American Petroleum Institute

Smart Leak Detection and Repair (LDAR) for Control of Fugitive Emissions

Regulatory Analysis & Scientific Affairs
June 2004

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Smart Leak Detection and Repair (LDAR) for Control of Fugitive Emissions

Executive Summary

The Smart LDAR project is aimed at developing more efficient procedures and technologies for the control of fugitive emissions from process piping components (e.g. valves, pumps, connectors, etc.). A large refinery in the U.S. can spend over $1MM annually in monitoring, control measures, record keeping and reporting. Most of this effort appears to be wasted, since the vast majority of piping components (generally over 98%) do not leak. A recent API study showed that over 90% of controllable emissions come from about 0.13% of the components. A Smart LDAR program would focus efforts on these high leaking components.

This report presents a summary of the Smart LDAR concept, potential technologies, plant demonstrations and laboratory test results. Smart LDAR focuses on locating and repairing the most significant leaking components more cost effectively than existing practices while providing environmental protection equivalent or better than the current programs. While current LDAR programs have been successful in identifying and significantly reducing fugitive emissions from regulated components at industrial facilities, they are time consuming, labor intensive and costly. An operator must visit and measure each potential leak site; of which there are hundreds-of-thousands at an industrial plant. A Smart LDAR program that focuses on finding and repairing this minority of high "leakers" could achieve equivalent or better environmental protection at a lower cost.

Emerging optical imaging technologies provide a tool to more quickly identify high leaking components. Laser-based optical imagers have been identified. Remote sensing and instantaneous detection capabilities of these laser-based optical imaging technologies allow an operator to quickly scan large areas containing tens to hundreds of potential leaks. Significant leaks are identified immediately, allowing quicker repair, and ensuring efficient use of resources.

Monte Carlo Analyses have been performed to determine control equivalence for the optical imaging technology compared to current methods (i.e. EPA Reference Method 21). Environmental benefit equivalent to the current work practice is demonstrated when Monte Carlo simulations show that emission reduction for an alternative technology is the same as, or larger than, the current work practice emission reduction. In current fugitive emission control programs, quarterly monitoring is usually required for most components with leak definitions of 10,000 ppmv, 1,000 ppmv or 500 ppmv. Pumps are monitored monthly. The Monte Carlo analyses showed that for valves, optical imaging used at bi-monthly monitoring frequency, provides greater environmental protection than the current Method 21 quarterly monitoring.

Field and laboratory tests of optical imaging technologies have been conducted to demonstrate that the technologies could detect fugitive emissions at refineries and chemical plants under normal operating conditions and to determine detection limits. The project has been a cooperative effort of the petroleum industry, government funded laboratories, the U.S. EPA, and technology vendors.

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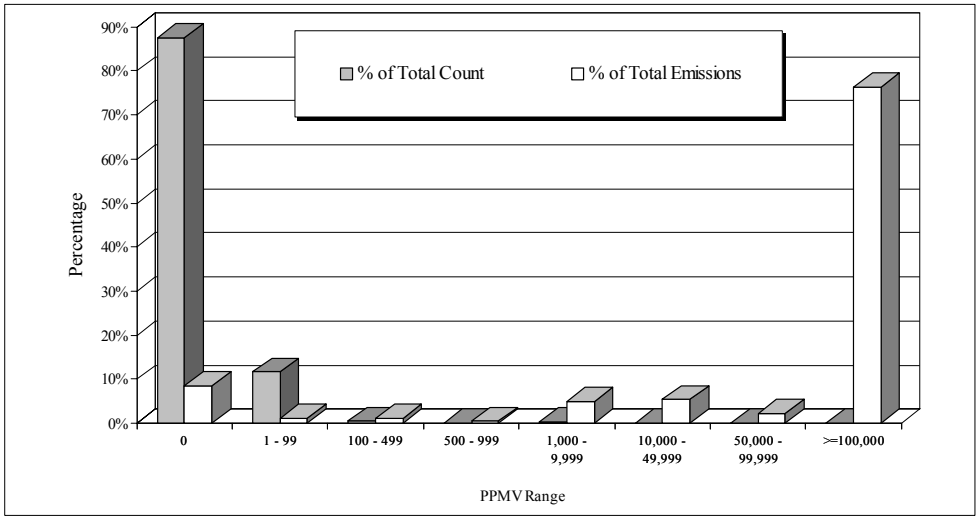
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ES-1.0 The Basis of Smart LDAR

