %

SECTION 3
DATA QUALITY INDICATORS

Data quality objectives for each measurement were developed and presented in the previous section. Data quality objectives specify values of key data quality indicators that must be attained in order to draw conclusions at a given level of confidence. This section describes how values for each of the data quality indicators will be established.

3.1   COMPLETENESS

Completeness is a measure of the amount of valid data obtained compared to the amount required to satisfy the study objectives. Completeness is established based on a count of valid data remaining after data validation is completed (see section 5.2).

3.2   PRECISION

Precision is a measure of the repeatability of a measurement and is generally expressed as an average deviation from a mean value (or standard deviation) when repeated measurements of the same quantity are performed. Analytical precision is normally determined based on repeat measurement of a known standard. Overall precision is generally comprised of sampling and analytical components. Overall precision is more difficult to determine and is generally addressed in a manner specific to the sampling/analytical system used.

For the bagging measurements, analytical precision will be determined as the standard deviation of the difference (normalized for changes in standard concentration) between GC response and gas standard concentration for the calibrations and quality control checks associated with a sample run. Each sample run will be bracketed by multipoint calibrations (3 upscale points) and will include the introduction of at least 1 QC standard during the analyses for a total of at least 7 data points to be used in determining the precision for the run. In general, a sample run will consist of one day's measurements and approximately 10 samples. Overall analytical precision for the study will also be calculated based on all calibrations and QC checks that were performed. Overall precision for the bagging measurements will be determined based on controlled leak studies and field controlled leak tests (see section 4.5).

For the HVCS measurements, analytical precision will be determined as the standard deviation of the difference (normalized for changes in standard concentration) between the portable analyzer response (Foxboro OVA 108) and certified standard gas concentrations. Each HVCS measurement will be bracketed by multipoint calibrations of the portable analyzer. It is expected that at least 12 HVCS determinations will be completed in the field per day. Precision will be determined on a daily basis and reported separately for each portable analyzer used for HVCS leak rate determinations. Since a sufficient number of comparisons will be available, precision will be reported at each of the 3 upscale standard levels. Overall precision for the HVCS measurements will be determined based on controlled leak studies and field controlled leak tests

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(see section 4.5). Precision of the screening measurements will be based on daily pre-test and post-test multipoint calibrations (for each analyzer) and calculated in the same manner. Calibration precision for each portable analyzer based on Method 21 performance tests will also be reported.

3.3   ACCURACY

Accuracy is a measure of the ability of a measurement to obtain the true value for the quantity being measured and is also known as bias. Accuracy determinations must be based on comparisons with known standards. Overall accuracy is comprised of sampling and analytical components. Accuracy is generally expressed as the average difference from the standard value expressed as a fraction (or percentage) of the standard value. This is also the calculation that will be used in this study.

For the bagging measurements, analytical accuracy will be determined on a daily basis as the average difference between GC response and standard gas concentration values based on the 7 comparisons with standard gases (see section 3.2). The overall accuracy of the bagging measurements will be determined based on the controlled leak studies and field controlled leak tests. The overall fractional bias in the bagging measurements is expressed in equation 7 (section 2.2).

For the HVCS measurements, analytical accuracy will be determined on a daily basis for each analyzer based on frequent multipoint calibrations. The overall accuracy of the HVCS measurement will be determined in the controlled leak testing and in the field testing. In the controlled leak testing, HVCS bias will be assessed in the conventional manner (against a known leak rate). The overall field bias in the HVCS measurements is expressed in equations 1 and 8 (section 2), and depends on the bias in the bagging measurements (B_E in equation 8) since, in the field, the bagging measurements are the reference against which the HVCS performance will be assessed.

The accuracy of the screening measurements will be determined based on daily pre-test and post-test multipoint calibrations for each portable analyzer and reported as the average difference between the analyzer response and certified gas concentration.

3.4   REPRESENTATIVENESS

Representativeness is a measure of the extent to which a measurement or measurements program represents the true quantities that are intended to be measured. Representativeness is generally addressed in terms of the study design and sampling plan. In this study, the objective is to evaluate the performance of the HVCS measurement systems and methodology under field conditions at gas production facilities. Thus, it is important to challenge HVCS performance for a range of component types, leak rates, and operating conditions that

satisfactorily characterizes leaking components at these types of facilities. The overall study design, sampling plan, and field operations have been conceived with this goal in mind.

The expected population of leaking components at gas production fields is described in recent screening work conducted by GRI (GRI, 1994) and API (API, 1993) at gas production fields in the Eastern and Western United States. This work was conducted at 14 gas production fields in the Louisiana and Appalachian regions of the Eastern United States, and 4 additional sites in the West. In this work, over 65,000 components were screened and nearly 3,000 leaking components were identified. The majority of leaking components (about 58 percent overall, 80 percent in the east, and 51 percent in the west) were among connectors. These were primarily threaded couplings 2 to 4 inches in diameter. Most of the remaining leaking components were valves (about 32 percent overall, 18 percent in the east, and 35 percent in the west). These were primarily smaller valves (2 inches and below) with 1/4 inch to 1/2 inch valve stems. There were also a fairly large number of leaking open ended lines pressure relief valves, and other miscellaneous components. Operating pressures associated with the majority of leaking components are 30 to 50 psi in the East and 200 to 400 psi in the West. The Louisiana sites are high pressure fields (2,000 to 3,000 psi) where much larger components are used (8 to 20 inches). However, these sites contained a very small number of leaking components. In general, valves and open ended lines were associated with the highest emissions (based primarily on screening values).

The controlled leak test bed will be constructed to represent this general population of leaking components (see section 4.5.1). The equipment inventory and screening values obtained in this study will provide information that will be used to assess the representativeness of the HVCS and bagging measurements in terms of the number and type of components, leak rates, and operating parameters (*e.g.,* pressure). The study report will include an analysis of representativeness based on these data.

3.5   COMPARABILITY

Comparability is a measure of the confidence with which one set of data can be compared with another. Comparability is generally established by ensuring that the data collected are of known quality through the use of QA planning, calibrations and quality control checks, audits and the determination of data quality indicators. Only validated data sets should be compared. Comparability may also be established through the use of equivalent sampling and analysis methods and procedures.

Many of the conclusions that will be drawn from this study will be based on comparisons between HVCS and bagging data pairs for the same component. It is important that the comparability of these data pairs is carefully established. For example, a change in leak rate between the two measurements would introduce an unwanted (and unquantified) bias into the comparison. To help ensure that the leak rate remains constant, the HVCS and bagging measurements will be made as close together in time as possible (the goal will be within 2 hours). In addition, screening values will be obtained before and after both bagging and HVCS measurements. Data

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screening procedures will include examination of the associated screening values and sampling times before the data are compared.

It is also important for this study that the conventional bagging and screening measurements be conducted in a manner that is equivalent to similar measurements that have been conducted in several previous studies involving many facilities, and hundreds of thousands of components. To ensure that this is accomplished, sampling and analytical procedures will be consistent with EPA standard reference methods (Method 21 and Method 18) and the EPA Protocol For Equipment Leak Emissions Estimates where the bagging methods are set forth.

SECTION 4
SAMPLING AND ANALYTICAL PROCEDURES

This section describes the sampling and analytical procedures to be used in the performance evaluation of the HVCS device and emissions measurement methodology. Detailed operating procedures, where necessary, are provided in the appendices or incorporated by reference to EPA Standard Methods and Protocol Documents. This section is subdivided according to the different measurements that will be made for this study.

4.1   COMPONENT SCREENING

The primary purpose of the screening measurements in this study is to identify leaking components and categorize them according to leak rate as indicated by concentration measurements in the vicinity of the component with a portable hydrocarbon analyzer. These measurements are known as instrument screening values or ISV's. Screening values will also be obtained before and after each HVCS and bagging measurement. These data will be used as an indication of whether the leak rate for that component changed during the measurement, or between the HVCS and bagging measurements.

Up to 25,000 components will be screened at two to three sites selected by EPA in conjunction with the American Petroleum Institute (API) and the Gas Research Institute (GRI). Experience from recent studies at Gulf and Appalachian gas production fields conducted by STAR Environmental on behalf of GRI indicate that screening 25,000 components can be expected to yield 400 to 600 small leaks (screening value less than 1000 ppm), 300 to 400 medium leaks (screening value less than 10,000 ppm), 200 to 300 large leaks (screening value greater than 10,000 ppm) and perhaps 20 very large leaks (screening value greater than 100,000 ppm). Leaking components will be classified by equipment type, type of service, and process location.

4.1.1   Screening Method Description
EPA Reference Method 21 specifies requirements for the use of portable analyzers to identify and categorize leaking components. Method 21 also gives procedures for operating a portable analyzer and for obtaining representative screening values. The description of Method 21 in the 40 Code of Federal Regulations (CFR) Part 60, Subpart A is short (2 pages). A companion document titled "Protocol for Equipment Leak Emission Estimates" (EPA-453/R-93-026) provides more detailed instructions for how to screen specific component types. The instrument screening value (ISV) is the maximum calibrated response (specific to a given calibration gas) of a portable hydrocarbon analyzer when the inlet is placed in the vicinity of a VOC leak. The ISV can be generally correlated with a mass emission rate as averaged over a relatively large number of components; however, an ISV is not necessarily closely related to the leak rate for any given component. Initially, a leaking component will be defined as yielding an ISV of more than 10 parts-per-million (ppm) above the ambient air response. This threshold may be revised if large numbers of leaking components are identified at this level.

Method 21 allows that any portable instrument that meets general performance criteria can be used. The Foxboro Model 108 Organic Vapor Analyzer (OVA) is commonly used for Method 21

screening and will also be used for this project. The Model 108 OVA was designed to be a portable instrument. The main component which houses the controls, pump, detector, battery and electronics, are worn on a strap over the operators shoulder. The sampling probe and analog meter output are located on a remote sampling head which is tethered to the main component by an umbilical. This permits the operator to view the response of the instrument quickly as the screening work is performed. The range of the Model 108 is from 1 to 10,000 parts ppm when the analyzer is calibrated for methane gas. The electrical signal output of the Foxboro Model 108 is proportional to the log of the gas concentration in the range of 1 to 10,000 ppm. The sweep of the analyzer's analog meter is 270 degrees with 100 ppm set at midscale in the twelve o'clock position. This analyzer uses the flame ionization detection (FID) principle, which is highly sensitive to trace organics in ambient air. In the FID, hydrocarbon containing molecules are combusted in a hydrogen flame. This combustion of the hydrocarbon generates ions which conduct a small (picoampere) electrical current. The current generated between the high voltage positively charged burner tip and the negatively charged collector located above the burner tip is responsive to the number of ions present.