In 1997, the American Petroleum Institute (API) conducted a study[1] to identify opportunities for conducting LDAR programs in a more cost-effective manner. The study evaluated data collected over more than 5 years at 7 Los Angeles, California refineries in the South Coast Air Quality Management District (SCAQMD). The data were examined to help determine if there were any design or operational characteristics that influence fugitive emissions, and whether a focused LDAR program could be more cost effective at controlling these emissions compared to the current method.

The API Study showed that 84 percent of the refinery fugitive emissions were from high leakers (>10,000 ppmv), which were only 0.13 percent of the total number of components (See Figure ES-1)[2]. Of the remaining 16 percent of the estimated emissions, 9.5 percent were from non-leakers (screening <100 ppmv), which constitute 99 percent of the components, and whose estimated emissions are based primarily upon an EPA specified, "zero default," value for components that screen at the background concentration. Thus, the high leakers account for 92 percent of the controllable (i.e., non-default zero) emissions.

Figure ES-1: Distribution of Component Count and Estimated Emissions by Screening Range



The study also found that there were no chronic leakers and only 5.4 percent of all emissions were from repeat leakers. Instead, the high leakers were found to occur randomly. No systematic explanation for their occurrence was apparent. The Study concluded that a more cost effective LDAR program would be one that emphasizes the location and repair of high leakers. The API has named such a program Smart LDAR.

ES-2.0 Optical Imagers for Locating Leaking Components

Two technologies have been tested at plants by the API led work group and have successfully found leaking components:

[1] American Petroleum Institute, "***Analysis of Refinery Screening Data,"*** Publication # 310, Washington, DC, November 1997.

[2] The overall percentage of high leakers (screening∃10,000) in any of the seven refineries was less than 0.2 percent.

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- A CO_2 laser imager. This is a commercially available instrument, manufactured and marketed by Laser Imaging Systems (LIS) under the brand "Gas Vue®." Gas Vue® utilizes a CO_2 laser. The Gas Vue® was successfully tested at two chemical plants and is referred to as a CO_2 laser imager throughout this report.

- A "fiber" laser imager. This instrument, developed by Sandia National Laboratory's (SNL) Lawrence Livermore facility, utilizes a backscatter technique patented by LIS. It is referred to as a "fiber" laser in reference to its optical fiber laser amplifier. It was successfully tested at two refineries and a chemical plant.

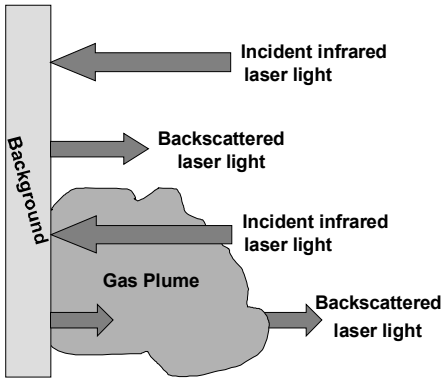
Each laser is tuned to emit a specific wavelength of infrared light that provides specific compound or compound type detection. The CO_2 laser is discreetly tunable in the 8-10 micron spectral region. The fiber laser is continuously tunable in the 3 micron spectral region.

ES-2.1 Backscatter Absorption Gas Imaging (BAGI)

The principle of operation of the CO_2 laser and fiber laser is Backscatter Absorption Gas Imaging (BAGI). In BAGI, a live video image is produced by illuminating the view area with laser light in the infrared frequency range. The reflected (backscattered) laser light is detected with a camera sensitive to that light. When the chosen laser wavelength is strongly absorbed by the gas of interest, a cloud of that gas is revealed as a dark image as shown in Figure ES 2-1.

A video camera-type scanner both sends out the laser beam and picks up the backscattered infrared light. The camera converts this backscattered infrared light to an electronic signal, which is displayed in real-time as an image on both the viewfinder and a video monitor. The same image will be seen whether the scanning is done in daylight or at night because the scanner is only sensitive to illumination coming from the infrared light source, not the sun. The imager can be switched between visible and infrared views.

Figure ES 2-1. Schematic Description of BAGI Process



Source: As Adapted from McRae, Tom, *GasVue: A Rapid Leak Location Technology for Large VOC Fugitive Emissions*. (Presentation at the CSI Petroleum Refining Sector Equipment Leaks Group, Washington, DC, Sept. 9, 1997). See U.S. Patent # 4,555,627.

Note: Although this Figure shows the gas in contact with the background material, it is not a requirement that the gas be in contact with the background. The gas plume need only be between the background and the infrared camera.

Figures ES 2-2 and ES 2-3 show the visible light and infrared views of leaking components viewed with the CO_2 and fiber lasers.

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Figure ES 2-2. CO_2 Laser Views of a Leaking Connector in Visible and Infrared Light

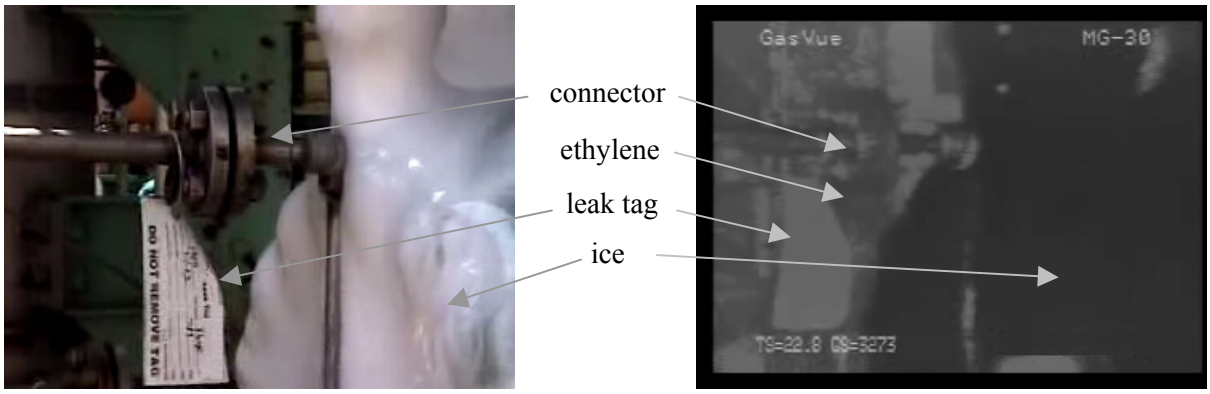


Figure ES 2-3. Fiber Laser Views of Leaking Flange in Visible and Infrared Light

Visible light view of leaking flange **Infrared view of leaking flange**



ES-3.0 Variability in Method 21

There is significant variability in EPA Reference Method 21. As shown in Figure ES 3-1, for a fixed mass rate, the screening value can range over several orders of magnitude. This uncertainty in Method 21 leads to bottom false positives and false negatives when compared to regulatory leak limits.

False negatives from Method 21 can result in significant emissions because these components would not be repaired and would continue to leak under a Method 21 based program. Since these components would be identified as leakers by the optical imaging instrument, the reduction of these emissions, which were "missed" by Method 21, is a major advantage for using the optical imaging technology. Thus, the new Smart LDAR approach using optical imaging allows a much higher mass leak definition than when using Method 21 since these missed leaks (the false negatives) are found and repaired more frequently.