Method 21 lists specific types of components such as valves, flanges and pressure relief vents etc. that are to be checked for fugitive emissions. The method describes the particular mechanical features of each component and highlights the specific areas to check with the screening analyzer. In most instances, the VOC escapes from a mechanical seal within the component. These would be the packing materials used around a valve stem, the seals around a pump or compressor, or an open ended line downstream of a valve or pressure relief device. Method 21 also describes proper measurement technique, such as the positioning of the analyzer relative to the component.

4.1.2 Screening Test Procedures
The daily operation of the portable OVA 108 analyzers is described in this section. In accordance with Method 21, the analyzers will be prepared for use by following the manufacturer's operational instructions. The important features of these instructions include replenishment of the hydrogen fuel for the analyzer's detector and positioning of the control switches for the power-up of the pump and electronic components. The analyzer's detector is ignited by depressing the ignite switch and watching the signal displayed on the analog meter for a positive short duration response. After successful ignition of the detector, the analyzers can be disconnected from their battery chargers. After ignition the analyzers should be allowed approximately ten minutes to stabilize.

The daily calibration of the OVA will be performed by introducing a zero gas followed by a span gas, with adjustment of the electronic gain of the amplifier so that the analyzer's display meter matches the concentration of the span gas. Additional mid-point span gases at lower concentrations than the first span gas can be used to verify the linearity and calibration of the analyzer. No adjustment of the analyzers response is made to these mid-point span gases. The first calibration of the day is a full multi-point calibration. Additional zero and single-point span checks will be performed at the midpoint of the days activities, or whenever deemed necessary by the operator. All data are recorded on standardized data sheets (see Appendix B).

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At the start of each day, each operator will be assigned groups of components by the field coordinator. A component inventory, process flow diagram, or production field map will be used to assign the components and direct the operators to the correct locations. Approximately 50 components are expected to be screened per hour. The operator will record the data generated during the screening activities on standardized field data sheets. The list of items on the field data sheets will include the facility name, date, time, component and process ID from the process map or inventory list, type of component and initial screening value. An example data sheet is provided in Appendix B. At the completion of daily screening activities, the analyzers will be recalibrated, serviced and returned to battery chargers for the night. The data sheets will be reviewed by the field supervisor on a daily basis for completeness and accuracy.

4.1.3 Screening QA/QC Procedures

Prior to the start of screening activity, each analyzer will be tested to show compliance with the performance criteria specified in Method 21. These criteria include a calibration precision test with alternating zero and hi-span gases, measurement of sample demand rate and a response time test. The precision test, sample demand and response time tests need not be repeated on a daily basis, unless a mechanical change such as replacement of a pump has occurred and that would require these tests to be repeated. Other checks such as battery condition, fuel supply and condition of required safety equipment will be noted daily for project records as part of the morning calibration. Problems will be noted on the log sheets, reported immediately to the field coordinator, and appropriate corrective actions will be taken, including repair or replacement of the analyzer.

Calibration gases of ±2 percent certified by the manufacturer are sufficient to meet the requirements of this study as well as Method 21 and will be used. Copies of the gas certifications will be maintained in project files, available for inspection. The calibration gas concentrations will be approximately 100, 1,000, and 9000 parts per million of methane in hydrocarbon free air. These calibration gases will be contained in high pressure cylinders and delivered at approximately 1.1 times the total analyzer demand rate at atmospheric pressure using a flow-through manifold. The analyzers will draw off their own supply of calibration gas and the excess will be vented through a rotameter. The rotameter will be used to monitor and maintain calibration gas flow rates through the manifold system. If an analyzer has drifted by more than 20 percent beyond its precalibration response, the data collected will be considered suspect. Components will be flagged for re-screening if the drift was sufficient that leaking components would have been incorrectly identified (at the 10 ppm level). In most cases, the drift will be downward so, components with screening values close to 12 ppm would be re-screened. In other cases, a downwardly biased screening value would result only in some components being miscategorized, for example, from large to medium, or medium to small. This should not have a serious adverse impact on the study unless large numbers of components are miscategorized.

The OVA 108 analyzers use the same sample air that is being analyzed by the FID detector to combust the hydrogen flame in the detector. If a very high concentration source is suddenly discovered during screening, the lack of oxygen in the sample stream will extinguish the flame. If flame out of the FID occurs during screening activities because of momentary oxygen starvation, the operators will perform only a single point calibration check using the 1000 ppm

span gas (this concentration is reliably read on the logarithmic analyzer readout). If the response of the analyzer is within 10 percent of the span gas concentration, screening operations will continue. If the response differs by more than 10 percent, the operator will return the analyzer for a complete multipoint recalibration. Flameouts caused by moisture or contamination entering the probe will require servicing the OVA analyzer. This situation will be apparent if the flame cannot be re-ignited or if a major baseline shift occurs.

4.2   HVCS MEASUREMENTS

The High Volume Collection System (HVCS) has been developed by Star Environmental to provide a rapid, simple, and cost-effective approach to getting direct measurements of mass emission rates without the need for tenting and bagging. The field performance of the HVCS is being tested in this project. This performance evaluation is based on direct comparisons of HVCS measurements against EPA Protocol bagging measurements. (The tent and bag procedures are described in the section 4.3) Emissions from a total of 200 leaking components will be measured using the HVCS. 125 of these 200 components for will be selected for direct checks against EPA protocol tent and bag procedures.

4.2.1   HVCS Description

In both the HVCS and bagging measurements, emissions from a leaking component are determined by capturing the leaking gas in a known volume of carrier gas and measuring the pollutant concentration in the carrier gas. The emission rate is the product of the flow rate and the concentration. The HVCS generates a fast-moving slip stream of ambient air around a leaking component. Fugitive emissions are entrained in this slip stream for measurement. The HVCS is a portable dynamic dilution device that is fitted to the regular sample probe of the Model 108 OVA. It uses a battery operated pump coupled with three calibrated rotameters (2 to 20, 20 to 100 and 100 to 1000 scfh) to draw a known volume of ambient air across a leaking component at flow rates between 10 and 500 standard cubic feet per hour (SCFH). Sample flow rates through the rotameters are metered by means of valves on the three rotameters. The FID measures the VOC concentration in the diluted air. The output of the FID is measured with a small digital voltmeter attached to the recorder output jack of the Model 108. This voltage is proportional to the log of the concentration. Obtaining the OVA output as a voltage from the recorder jack allows for concentration measurements somewhat in excess of full scale (10,000 ppm) up to about 17,000 ppm to be obtained.

Measurements at more than one HVCS flow rate are performed to verify the capture efficiency of the system. VOC concentration will increase as the airflow across the leaking component is reduced. If all of the leaking gas is captured, the same leak rate should be obtained for different air flows. To aid in the capture of the fugitives, the sample inlet of the HVCS probe is shaped like mouthpiece of a snorkel and it is held in close proximity to the leaking component. The capture efficiency for large (>4"pipe flanges) of the Star HVCS may be enhanced by shielding the component with mylar film so that the airflow is directed across the entire leaking surface. Further information on the HVCS is available in the Protocol For Using HVCS by Star Environmental (see Appendix A). Star has also produced a draft report on preliminary laboratory and field testing of the HVCS that contains some details of HVCS design and operation.

4.2.2   HVCS Test Procedures

This section describes the daily operation of the HVCS in the field. Detailed operating procedures are presented in Star Environmental's Protocol for Using HVCS (Appendix A). Initial preparations for using the HVCS include calibration of the rotameters against traceable flow standards (dry gas meters) and Method 21 performance checks on the OVA. The HVCS testing will begin when screening work has identified a sufficient number of leaking components. Daily Preparation of the HVCS includes a leak check, and checking battery condition.

Before and after each HVCS measurement, a screening value for the component is obtained (see section 4.1). Screening also serves to identify the location of the leak as indicated by the point at which the maximum OVA reading is obtained. For HVCS measurements, multipoint calibrations are performed before and after each emissions determination. This is to ensure that the optimum accuracy of the portable analyzer is attained. Prior to making HVCS measurements, background readings are taken in the vicinity of the leaking component. HVCS measurements are then made at 3 flow rate settings. The first setting uses the highest possible flow rate, yielding a concentration close to the lowest calibration standard. The other flow settings are selected so that the concentration reading is close to the mid and low calibration standard values. For very high leak rates, the range of the OVA (10,000 ppm) may be exceeded, even at the highest flow setting. In such cases, the OVA 108 dilution probe adaptor supplied by the manufacturer can be used in making the HVCS measurements.   This provides dilution ratios between 10 and 150 and extends the OVA range up to 1,000,000 ppm (100 percent). It is important that the dilution air is drawn from a point away from sources of hydrocarbon. This should be verified with a background reading near the dilution air inlet. Finally, the HVCS is again leak checked at the conclusion of daily activities. Data will be recorded on standardized field data sheets (see Appendix B).

4.2.3   HVCS QA/QC Procedures

The same QA/QC requirements that apply to the operation of the OVA 108 FID during the screening work will still apply during the HVCS phase.

The rotameters used in the HVCS will be subjected to three point calibrations against a flow standard (dry gas meter) traceable to a primary standard (spirometer) before and after the test program to verify the engraved markings of the manufacturer. Care should be taken to avoid particulate contamination of the HVCS inlet as any debris that clings to the rotameter ball or inside walls affects the accuracy of the rotameter.   Other visual qualitative checks of the HVCS should be concerned with battery condition, sample line leaks and residual organic contamination.

If results of post measurement OVA calibrations indicate a change of more than 15 percent for any point from pre-measurement results, the measurement will be repeated. If acceptable results cannot be obtained, a problem is indicated. This will be documented and corrective actions will be initiated.

During the field studies, at least 3 controlled leak rate tests will be conducted at each site (before, during, and after testing). If there is more than one HVCS operator, each operator will complete

the same number of tests (3). These will be blind tests. The results will be used to assess operator bias and to identify problems with the performance of the overall HVCS system.

The HVCS results will be compared against the bagging results for the same components as the study is underway. It is expected that emission rates for the two systems should agree to within about 20 percent. If the two methods do not agree to within 20 percent, every effort will be made to independently verify the procedures and measurement accuracy of each individual method. The results from the laboratory study will provide performance baselines for the two methods.

4.3   EPA PROTOCOL MASS EMISSIONS (BAGGING) MEASUREMENTS

The bagging measurements are the reference against which the field performance of the HVCS system will be assessed in this study. Emissions from a total of 125 components will be measured by bagging for direct comparison against HVCS measurement of emissions from the same components. The "Blow-Through" bagging method recommended in the EPA protocol will be used in this study. The "Blow-Through" method was selected primarily because of the simpler sampling train. Nitrogen will be used as the carrier gas for the bagging measurements. This will prevent the possibility of explosive atmospheres in the sampling bags. The EPA protocol Document (Section 4.2) provides a detailed discussion of the comparative advantages of the "Blow-Through", and the alternative "Vacuum bag" methods.