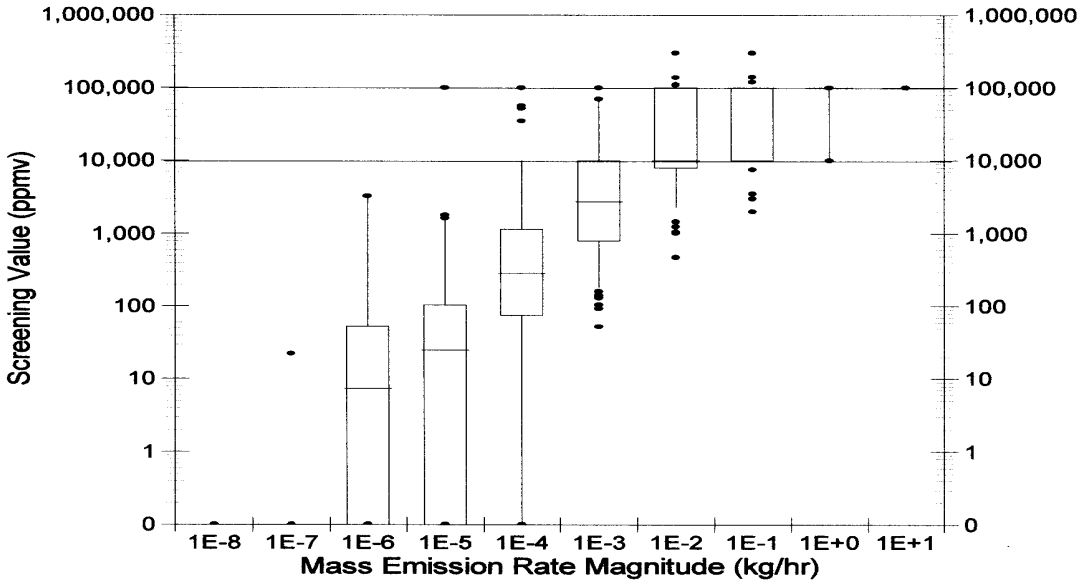
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In the current fugitive emission control program required by U.S.EPA regulation, monthly monitoring is required for pumps and quarterly monitoring is required for other components with leak definitions for repair of 500, 1,000 and 10,000 ppmv. Less frequent monitoring is allowed if the percent of leaking components remains below a specified level for a specified number of periods. Lower leak definitions for repair do not necessarily lead to better emissions control since, as the leak level is decreased, few additional leaking components are added to the repair group and these contribute very little to the overall mass emissions.

Figure ES 3-1. Variability of Method 21 Results for Equivalent Mass Emission Rates

Note: In a box plot, boxes enclose the middle half of the data spread, from the 25th to the 75th percentiles, with a horizontal line drawn inside the box at the median (50th percentile) value; whiskers extend below the box to the 5th percentile value and above the box to the 95th percentile value; and "dots" indicate values smaller than the 5th percentile value or larger than the 95th percentile value.

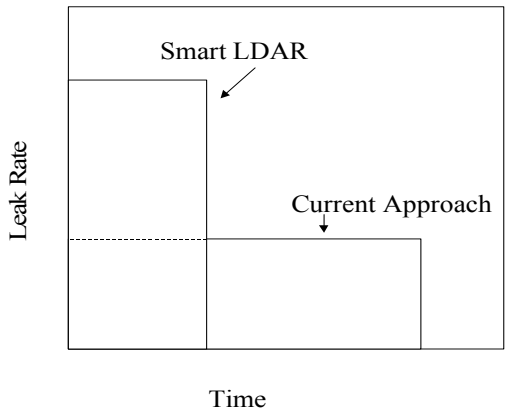
This illustration shows box plots for 1993-94 Petroleum Industry bagging data-set (American Petroleum Institute, 1993a; 1993b; and 1994) depicting reported screening value ranges (ppmv) for different "levels" of mass emission rates, denoted by mass magnitude bins (e.g., mass emission rate magnitude "1E-8" indicates mass emission rates with units of 10^{-8} kg/hr; i.e., values 1H10^{-9} kg/hr or larger, and less than 1H10^{-8} kg/hr, because the integer portion of the base-10 logarithm for values between these bounds is "-8")



The Smart LDAR approach focuses on identifying and repairing the highest leakers since these are the source of almost all the mass emissions. Equivalence is obtained by more quickly finding and repairing these large leaks, which more than off-sets the emission rates from components with low ppmv readings that leak for longer periods under current guidelines. Figure ES 3-2 illustrates the concept that Smart LDAR (on average) finds large leaks in shorter time, while the current approach (on average) finds smaller leaks over longer time. The total emission is equal under both approaches but more cost-effective

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Figure ES 3-2. Equivalence From Quicker Repair of Highest Leakers



Note: Not drawn to scale.

using the Smart LDAR approach. The use of optical imaging provides a more cost effective approach to more quickly find the high leakers. This, combined with the potential to find the false negatives (missed high leakers) from the Method 21 approach, results in the benefits from the Smart LDAR technique using the optical imaging technology.

ES-4.0 Testing and Demonstrating Applicability of Optical Imaging

Several field and laboratory studies have been conducted to demonstrate the use of optical imaging for fugitive emissions monitoring. These studies, their purpose and overall outcomes are summarized in Table ES 4-1.

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Table ES 4–1. Laboratory and Field Tests and Demonstrations of the Fiber- and CO_2 Lasers

Test/Year	Purpose	Outcome	Chapter for Details
Refinery Demonstration of Van-mounted Fiber Laser Technology, 1999	Determine if fiber laser could detect aliphatic emissions at a refinery under normal operating conditions.	Successfully detected leakers.	Chapter 6
Laboratory Tests of Portable Fiber Laser, 2000	Explore influence of viewing distance, wind speed, leak rate, reflective background, on the performance of the instrument in a controlled environment.	Data obtained on mass rate detection threshold for controlled wind speed, distance and reflective background. The lowest detected leak was at 8 g/hr[3] seen from 10 ft away at wind speed of 1 m/s.	Chapter 7
Laboratory Tests of Portable Fiber Laser, 2001	Determine the influence of viewing distance, wind speed, mass leak rate, reflective background, on the detection thresholds in: (1) a controlled wind-tunnel and (2) in out-door test with "blind" elements	Test determined the leak detection threshold of the fiber laser. Lowest detected leak was about 0.2g/hr.	Chapter 8
Ethylene Chemical Plant Demonstrations of CO_2 Laser, 2002	Test whether the CO_2 laser can detect fugitive emissions at ethylene plants under normal operating conditions.	CO_2 laser successfully detected leaks from components with a mass leak rate greater than 1 g/hr.	Chapter 10
Refinery Test of Fiber laser, 2003	Test whether the fiber laser can detect fugitive emissions at a refinery under normal operating conditions	Fiber laser successfully detected leaks from components with a mass leak greater than 20 g/hr.	Chapter 9