4.3.1   Bagging Measurement Description

Like the HVCS measurement, the bagging measurement is based on measuring a pollutant concentration in a known flow of carrier gas. Essentially, the product of the flow rate and the concentration is the leak rate. A detailed description of the "Blow-Through" sampling method is given in section 4.2 of the EPA Protocol. In general, the leaking component and leak location are first identified based on method 21 screening. The leak is enclosed by constructing a tent of a non-porous film that is also chemically inert relative to the leaking compounds to be measured. The tent is secured in place using adhesive tape, rope or clamps. The diluent gas is introduced at one or more openings in the tent as necessary to ensure good mixing. Another opening is used as the sampling port. The oxygen concentration in the effluent from the tent is measured as an indicator of when the initial air in the enclosure has been displaced by the carrier gas. Since it can take a long time to completely displace the air in the tent, the protocol provides for correcting the effluent flow rate based on the remaining oxygen level at the time of sampling. The tent should be purged long enough for oxygen levels to fall below 5 percent (by volume). Percent oxygen levels will be monitored using a portable infrared analyzer (Geo-Group Infrared Gas Analyzer). Analysis of the sampled hydrocarbon is performed by gas chromatography (see section 4.4).

4.3.2 Bag Sampling Procedures

Detailed sampling procedures for the "Blow-Through" method are given in section 4.2 of the EPA Protocol. These will be followed closely. Analytical procedures for the bagging measurements are discussed in section 4.4. The following is a general description of the sequence of events in the bag sampling procedure. First, the selected component is re-screened following Method 21 to obtain a new screening value and identify (as closely as possible) the exact location of the leak. A tent is then constructed over the area of the leak. Carrier gas is introduced at a steady flow rate. The flow rate should be sufficient to establish an equilibrium with the leaking gas in the bag, but not so large that the hydrocarbon concentration in the samples is below the detection limit of the analyzer. The portable OVA used for screening can be used to monitor the hydrocarbon concentration in the effluent from the bag while selecting a suitable flow. Concentrations should be within the calibration range selected for the analyzer (see section 4.4). In general, flow rates of less than 60 lpm will be used. Sufficient time is allowed for mixing of the carrier gas with the pollutant in the bag and for purging of ambient air remaining in the bag. Mixing can be verified by probing at various locations in the bag with the portable analyzer. Oxygen levels are monitored to determine when sufficient purging has taken place. Once the tent is equilibrated, two Mylar sample bags (1-2 liters) are filled from the effluent stream using a portable sampling pump and transported to the field laboratory for analysis. These bags will be nitrogen purged before use. Analysis should take place within 2 hour of sample collection. All readings, sampling conditions, and notes are recorded on standardized data forms. One form is used for each sample.

4.3.3 QA/QC for Bag Sampling

Quality assurance considerations and quality control checks for the bag sampling protocols are addressed in detail in the EPA Protocol. Some additional general considerations are mentioned here. Leak enclosures do not have to be leak tight, but should be tight enough to ensure that equilibration is maintained. In situations where leaks are suspected, the portable analyzer can be used to screen the edges of the enclosure. Enclosures and sampling bags will be constructed of Mylar. In most cases, enclosure materials will not be re-used; however sample bags will be re-used. Sample bags will be purged after each use at least twice with clean nitrogen gas. Purge gas from a portion of the bags will be analyzed by GC to verify the integrity of the purging procedure. During purging, the sample bags will be checked for leaks, and leaking bags repaired or discarded. The integrity of the diluent gas in each bottle purchased will also be verified by GC analysis. Sample bag preparation activities will be logged.

Field leak rate checks will be conducted at least 3 times per field trip by each bagging technician. Field leak rate checks will be conducted by performing the complete bagging operation on a component with a controlled leak rate as described in section 4.5. These will be blind checks. These checks will test the overall sampling, analytical, and field operation components of the measurement. Corrective action will be called for when the field leak rate test is unable to reproduce the true leak rate within 20 percent.

Quality assurance procedures also include calibrations of all measuring devices used in the procedure. Flows will be measured using a calibrated rotameter (4 to 40 lpm). The rotameter will be calibrated at the beginning and end of the field program against a dry gas meter traceable

to a primary standard (spirometer). The response of the oxygen meter will be checked against a zero (pure nitrogen gas) and standard atmospheric oxygen levels (21 percent). Factory calibrations will be relied on for the temperature probe. Calibration of the GC is addressed in section 4.4.

4.4   GAS CHROMATOGRAPHY

The 125 bagged samples collected during the mass emission sampling will be analyzed by gas chromatography to determine methane and total hydrocarbon concentration. Fifty of these samples will be further speciated to determine light hydrocarbons that comprise the bulk of the material found in gas production facilities (ethane, propane, and n-butane). This will allow for a more accurate determination of the actual emission rate as opposed to determining the emissions solely as methane. EPA Reference Method 18 is frequently used for source emission and ambient air testing to speciate and quantify selected organics using Gas Chromatography (GC). The description and procedures for Method 18 in the Federal register are basic procedures considering the wide variety of techniques available to skilled chromatographers. Reference Method 18 will be used in this project as a basis for all analyses by gas chromatography.

4.4.1 Gas Chromatography Description
In gas chromatography individual compounds from a sample are separated according to selected physical properties and introduced sequentially to one or more detectors. A small quantity of a sample mixture is injected onto the inlet of a chromatographic column. An inert carrier gas flows through the column and the interaction of a carrier gas working against the effect of the column causes the compounds to separate and elute at discrete intervals over a given time period. The sequential elutions of compounds are sensed by a calibrated detector and the output is directed to a recording device or integrator. The integrator displays the chromatogram as a series of spikes rising above a baseline and calculates an area for each of the peaks. The retention times of the compounds are given by the integrator and these are used to identify the compounds. Commonly used detectors include the Flame Ionization Detector (FID) which is highly specific and linear for part-per-million level organics and the Thermal Conductivity Detector (TCD) which is sensitive to percent level changes in gas compositions. Quantifications are based on compound specific calibrations of detector response.

EPA Reference Method 18 lays out general guidelines for developing specific sampling, analysis and quality assurance procedures for a given measurement program. The procedures for Method 18 are given in 40 CFR Part 60, Subpart A. The quality assurance guide for Method 18 is part of the EPA Quality Assurance Handbook for Air Pollution Measurement Systems, Volume III for Stationary Source Specific Methods (EPA-600/4-77-027c). These documents will be used directly as a guide for chromatographic measurements conducted for this project. Method 18 permits different analytical components such as detectors and chromatographic columns, as well as different sampling techniques/interfaces to be used. The method allows for expert judgement on the part of the GC operator in selecting the most appropriate equipment and procedures. Details of the Method 18 configurations intended for this project are presented below as part of the test procedures.

4.4.2 Method 18 Test Procedures

Method 18 describes a start-to-finish approach for conducting gas chromatographic analysis of samples starting with a pre-survey sampling phase and an analytical development phase, before the actual measurement phase. The compounds of interest in this project are methane and other light hydrocarbons. Chromatographic methods for methane analysis are well established with multiple published references. Thus, there is no need to conduct presampling and analytical developmental phases for this project.

The GC to be used in this project is a Hewlett Packard Model 5890 Series II GC. The data output from the GC will be directed to a Hewlett Packard Model 3396B dual channel integrator. The integrator accepts data simultaneously on two channels, displaying real-time data of one channel and electronically buffering the second channel for immediate printing after the completion of the sample run. The FID and TCD detectors intended for use in this project will permit the analysis of gas species over the widest of anticipated concentrations, from high part-per-billion concentrations of organics to percent concentrations with the fixed gases. Chromatographic columns have been selected according to published guidelines and vendor literature with prime consideration given to the resolvability of the expected compounds and durability under adverse conditions. The packed type chromatographic columns selected for this project are Haysep D porous carbosieves in 10' by 1/8" and 30' x 1/8" metal tubing. The carrier gas will be high purity helium. Column flows and programmed oven temperatures will be decided by initial test experiments to give the best compound separations with rapid sample turn-around-time.

A Valco brand ten port gas sampling valve with two independent fixed size sample loops will be used on the GC to introduce the sample simultaneously to different packed columns and both detectors. The advantage in using the gas valve and sample loop is the elimination of manual syringe injections and associated imprecision. The zero plus three upscale calibration gases used for the GC/FID will be the same 100, 1000 and 9000 ppm methane in air cylinders used for the Method 21 OVA analyzers. Higher concentrations of methane in air, if needed for the FID, will be obtained using dynamic blending of pure standards and diluent gases as described in Method 18. Method 18 does not specify a detection range of target calibration gas concentrations, but only requires that the concentrations of calibration standards bracket the expected sample concentrations. The linearity of the FID, over a wide range of concentrations, will be established using multiple methane concentrations. Factory specifications list FID midscale error at less than 10 percent over a range of 10^7 in concentration. Since the target test facilities for this study are natural gas production facilities, methane is the component of most importance. The FID will be calibrated for other light volatile organics (ethane, propane and n-butane) using two additional standards. The calibration of the GC will be accomplished by performing a least squares linear regression of the GC response or area counts (AC) against the concentrations of the calibration standards in parts per million (ppm). Estimation of the minimum detectable limits of the GC will be the intercept generated by the least squares linear regression divided by the slope of the regression. Calibration of the TCD will be accomplished using dynamic dilution of air or nitrogen or methane with helium to generate three different percent concentration standards. Factory specifications list TCD midscale error at less than 5 percent over a range of 10^5 in concentration. Multipoint calibration of the GC/FID/TCD will be performed daily, before and after the sample analyses. A midday zero and span check will also be performed each day.

Field samples will be introduced to the GC using Mylar bags because methane exhibits virtually no affinity or reactivity with the Mylar surfaces. Proper operation of the GC requires that the samples be introduced to the system using the same technique in which the calibration gases are introduced. Calibration gases or samples will be drawn or pushed through the valve sample loops using a downstream pump. This will be done for approximately 60 seconds while the GC is idling between runs. Sample flow through the sample valve will be monitored with a small exit rotameter. The pump will be powered-off and the pressures in the sample loop allowed to equalize with atmospheric. Ten seconds will be allowed to elapse after the rotameter ball has returned to zero, thus indicating zero flow through the sample valve. The GC operator will manually and simultaneously activate the sampling valve from Load to Inject positions and depress the GC's start-run button. The GC will output the chromatogram to the integrator. The sample identification and any other pertinent data will be noted on each chromatogram. The GC will stop automatically at the end of a preset time interval. Following completion of the GC run, the gas valve will be returned to the load position to repeat the process. Run times will only be long enough to elute all of the compounds of interest to permit a rapid analytical turn-around.