ES 4-2. Laboratory Testing of Fiber Laser

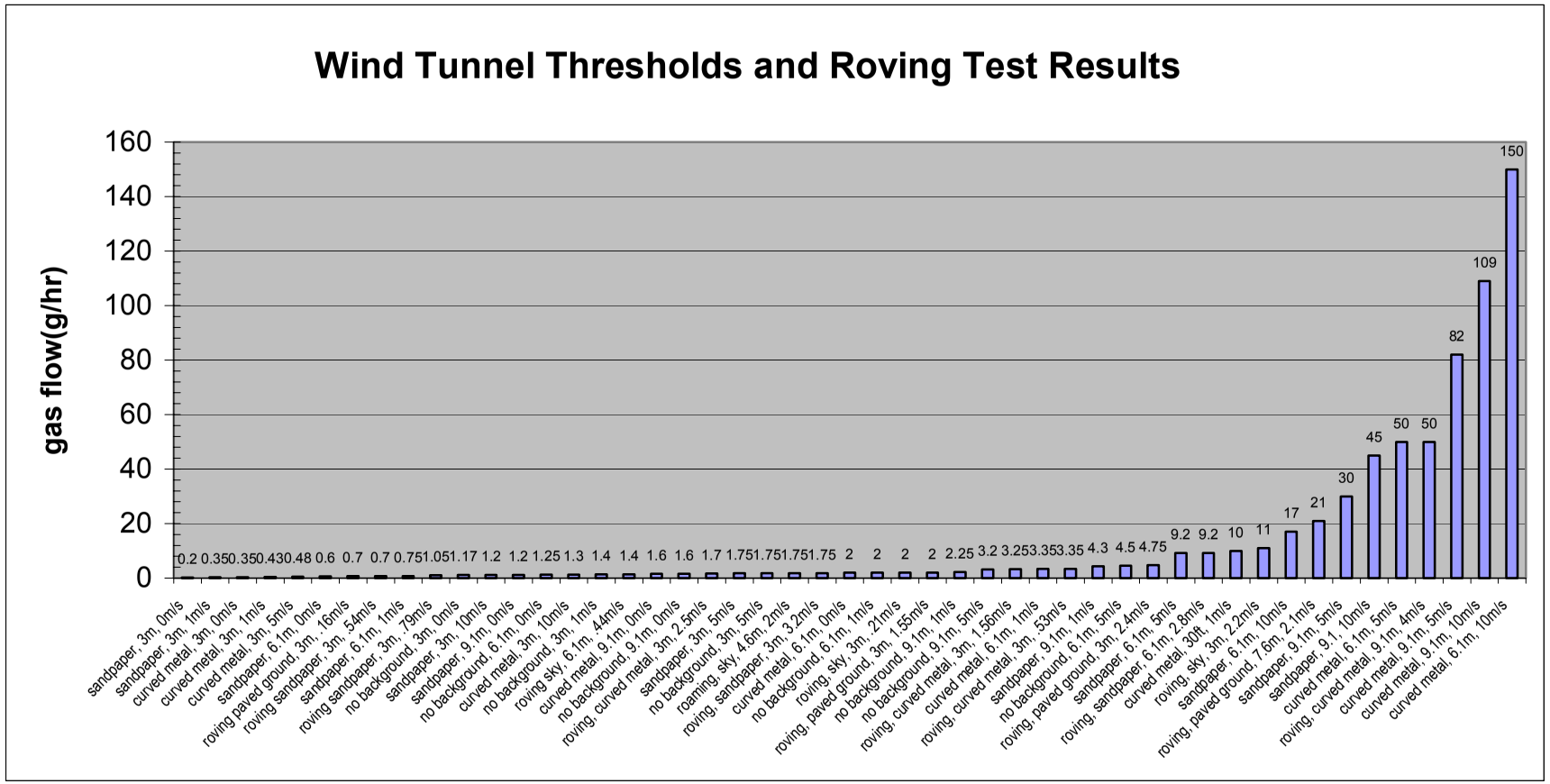
The results of the laboratory testing (wind tunnel and out-door roving tests) of the fiber laser for all conditions are shown in Figure ES 4-1. As shown in the plot, the mass rate detection threshold exceeded 10 g/hr in only 10 cases. Seventy-three percent of the mass detection thresholds determined in the lab test were below 5 g/hr.

[3] Leak rate set at test component.

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Figure ES 4-1. Minimum Detected Mass Flow Rate for all Leak Conditions under Laboratory Testing



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Results of refinery testing with the fiber laser showed that the imager detected all leaks above 20 g/hr (see Figure ES 4-2). The mass leak rates were determined with bagging analysis. Below 20 g/hr, the fiber laser detected roughly 50 percent of the leaks. Some leaks at lower mass rates were detected when a background was added behind the gas cloud.