In all bagged samples, Method 18 will be used to report methane concentrations in ppm. This will be accomplished by subtracting the least squares regression intercept from the methane area counts and then dividing the remaining methane area counts by the least squares regression slope. The total hydrocarbon (as methane) concentrations for the 125 bagged samples will be reported using the same procedure except that the total area counts for all other peaks plus methane will be used. For the samples that require speciation, the area counts for each individual compound, as identified by the retention times, will be converted to ppm using the appropriate least squares intercept and slope.

4.4.3   Method 18 QA/QC

QA/QC guidelines for the Method 18 procedures used in this project can be found in the previously mentioned QA Handbook. Method 18 spells out the number of calibration points (3 upscale that bracket sample concentrations) and the allowances for analyzer drift (10 percent) and calibration error (7 percent curve fit on individual points). GC drift checks are easily performed by re-analyzing selected calibration standards. The normal procedure when using bagged samples is to analyze the samples within two hours of collection. A degradation study will be conducted at the beginning of the project to verify the non-reactivity of the target compounds with the Mylar bag surfaces. The use of external audit cylinder standards for this project is neither anticipated or needed. In addition to the pre- and post-calibrations, periodic calibration checks of the GC/FID/TCD will be interspersed with the samples as deemed necessary by the operator to ensure calibration accuracy (at least once per day). If the GC/FID/TCD shows more than a 10 percent relative standard difference between a calibration standard and the calculated value through the calibration curve, then the GC will be subjected to a complete multipoint recalibration.

The setup of the GC and its operating parameters such as column flow and programmed temperatures will be determined before field testing so that baseline separation of eluting compounds on the chromatogram exhibit as nearly complete baseline separation as possible (maximum 5 percent peak overlap at baseline). Identification of peaks will be accomplished by

injecting analytes singly to establish retention times and the sequential order of elution. Calibration of the GC will be required if the retention times shift by more than 0.5 minutes. Copies of certification sheets for compressed gas calibration cylinders will be included with the report.

4.5　CONTROLLED LEAK TESTING

A careful, controlled leak study is an important element of the overall experimental design. The primary function of the controlled leak study is to assess the precision and accuracy of the overall bagging method under controlled laboratory conditions. This is necessary because the bagging measurements will be used in this study as the standard against which the performance of the HVCS method will be assessed. Since this is a field evaluation, it is also important that the laboratory testing closely simulate "real world" sampling conditions and include a representative range of component types, leak rates, and operating conditions. The controlled leak study will be performed on a test bed containing a representative range of component types and sizes, with apparatus for precisely metering and controlling the leak rate of a known concentration (99.9 percent) of methane. The test bed will also be capable of simulating different types of leaks (e.g., jet or diffuse leaks). The test components will be modified to create a leak, for example, by loosening the packing nut on a valve stem, or scoring the gasket on a flange. Components will be tented and samples bagged and analyzed according to the same procedures to be used in the field. The test bed will also be used to evaluate the performance of the HVCS under controlled conditions.

This testing will be more representative of field conditions than the leak rate tests discussed in the EPA protocol or conducted in earlier studies for EPA (EPA, 1980c). Sections 2 and 3 of this plan show exactly how the data from the controlled leak test will be applied to the overall analysis and quality assessment of the data for this study. The test bed will contain a total of 5 components which will each be tested at up to 5 different leak rates in the range from 0.1 to 20 lpm, and over a range of pressures (up to 100 psig).

4.5.1　Controlled Leak Test Bed Description
Past extensive screening and mass emission measurements at gas and oil production fields provides a rich data set from which representative populations of the leaking components (leak configurations) can be characterized in terms of the component type and size, leak rate, and operating pressure. The population of leaking components at U.S. gas production fields is characterized in section 3.4. Based on this characterization, the following components and leak types were selected for the test bed:

- 4" threaded connector, (1) not tight, (2) threads scored
- 2" gate valve (1/4 to 1/2 inch shaft), (1) packing not tight, (2) packing damaged
- 2" pressure relief valve, (1) seal damaged
- 4" open ended line
- 4" flange, (1) not tight, (2) gasket scored

Where feasible, larger components were selected in order to present more of a challenge to the methods. The cost of components is also a consideration in their selection.

The challenge in constructing the test bed is to accurately meter the flow rate while leaving the test components under simulated field conditions. It is not generally possible to meter the leak rate downstream of the test component as this would limit the types of leaks that could be constructed and could interfere with the bagging and HVCS measurements. Use of common flow metering devices such as bubble meters and rotameters for upstream flow metering is complicated by the need to achieve pressures internal to the components as high as 100 psi.

A bubble flowmeter measures the true volume of the gas at the given internal component pressure (e.g, 30 psi). A simple pressure correction would give the actual volume of the leak at ambient (or standard) conditions. However, commercially available bubble flowmeters are designed to be operated at ambient pressures and might not withstand elevated pressures. A rotameter reading depends on the density of the gas passing the float, and should therefore be calibrated specific to the gas that will be metered (methane) and the pressure at which it will be used. Pressures necessary to achieve a desired leak rate (over the range of 0.05 to 20 lpm) in a given component are expected to vary widely (over the range from 1 to 50 psi).

The approach to metering test bed flows is based on the use of rotameters calibrated over a range of pressures. Before the test, the rotameters will be calibrated over a range of pressures using the apparatus illustrated in Figure 4-1. A valve will be used to control the pressure downstream of the rotameter and a bubble flow meter (primary standard) will be used (at ambient outlet conditions) as the flow standard. Rotameter flow as a function of pressure and temperature is expressed by:

$$Q_2 = Q_1 \sqrt{\frac{P_1 T_2}{P_2 T_1}} \qquad (14)$$

where, 1 is initial conditions, 2 is final conditions, Q is flow, P is pressure, and T is temperature. However, it is generally recommended that rotameters be calibrated under the exact conditions under which they will be used. To accomplish this a family of calibration curves will be generated for various flows over a range of pressures. A sufficient number of curves will be developed so that there is no more than a 10 percent difference in flow between pressure curves. During the tests, pressure will be monitored and rotameter flow will be determined from the appropriate calibration curve for the pressure during that test to obtain the true flow under standard conditions. The test bed flow metering scheme is also illustrated in Figure 4-1.

Two parallel series of tests will be conducted on each test component; one for the bagging method, and one for the HVCS method. Each series will consist of tests at at least 3 leak rates and up to 3 internal pressures. The controlled leak test matrix is given in Table 1-2. Once a leak rate is established, it will be measured by both methods. Selection of leak rates and pressures for each component will depend on the component and leak type. The goal is to test leak rates over the range of 0.1 to 20 lpm under pressures up to 100 psig. However, as a practical matter it may not be possible to achieve this range for each component. It is expected, however, that the overall range will be achieved for the test bed as a whole. All components will be connected

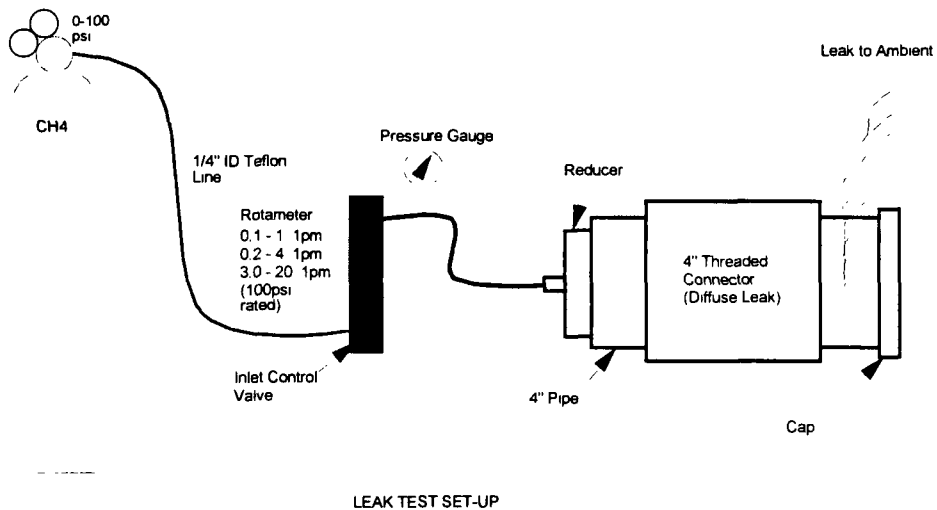CALIBRATION SET-UP

LEAK TEST SET-UP
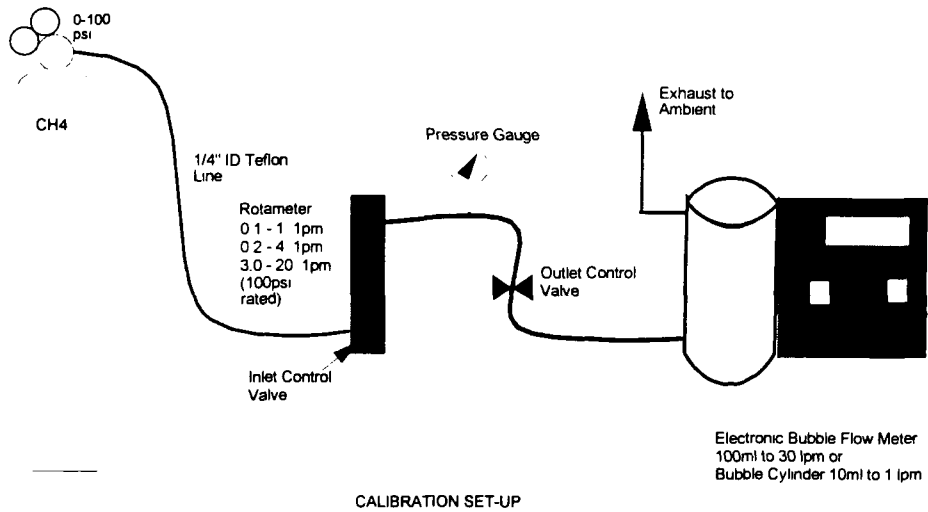
Figure 4-1. Flow Metering Schematic For Controlled Leak Test Bed

to the flow metering apparatus using caps, reducers, and other fittings as needed. The entire system should be leak tight except for the intended area of the leak. This will be verified by screening with soap solution.

For the field leak rate tests, only one component from the test bench will be used. The selected component will be capable of achieving a wide range of leak rates and should be a challenging (but not too difficult) test for both the bagging and HVCS methods. The threaded coupling is probably the best candidate for use in the field leak rate tests since the majority of leaks identified in recent studies have been associated with this type of component.

4.5.2   Controlled Leak Test Bed Procedures

Measurements of emissions from the simulated leaking components will be conducted in the same manner as the field measurements. As in the field, screening values will be obtained before and after each HVCS and bagging measurement. HVCS and bagging measurements in the controlled leak study will be conducted according to the identical procedures described for the field study in sections 4.2 and 4.3 above. The standard field data forms will be used. The only additional procedures are metering the controlled flow rates and calibrating the flow metering apparatus. These procedures were described in the test bed description above. The calibration curves generated for the test will be included in the study report.

4.5.3   Controlled Leak Test QA/QC

QA/QC for the OVA screening, the HVCS and the bagging measurements will be the same as described above (see sections 4.1-4.4). The methods to operate and calibrate the flow measurement devices (rotameters and bubble flow meters) are listed in EPA stationary source and ambient air method descriptions. Details may be found in found in several sections of the EPA QA for Air Pollution Measurement Systems Handbooks (the Redbooks). One such write-up is included in Volume III Section 3.4 for EPA Reference Method 5--Determination of Particulate Emissions from Stationary Sources.

SECTION 5
DATA REDUCTION, VALIDATION, AND REPORTING

This section presents a brief description of methods and procedures for data reduction, validation and reporting as applicable to key measurement parameters. These key data elements are (1) the instrument screening values and component descriptions gathered during the screening, (2) flow rates and total hydrocarbon concentration values for leak rate determinations by HVCS and bag sampling, and (3) concentrations of speciated compounds. Other supporting information includes the component inventory or process description, and results from calibrations and quality control checks. Figure 5-1 shows a generalized data flow diagram illustrating how key data elements feed into the comparative analyses which will be the focus of the data analysis. This Figure follows the study design overview presented in section 1.3.

5.1   DATA REDUCTION

Descriptions of necessary calculations to determine leak rates are given in section 4 of this plan or are referred to in the detailed procedures found in the appendices to this plan and in referenced EPA documents. The primary measurement quantities and units for this study are hydrocarbon concentration (volume ratio, *e.g.,* percent, ppm), flow (lpm), temperature (Kelvin), and pressure (Torr). Some measurement devices that will be used provide direct readings in English units (e.g., HVCS rotameters read in standard cubic feet per hour). All final data will be reported at standard conditions (760 torr, 296 °K) in metric units. Standard unit conversions will be used as necessary. Computerized spreadsheets will be used to automate calculations and provide a high level of consistency.

Descriptions of calculations to produce summary results that will be used as data quality indicators are given in section 3 for each measurement. Other summary calculations will include totals and standard descriptive statistics for measures of central tendency (mean, median, and mode), and variability (standard deviation, variance, range).

5.2   DATA VALIDATION

The QA/QC procedures for each measurement presented in section 4 in this plan describe tests and checks designed to verify that all sampling and analytical procedures, apparatus, and instrumentation are functioning properly. These procedures also spell out conditions that call for corrective action and that may indicate that collected data should be considered as suspect or invalid. These conditions are summarized for each measurement in Table 5-1. Suspect data can not be completely relied upon, but may contain useful information. For invalid data, the quality of the data has been so severely compromised that it is of no use to the study. In general, a non-valid (invalid or suspect) status would apply to all data collected subsequent to the last successful calibration, check or test. In all cases, failure to meet such conditions will be documented on standardized field data forms, calibration sheets, logs, and problem reports. All data collected for this study will be examined to determine its validity.

Component Inventory ----► Screening

or Process Desc.

ISV's, Component Desc.

Screening Data Review

Select Leaking
Components For Testing

◄ *

▼

HVCS ► OVA *► Leak Rate HVCS

Flow THC Concentration

▼

Bag Sampling * ► GC * ► Leak Rate Bagging

Flow THC/Speciation

(Speciated Data)

▼

Final Data Review ◄

▼ ▼

Overall Comparative ► HVCS Performance Data Quality Reporting
Analyses Criteria

Leak Type Leak Rate Component Type Operating Conditions

*
Indicates field data review and corrective action decision point.
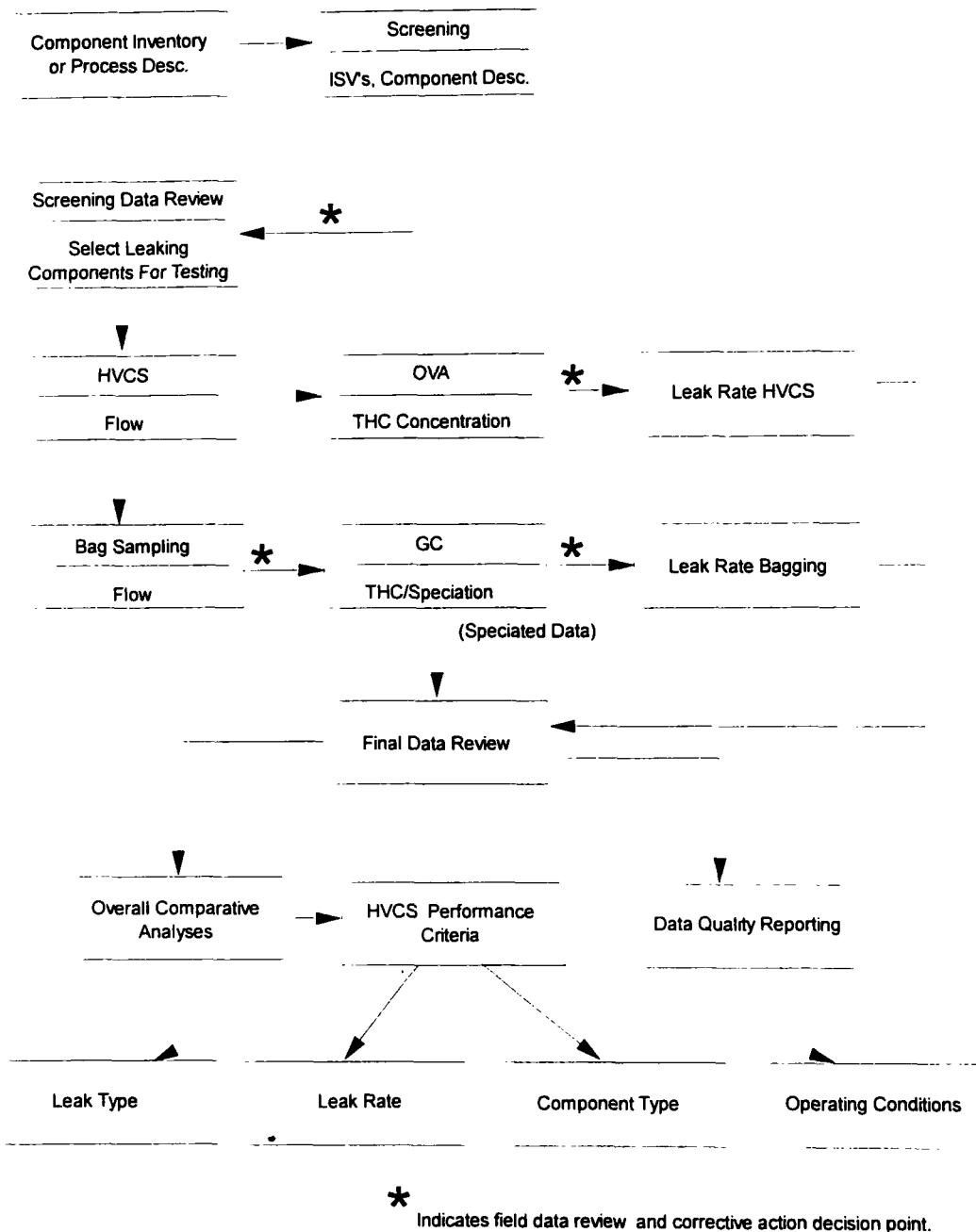
Figure 5-1. Generalized Data Flow

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Data validity will largely be determined by association with operational problems that are known to have occurred during sampling or analysis based on checks and tests as described above and on any additional observations made by the operators. Operational data validation will be based on examination of field data sheets, calibrations, logs and problem reports. An exploratory or statistical data validation approach will also be used. This consists of examining the end data to look for impossible values (*e.g.,* negative concentrations), extraneous values (outliers) or unusual patterns. In general, an outlier is no more than an observation that does not conform to the pattern of other observations in the data set. When an outlier is suspected, operational evidence explaining the presence of the outlier will be sought. If no operational evidence is available, appropriate statistical outlier tests will be used as necessary to investigate the significance of the outlier. If the apparent outlier cannot be explained based on operational evidence, or clearly shown to be an outlier in a statistical sense (*e.g.,* at a 95 percent significance level), then the datum must be retained. However, subsequent data analysis may treat the data with and without the "outliers" as separate cases.

5.3   Data Reporting

The study report will describe the findings of the field and laboratory studies and document the means by which these findings were obtained. SRI will use the data collected to assess the performance of the HVCS and identify factors that affect its performance. The 125 HVCS/bagging data pairs are key data elements that will be analyzed to assess the overall performance of the HVCS system. The screening data and component inventory will be used to demonstrate the overall representativeness of these comparisons in terms of component type, leak rate, and operating conditions encountered in the field. The methane/non-methane and speciated data will provide information that will be used to estimate the actual leak rates in terms of the compound specific FID response for the compounds actually present in the gas stream.

In addition to an assessment of overall HVCS performance, the data analysis will include a break down of HVCS performance for different component types, leak rates, and operating conditions (*e.g.,* gas or liquid service, and pressure). The operating conditions of the HVCS (*e.g.,* flow rate, measured concentration range) will also be considered. Based on these analyses, SRI will assess the accuracy of the HVCS under field conditions and establish performance criteria for use of the HVCS in the field.

The data collected for the study will also be used to compare overall emissions estimates based on HVCS, tenting and bagging, and EPA protocol emission factor and correlation approaches. In so doing, it is important to note that the EPA correlations and emission factors should be applied only to groups of similar components and not to individual components. This is because emission rates determined using the emission factors and correlations in the EPA protocol represent the average emissions expected if a large number of similar components were measured. According to the EPA protocol, the actual mass emission rate for a given component may be more than an order of magnitude greater or less than the estimated emissions, depending on the type of equipment and the operating parameters.