Figure ES 4-2. Fiber Laser Performance at Refinery during 2003 Testing[4]

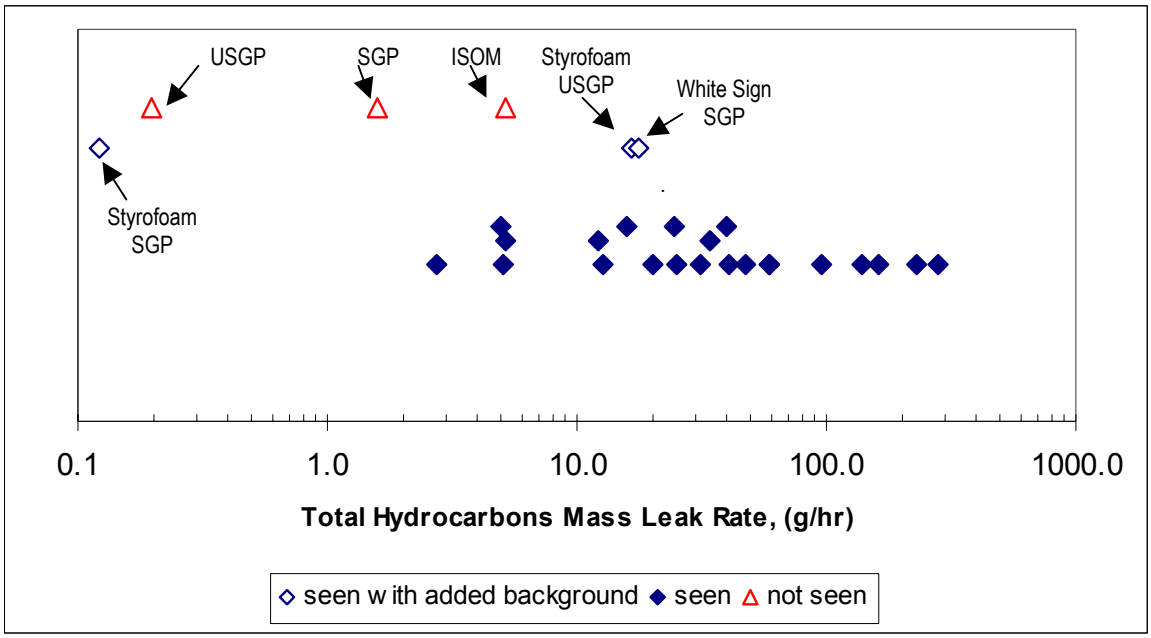
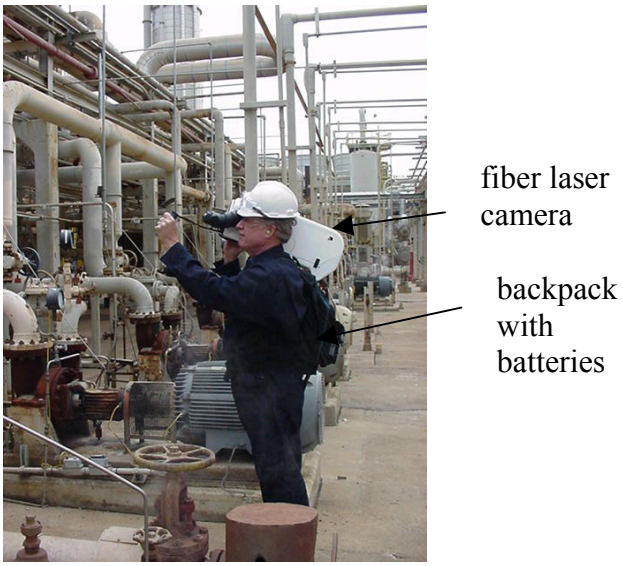


Figure ES 4-3. Scanning Refinery Components with Fiber Laser



[4] SGP – saturated gas plant; USGP – unsaturated gas plant; ISOM – isomerization plant

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