Table 5-1. QA/QC Test Conditions, Data Validity and Corrective Actions		
Condition	**Validation Status**	**Corrective Action**
Screening Measurements		
OVA fails Method 21 performance tests.	Test conducted prior to measurements. Data not affected.	Repair or replace analyzer. Repeat test.
OVA fails daily operation checks.	Test conducted prior to measurements. Data not affected.	Repair or replace analyzer. Repeat test.
Repeatability check failure.	Collected data suspect.	Recalibrate OVA. Examine screening method.
OVA fails drift check.	Collected data suspect.	Flag components for re-screening as needed. Recalibrate OVA.
OVA flame out.	Data may be suspect or invalid if flame out is due to moisture or contamination.	Perform single point check. Continue screening or return for multipoint as indicated.
HVCS Measurements		
HVCS fails leak check.	Test conducted prior to measurements. Data not affected.	Repair. Repeat check.
OVA fails drift check.	Data invalid.	Recalibrate. Repeat measurement.
Field leak rate test failure.	Data may be suspect or invalid depending on cause of failure.	Determine and correct cause of failure.
Bagging Measurements		
Field leak rate test failure.	Data may be suspect or invalid depending on cause of failure.	Determine and correct cause of failure.
Gas Chromatography		
GC fails drift check.	Data invalid.	Perform multipoint calibration. Re-analyze samples.
Sample hold time exceeded.	Data suspect.	Collect new samples as needed.

The report will also include an assessment of overall data quality based on the calibration, laboratory test results, and other QA/QC data collected for the study. Measurement precision and accuracy will be reported for all portable FID's, and the GC based on frequent comparisons with known standards. In addition, an assessment will be made of overall operational precision and accuracy for the HVCS and tent/bag sampling and analytical methods based on the controlled leak testing in the laboratory. All reported data will be carefully screened based on a study of field logs, calibration records, and problems and corrective actions. The results of this screening will be included in the report. Screened data will be clearly identified and the justification for removing any data will be stated.

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Finally, the report will include summary tables of data collected for the study. These tables will include (1) component identification/description and screening values for all components with screening values over 10 ppmv, (2) calibration results for all portable FID's, (3) calibration results for the GC, (3) laboratory test results for the HVCS and bagging measurements. Raw data will be recorded and maintained on standardized field data forms (see Appendix B). These forms will be kept on file and made available for inspection upon request. Other information that will be maintained on file will include calibration gas certifications, and problem logs. To expedite data analysis and preparation of summary tables and graphs for data presentation, much of the field data will also be entered and stored in machine readable data tables in standard PC compatible spreadsheet and database formats (Lotus 123, Paradox).

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SECTION 6
AUDITS

There is no plan to make use of an independent auditor beyond the staff principally involved in the study. However, quality assurance tests built into the study as part of this plan do perform an auditing function. The blind field leak rate tests serve as an internal performance audit on the HVCS and bagging measurements procedures. The field leak rate tests will also serve as a "blind" check on total hydrocarbon determinations by GC/FID/TCD. The repeatability checks serve as an audit of the screening measurements. Assurance that these procedures have been followed will be provided by documentation of the results of these tests. While there is no provision for a technical systems audit, this quality assurance plan has received internal and external review and approval before its implementation in the field. Assurance that the plan is followed is provided by the "paper trail" of documentation for the study and the content of the study report.

SECTION 7
CORRECTIVE ACTION

This section presents procedures that will be followed to ensure that appropriate corrective actions are implemented in response to any problems encountered in the laboratory or field testing. The QA/QC procedures given for each measurement in section 4 of this QAPjP also state conditions requiring corrective action. These conditions are summarized in Table 5-1 (presented in section 5 above). Corrective action procedures will be initiated when any of these conditions are encountered. In addition, the field technicians who will be employed in the testing are trained to recognize unanticipated problems. Corrective action procedures can be initiated by any field or laboratory personnel if they feel that a problem that could compromise data quality has occurred or is likely to occur.

Corrective action procedures begin when a problem is reported to the field coordinator. Problems should be reported by the person directly responsible for the measurement. The field coordinator will then initiate corrective action procedures. Corrective action procedures consist of (1) clearly identifying the problem, (2) identifying and implementing a solution, (3) verifying that the problem is solved, (4) assessing the impact of the problem on data quality (5) implementing steps to flag and/or recover data, and (6) documenting all steps taken in the problems log. For example, a portable OVA being used for screening fails a drift check. As called for in the QA/QC procedures, the OVA is returned for checkout and a multipoint calibration. During checkout, the drift is verified and it is discovered that the drift was probably caused by a low battery charge. It is verified that the battery had been properly charged the night before. The battery is replaced with a new battery and the OVA is subjected to a calibration precision test over a period of several hours. Drift is now within acceptable limits and the OVA is put back into service. Screening data collected prior to the failed drift check and subsequent to the last successful drift check is flagged as suspect and examined. Components with low screening values near the leak criteria (10 ppm) are flagged for re-screening since there is the potential that one or more of these is leaking, but was not identified as such during the initial screening.

SECTION 8
PROJECT ORGANIZATION

Mr. Stephen Piccot will serve as project manager and, as such, will have overall responsibility for SRI's technical and budget performance. Mr. Eric Ringler will serve as principal investigator. Mr. Ringler will oversee all routine project activities and will provide direct support for preparation of the QAPjP, field measurements, data analysis, and report preparation. In the field, Mr. Ringler will serve as the field coordinator. Mr. John Sokash will coordinate mobilization for the field measurements, conduct laboratory testing of the HVCS and bagging methods, perform GC analyses, and support data analysis and preparation of the QAPjP. In addition, SRI will employ a field technician trained in Method 21 screening and EPA protocol tenting/bagging for field and laboratory measurements activities. Internal quality assurance will be provided by Larry Felix in SRI's Birmingham office. Mr. Felix will review the QAPjP and will also review QA/QC data collected during each measurements trip. Mr. Felix will have no direct project involvement other than for internal QA, and does not report within the direct management of the project. SRI will employ a subcontractor to conduct screening and HVCS measurements and provide support for evaluation of the HVCS. SRI has concluded that the developers of the HVCS method, STAR Environmental, would be the ideal subcontractor. STAR's experience in developing the method and in the initial field and laboratory testing are essential for the successful completion of the project in a timely and cost effect manner. STAR also has extensive experience with measurement of fugitive VOC leaks at gas and oil production facilities

SECTION 9
TEST PROGRAM HEALTH AND SAFETY

This section discusses Health and Safety practices for the laboratory and field components of this project. All safety issues start with the recognition of potentially dangerous conditions and require the best possible avoidance of them. This section cannot cover every conceivable issue that may be encountered. Personnel will be trained in hazard recognition and avoidance.

9.1   GENERAL SAFETY ISSUES

All personnel on this project will be given a copy of this safety section for reference, and be required to read and sign-off on this Section 9 of the QAPjP before being permitted to work on this project. Serious safety hazards such as exposure to dangerous or carcinogenic chemicals, radioactive substances and biological agents are not expected. Material Safety Data Sheets (MSDS) for those materials supplied by vendors will be kept in a project file for ready reference by test personnel. All personnel are ultimately responsible for their own safety and the safety of others. Any unusual incidents or potential safety problems should be brought to the attention of the field coordinator in a timely manner. All personnel will report injuries to the project supervisors no matter how insignificant.

One universal hazard in this project involves the use of and potential exposure to flammable gases, such as methane. The upper and lower explosive limits of methane are 15.4 and 5 percent by volume at normal atmospheric pressures and oxygen concentration. The explosive limits of methane decrease as the pressures of the storage vessel increases. As a safety concern, no blends of calibration gases or collection of samples will be permitted to have methane concentrations below 25 percent, or above 1.25 percent. The volumes of samples collected in bags for later analysis will be limited to a maximum of two liters. No open flames or sources of ignition will be permitted in any area where methane vapors may be present. No spark producing devices will be used on this project. Spark producing devices include any steel-on-steel striking or contacting devices. Other common spark producing devices which field personnel must recognize include series wound motors which are identifiable by the use of carbon brushes between the field and armature windings; and shaded pole motors with mechanically activated starter windings which are identifiable by a clicking sound as the motor starts or decelerate Any motors used in the vicinity of potentially flammable methane atmospheres must be labeled as intrinsically safe. If there is any doubt as to the intrinsic safety rating of a device, it will be kept distant from sources of flammable gas, or sealed in a container and kept under a nitrogen purge.

Compressed gas cylinders will be used in this project. Compressed Gas Manufacturers Association (CGA) Guidelines will govern the storage, use and handling of compressed gas cylinders. A complete copy of the Handbook of Compressed Gases will be available, and the section detailing use and handling will be given to all test personnel. Cylinders will be kept secure at all times and not be permitted to strike each other. Regulators attached to cylinders will be leak-checked upon initial installation. A secondary risk of compressed gas cylinders involves the possibility of simple asphyxiation within confined spaces as normal oxygen levels are displaced. No uncontrolled release of a compressed gas will be permitted.

The use of any electrical devices will be in accordance with National Electric Code (NEC) guidelines. The use of Ground Fault Circuit Interrupting (GFCI) devices will be required whenever moist surfaces or water may be encountered, and at all times when outside of permanently constructed buildings. All AC-powered equipment must have working three-wire grounding plugs.

The use of safety glasses (eye protection) with side shields is required at all times in the laboratory and field. Long hair must be tied back whenever in the laboratory or in the field. The use of steel toed safety shoes in the field is required. Footwear that does not provide for adequate traction will not be permitted. Conditions leading to slips, trips or falls, especially on wet surfaces must be avoided. All walkways will be kept free of equipment, tools or debris. Access to fire extinguishers or emergency exits will not be blocked. Each work area will have two exits, remotely located. No personnel are to lift any materials over 45 pounds without assistance. All lifting shall be done by keeping a straight back and bending at the knees. Objects will be brought straight up without bending or twisting at the back.

9.2   PROJECT SPECIFIC SAFETY ISSUES

Initial site surveys will be conducted by SRI before final arrangements are made for field measurements. During these surveys, information on site specific safety concerns will be obtained from the site's safety officer. All SRI and subcontractor personnel will be briefed on site specific hazard recognition and avoidance before being allowed on site. The following general site safety issues are based on previous experience at similar facilities.

The first responsibility of all project personnel upon entering a site will be to attend a safety orientation at the facility. Project supervisors will obtain information on and directions to the nearest emergency treatment center or hospital. Project supervisors will maintain a limited first aid supply cabinet at the field site for use with minor cuts and scratches. Personnel will be expected to have a basic knowledge of facility emergency procedures, sirens, the location of emergency exits, safety showers and eye wash stations, and emergency assembly points. In the event of an facility evacuation, field personnel will determine the prevailing wind direction and evacuate the facility at right angles to the wind direction and away from the danger zone. Project supervisors will conduct a head-count or test personnel at the emergency assembly point. No SRI personnel will be permitted to return to an evacuated area until clearance for re-entry from plant personnel is obtained.

All field personnel will remain within visual sight of each other or within radio communication. Field personnel will not climb on portable extension ladders or any equipment ladders more than 12 feet above ground level. Field personnel will not venture into any areas that would require a safety harness and tie-off, or leave the confines of a standard guard-rail equipped walkway. Field personnel will not make any entry into confined spaces. A confined space is any area where the potential lack of free air movement exists, or any area where vapors may accumulate causing normal oxygen levels to be reduced below 19 percent. Examples of confined spaces include manways into tanks, closed rooms on two or more sides, trenches, and containment berms around tanks. Field personnel will not enter any areas where respiratory protection or self-contained breathing apparatus would be required. Hard hats will be required whenever there is

a risk of injury from falling or stationary overhead equipment. Hearing protection will be required whenever elevated noise levels make it difficult to understand a person speaking from 3 feet away. The use of close fitting, organic fibre long sleeve shirts in the field will be required whenever there is a potential risk of thermal (hot and cold) burns. Cryogenic temperatures may be encountered around liquid natural gas storage vessels or piping. Sandals or cut-off clothing will not be permitted.

Working in the vicinity of high pressure gas production and pipelines can present a special hazard. High pressure leaks can cause serious injury to body parts, and can accelerate dust/dirt particles to supersonic velocities. Field personnel will not be permitted to check components using their bare hands. Field personnel will be required to wear leather gloves at all times when checking components with the portable analyzers.

Field work will be suspended whenever thunderstorms are in the vicinity of the field site. This is defined as audible thunder overhead or lightning visible within 5 miles of the field site. Field personnel will keep abreast of weather forecasts for the field site by monitoring a portable weather radio or local radio station. If a possibility of severe weather exists, field personnel will determine the location of a suitable severe-weather shelter and be prepared to relocate to that shelter immediately when conditions warrant. Field personnel should be aware of the hazards of heat prostration and maintain fluid intakes accordingly. Fluids will be available to field personnel whenever outside air temperatures are above 75 °F Work schedules may be adjusted accordingly to permit work in the cooler morning and early evening hours.

SECTION 10
REFERENCES

Clifford, A.A., *Multivariate Error Analysis*, John Wiley and Sons, NY, 1973.

Gilbert, R.O., *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, NY 1987.

Hausle, K.J., *Protocol for Equipment Leak Emission Estimates*, EPA-453/R-93-026, (NTIS PB93-229219), 1993.

Wetherold, R.G., et. al., *Assessment of Atmospheric Emissions from Petroleum Refining*, Volumes 1-4 including Appendices A-E. EPA-600/2-80-075a-d (NTIS PB80-225253, -225261, -225279, and PB81-103830), 1980.

American Petroleum Institute, *Fugitive Hydrocarbon Emissions from Oil and Gas Production Operations,* API publication number 4589, 1993.

Gas Research Institute, *Fugitive Hydrocarbon Emissions - Eastern Gas Wells*, GRI Publication No. GRI-95 0117, 1995.

APPENDIX A
HVCS MEASUREMENT PROCEDURE

The following procedure was prepared by STAR Environmental and incorporated into this QAPjP by SRI.

Screening of the Component

The component is screened using a portable monitoring instrument to determine the point of highest emission and the maximum instrument screening value (ISV). Screening is conducted in accordance with EPA Method 21 "Determination of Volatile Organic Compounds Leaks", and the highest instantaneous reading is recorded.

Collection of fugitive emissions using HVCS

The main principle of the HVCS is the drawing of ambient air around a fugitive hydrocarbon source at a sufficiently high rate so as to effect complete capture of the hydrocarbon. The resulting mixture of ambient air and hydrocarbon is measure volumetrically using a series of rotameters. The hydrocarbon fraction of the mixture is measured at the outlet of the HVCS with a separate flame ionization detector (FID) instrument. The range of measurement for FID instruments is typically 10 ppmv to 10,000 ppmv hydrocarbon (0.00001% to 1%); therefore, large leaks can only be quantified by attaching a dilution tip to the FID probe to dilute the HVCS outlet stream to a level that is within the FID range.

Calibration of the HVCS

The three flow meters on the HVCS have been calibrated at the STAR laboratory. No field calibration is necessary, but attention should be given to the condition of each flow meter before using the HVCS. Dirt, moisture, or other foreign objects on the ball inside the flow meters or on the walls of the flow meters will result in incorrect readings. The speed of the air pump in the HVCS is a function of battery condition. Air flow through the air pump is controlled solely by the valves on the three flow meters. If field calibration of the flow meters is deemed necessary, it can be done using a dry gas meter, bubble tube, or other type of meter of known calibration.

Checking the HVCS for leaks

Every morning before use the HVCS inlet should be checked by opening the smallest flow meter to its maximum rate (above 20 scfh) and holding the palm of the hand across the inlet tube to stop all flow. The flow meter must drop to zero. The outlet is checked by placing the palm of the hand across the outlet tube to stop all flow. The flow meter must drop to zero. If the meter fails to drop to zero during either the check of the inlet or outlet tube, the HVCS cannot be used until the condition is corrected. At the end of each day the inlet and outlet tube are again checked. If the meter fails to drop to zero during either check, the meter reading is recorded on the data sheet.

Calibration of FID

The response of the FID is affected by temperature, battery condition, and other parameters that are subject to change within a few minutes time, therefore the FID must be calibrate before quantification of each sample using zero air, a low calibration gas (20 to 100 ppmv methane in air), a medium calibration gas (3,000 to 5,000 ppmv in air), and a high calibration gas (approximately 10,000 ppmv methane in air). The FID output voltages are recorded on the field sheet. The following equations are used to relate FID output voltage to part per million by volume of methane.

$$Concentration(ppm) = 10^{(ax + b)}$$

$$a\ (slope) = \frac{\log m - \log k}{n \quad l}$$

$$b\ (intercept) = \log k - al$$

where, k = low standard (ppm), l = low standard (volts)
m = high standard (ppm), n = high standard (volts)

If a dilution tip is to be used, the dilution tip is immediately attached to the instrument probe and a new reading of the high calibration gas is taken. The dilution ratio of the tip is the reading of the high calibration gas without the dilution tip in place divided by the reading of the same gas with the dilution tip in place. The dilution tip must be calibrated in the same configuration as it will be used; i.e., the side-arm supply line must attached with the fresh air supply end located at the position it will be in during the testing. [NOTE: Only the high gas will give a sufficiently high response with the dilution tip in place to allow calculation of the dilution ratio. The reading of the low calibration gas through the dilution tip will be near the lower detection limit of the instrument.]

The dilution ratio should be set between 10 and 150. The accuracy of dilution ratios above 150 have not been verified in the laboratory. Also the flow rate through the dilution tip decreases with increasing ratio. At a ratio of 150, flow thorough the tip is approximately 7 cubic centimeters per minute. Higher dilution ratios and the resulting lower flows would greatly increase the time required to collect a representative sample of the HVCS exhaust.

Measurement of Background Readings

Background readings must be taken in the area of the component to be tested and in the area used to supply fresh air to the dilution tip side-arm to assure that no other high leaks interfere with the collection and quantification of the target component.

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Attaching the HVCS Inlet Tube to the Leak

The HVCS sample line inlet is secured on the component being tested at the point of highest ISV (as determined during screening). Thin plastic film (such as Saran Warp) or duct tape is applied to the leak to channel all hydrocarbon emissions to the HVCS sample line and to deflect wind. Care must be taken to avoid over-sealing the area and thus preventing flow of ambient air across the leak.

Location of HVCS unit relative to leak

The high intake rate of the HVCS (and the corresponding high outlet rate) creates the potential for recirculation of air from the outlet tube to the inlet tube of the HVCS. Recirculation would result in erroneously high readings. Therefore, the outlet of the HVCS must be kept at least 6 feet (2 meters) from the inlet tube to prevent recirculation.

Location of the Ambient Air Line to the Dilution Tip Sidearm

Fresh air for the dilution tip side arm must be obtained at least 16 feet (5 meters) from the HVCS outlet. The hydrocarbon concentration in the ambient air coming through the tube must be checked and recorded each time the HVCS is relocated.

Operation of the Flow Meters

The HVCS contains three flow meters with the following ranges; 100 to 1000 scfh, 20 to 100 scfh, 2 to 20 scfh. Only one flow meter should be opened during each measurement, the other two must be closed to assure accurate flow measurements.

Collection of Quantification Data

Collection is begun at a high sampling rate. The FID reading of the HVCS outlet is allowed to stabilize and then it is recorded. The sampling flow rate is decreased (and recorded) in a number of steps while the corresponding increases in FID output voltage are recorded until the minimum flow of the HVCS is reached (approximately 3 cfh) or the hydrocarbon concentration becomes too high for the FID (approximately 10,000 ppmv with or without the dilution tip). NOTE: The accuracy of readings above 10,000 ppmv with the dilution tip in place have not been verified in the laboratory.

A minimum of three different flow rates are used for each component with the flow rates selected so that the FID voltages are approximately the same as those obtained from the high, medium, and low calibration gases. [NOTE: Readings within a factor of 100 times the background concentrations should be avoided.]

As each HVCS flow rate and corresponding voltage are recorded, the leak rate is calculated as follows:

$$Volume\ of\ leak\ =\ Concentration\ (ppm)\ *\ HVCS\ Flow$$

Where the concentration is determined from the OVA output voltage using the equation presented earlier. If the three predicted rates vary by more than 20% over-all, the possible causes should be investigated. Possible causes include: (1) another high leak in immediate proximity (2) hoses accidentally uncoupled, (3) battery failure, (4) actual change in process at facility, (5) incorrect recording of reading. After the possible causes have been investigated and remedied, if possible, the quantification must be repeated.

Verification of FID response
After each HVCS sampling is completed, the FID is immediately recalibrated using low and high concentrations of calibration gas to determine if the FID output has drifted. The voltage are recorded on the field sheet. If the dilution tip has been used, its response to the high concentration of calibration gas is immediately measured and recorded.

Calculation of hydrocarbon mass emission rate
The calculation of parts-per-million from FID voltages and hydrocarbon flow rates are calculated a second time at the STAR offices using the original field sheets as a quality assurance measure.

An exponential equation that relates the calibration gas concentration to FID output voltage is calculated for each calibration session. The voltage readings obtained during the sample collection period are then converted to "parts-per-million volume as methane" using this equation. If the dilution tip has been used the "ppmv" reading thus obtained are corrected to true "ppmv" readings by multiplying by the dilution ratio.

Total volumetric flow rates through the HVCS as recorded from the meters are multiplied by the calculated parts-per-millions of hydrocarbon to determine volumetric hydrocarbon flow rates (as methane). These in turn are converted to mass hydrocarbon emission rates by assuming a molecular weight of 16 pounds of hydrocarbon (methane) per 370 cubic feet of hydrocarbon.

The average mass emission rate of hydrocarbon is calculated as the mean of at least three measurements made at different volumetric flow rates; the standard deviation of the measurements around the mean is expressed as percent of mean.

APPENDIX B
FIELD DATA FORMS

Table B-1 lists and describes the data forms that will be used in the field and laboratory studies for the HVCS evaluation. The laboratory testing and field leak rate tests will be performed in the same manner as the field tests and documented on the same forms. An example of each form follows.

Table B-1. Field Data Forms	
Form Name	**Form Usage**
Screening Measurements	
Component Screening Field Data Form	One form is completed for each wellhead or other functional unit. Form records descriptive information and screening values for components with screening values more than 10 ppm above the local background. Form also inventories (checklist) components screened. Component ID's will be assigned to leakers.
Portable OVA Calibration and QC Check Form.	One form is completed per OVA per day.
Method 21 performance check form.	One form is completed per OVA per measurements trip.
HVCS Measurements	
HVCS Field Data Form	Form includes all information for an HVCS measurement (OVA pre/post calibrations, QC checks, component ID, pre/post ISV's, flows, concentrations). OVA Calibration and Method 21 performance check forms should be completed for the OVA.
HVCS Flow (Rotameter) Calibration	Complete one form for each HVCS for each field test.
Bagging Measurements	
Bagging Field Data Form	Form includes all sampling and analytical information for Blow-Through bagging protocol (QC checks, component ID, pre/post ISV's, flows, O_2 levels, THC concentration, speciated data (if applicable). Attach chromatograms.
Gas Chromatography	
GC Calibration Spreadsheet - EPA Method 18	Documents daily pre/post multipoints. Spreadsheet automates calculations. One sheet completed each day. File name MMDD.CAL
GC Data Reduction Spreadsheet - EPA Method 18	Documents GC data reduction. One sheet completed each sample. Filename COMPID.SMP

Bag Sampling Field Data Form			Date		Time:
Location			Operator		

Instructions: Complete one form for each bag sample. Sketch details of bag construction, component configuration. Show bag inlet/outlet.

Bags should be filled to about 75 % of capacity to avoid breakage. Fill/purge bags 3X with sample gas before collecting sample. All flows

are as indicated.

Wellhead or process unit ID:		Component Type:		Component ID:	
Ambient Conditions			Sketch		
Temperature (deg C)					
Pressure (torr)					
Screening Values					
Initial Screening ISV (ppm)		From Screening Form			
Pre Measurement ISV (ppm)		OVA			
Post Measurement ISV (ppm)		OVA			
Leak Character:		Soap and/or OVA			
QC Checks					
Leak Check Sampling Train		Plug inlet, zero flow.			
Leak Check Enclosure		Bag Should Collapse			
Bag Sampling Info	Method				
Induced Flow (lpm)		Minimum 5 lpm.			
Return Flow (lpm)					
Stabilized exhaust conc. CH4/O2		OVA or IR			
Bag 1 THC (ppm)		ID			
Bag 2 THC (ppm)		ID			
Comments					

HVCS Field Data Form

HVCS Field Data Form	**Date**
Location	**Operator**

Instructions: Complete one form for each HVCS measurement. Sketch construction of partial enclosures. OVA voltages must not exceed 5.5 VDC.

Wellhead or process unit ID:	**Component Type:**	**Component ID**
Operational Checks	**HVCS ID**	**Leak Check**
Analyzer ID	**Battery OK**	**OVA Flow OK** / **H2 Pressure**

Analyzer Calibrations

Pre Cal	Time:		Post Cal	Time:		Dilution Probe		Screening Values
Point	Cert. ppm	VDC	Point	Cert. ppm	VDC	Std. Conc.		Initial Screening ISV (ppm)
Zero	0		Zero	0		VDC		Pre Measurement ISV (ppm)
High			High			Calc Conc.		
Mid			Mid			Dil. Ratio		Post Measurement ISV (ppm)
Low			Low					

Slope	Slope	Ambient Conditions	Leak Character:
(LOG(HIPPM)-@LOG(LOWPPM))/(HIVOLTS-LOWVOLTS)		Temperature	
Intercept	Intercept	Pressure	
LOG(LOWPPM)-SLOPE*LOWVOLTS		Additional Instructions:	

HVCS Measurements — Calculate Concentration as 10^(SLOPE+INTERCEPT) from PreCal

Flow Range	OVA Volts	Flow Rate (scfh)	Conc (ppm) Direct	Conc (ppm) W/ Dilution	Leak Rate (lpm) Calculated	Sketch
High						
Med						
Low						
Other						
Other						

Leak Capture	Leak Rate Sigma	Leak Rate Avg.	Sigma/Avg.

Comments

Component Screening Field Data Form				Date		Page _____ of _____	

Location | **Operator**

Instructions: Complete one form for each well head or process unit. Multiple sheets may be used. Complete emitter screening data for components with ISV > 10 ppm. Complete total component inventory for all components. Return completed sheets to field coordinator ASAP.

Wellhead or process unit identification. | **3 Character unit abbreviation:**

Emitter Screening Data						Total Component Inventory	
No.	Component ID abr999	Cmp. Type - CN, VL, OL, PR, CS, PS, Ms	Line Size (inches)		ISV	Bckgrnd	Comp. Type	Number
1							Connectors (CN)	
2								
3							Valves (VL)	
4								
5							Open Lines (OL)	
6								
7							Pressure Relief (PR)	
8								
9							Compressor Seals (CS)	
10								
11							Pump Seals (PS)	
12								
13							Miscellaneous (MS)	
14								
15							Additional Instructions:	
16							A each wellhead or process unit, conduct screening from start to end in terms	
17							of gas flow. For example, a wellhead would be screened starting where the	
18							gas leaves the ground. Component ID's are assigned by the screener using a	
19							3 character abbreviation for the wellhead or process unit followed by	
20							sequential numbering. Complete total component inventory using hatch marks.	
21								
22								
23								
24								

110

Method 21 Performance Check Form	Date:
Location:	Operator:

Instructions: Complete one form per analyzer (OVA and IR) per measurements trip. This form kept at field office.

Analyzer Suitability Checklist	Analyzer ID:
Portable Analyzer Make/Model...	Foxboro OVA 108 Organic Vapor Analyzer
Intrinsically Safe Rated..	Certified Intrinsically Safe
All Components Present (list missing components if any)..........	
Detector Type:	Flame Ionization Detector (FID)
Analyte:	Natural Gas - Primarily Methane
Analyzer Flow Rate (0.1 to 3.0 lpm)...	lpm
Response Time (<30 seconds)..	seconds

Method 21 Calibration Precision Test

Species	Point	Cert. ppm	OVA ppm	Diff. (%)	Comments
Air	Zero 1	0			
Methane	Low	101.1			
Methane	Mid	1011			
Methane	High 1	9900			
Air	Zero 2	0			
Methane	High 2	9900			
Air	Zero 3	0			
Methane	High 3	9900			
Air	Zero 4	0			
Target Analyte	Response Factor				
Calculated Precision (Avg. Diff. of 3 Span Gases)					
Calculated Response Factor (Cert. ppm/OVA ppm)					

Daily OVA Calibration and QC Check Form				Date				
Location				Operator				

Instructions: Complete one form for each analyzer each day. Form travels with analyzer when in use, then filed in field office at end of each day. Recalibrate if span check differs from std. by more than 10 %. Record component ID's assocaited with initial and final Cals.

Daily QC Checks	Start	End	Analyzer ID:		Start	End
Battery Level			Electronic Low Span			
Hydrogen Pressure (Hi/Low)			Electronic High Span			
Flow Rate (0.1 to 3.0 lpm) - Unit vertical			Excess flow in CAL manifold (COB)			
Response Time (<30 seconds)			Other:			

Initial Calibration	Time:			Midday Span Check	Time:			Final Calibration	Time:		
Cert. PPM	Read PPM	VDC	Read/Std	Cert. PPM	Read PPM	VDC (opt)	Drift	Cert. PPM	Read PPM	VDC	Read/Std
0								0			
9900 (adj)								9900			
1011								1011			
101.1 (adj)								101.1			
Component ID (1st)				Component ID (Last)				Component ID (Last)			

Additional Calibration	Time:			Comments: Record all problems, flameouts. Note times.
Cert. PPM	Cert. ppm	OVA ppm	Drift	
0	0			
9900				
1011				
101.1				
Component ID (Last)				

Calculate drift as 1 minus the ratio of the PPM value read on the OVA scale and the standard value. Span check standard should be at or near the same concentration as the high standard used in the multipoint calibration.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/R-95-167	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Evaluation of the High Volume Collection System (HVCS) for Quantifying Fugitive Organic Vapor Leaks		**5. REPORT DATE** November 1995
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Eric S. Ringler		**8. PERFORMING ORGANIZATION REPORT NO.**
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southern Research Institute 6320 Quadrangle Drive, Suite 100 Chapel Hill, North Carolina 27514		**10. PROGRAM ELEMENT NO.**
		11. CONTRACT/GRANT NO. 68-D2-0062, Tasks 1/029 and 2/041
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air Pollution Prevention and Control Division Research Triangle Park, NC 27711		**13. TYPE OF REPORT AND PERIOD COVERED** Task Final; 3/94 - 6/95
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15. SUPPLEMENTARY NOTES APPCD project officer is Charles C. Masser, Mail Drop 62, 919/541-7586.		

16. ABSTRACT The report discusses a recently developed measurements technique that offers the potential for providing an easy-to-use and cost-effective means to directly measure organic vapor leaks. The method, called the High Volume Collection System (HVCS), uses a high volume sampling device and a portable flame ionization detector (FID) for field analysis. The HVCS can obtain direct measurements of mass emission rates without the need for tenting and bagging. This study of HVCS method performance included both field and laboratory testing. Laboratory evaluation of HVCS results closely matched EPA method results with a difference in total measured emissions of only about 3%. In one field test, the HVCS matched the EPA estimate of total facility emissions within about 4%. In the other field test, the HVCS measured approximately 18% more emissions than the EPA method. However, the bias was present only early in the test. Later in the test, after efforts were made to identify and correct the source of the bias, HVCS bias was essentially zero. With some physical and procedural enhancements, the HVCS may be offered to EPA for approval as an acceptable alternative to the EPA protocol bagging method with gas chromatographic analysis.

17.	KEY WORDS AND DOCUMENT ANALYSIS	
a. DESCRIPTORS	**b. IDENTIFIERS/OPEN ENDED TERMS**	**c. COSATI Field/Group**
Pollution Ionization Measurement Organic Compounds Emission Vapors Flames	Pollution Control Stationary Sources Volatile Organic Compounds (VOCs) Flame Ionization Fugitive Emissions	13B 07B 14G 07C 07D 21B
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