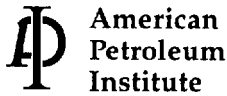


FUGITIVE EMISSIONS FROM EQUIPMENT LEAKS I: MONITORING MANUAL

Health and Environmental Affairs Department
Publication Number 342
May 1998



American Petroleum Institute

Environmental, Health, and Safety Mission and Guiding Principles

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Fugitive Emissions From Equipment Leaks I: Monitoring Manual

Health and Environmental Affairs Department

API PUBLICATION NUMBER 342

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ABSTRACT

The American Petroleum Institute (API) commissioned two manuals to be prepared, providing options and recommendations on procedures for obtaining inspection and maintenance (I/M) data from certain process equipment with the potential to leak "fugitive emissions." These manuals are designed to provide assistance to those who collect fugitive data, ensure regulatory compliance, and calculate emissions associated with these fugitive emissions. The manuals are focused on the recommended fugitive emission practices in the petroleum industry, specifically for refineries, petroleum marketing terminals, and the oil and gas production industries.

The first volume is entitled *Fugitive Emissions from Equipment Leaks I: Monitoring Manual*. This manual is designed primarily for those who manage or apply fugitive emission I/M programs at a facility. This manual discusses the compilation of a component inventory, describes monitoring equipment that meet specifications identified in the United States Environmental Protection Agency's (U.S. EPA) Method 21, describes quality control practices, explains the screening procedures, and addresses alternative measurement methods.

The second volume, entitled *Fugitive Emissions from Equipment Leaks II: Calculation Procedures for Petroleum Industry Facilities* (API Publ. 343), is designed primarily for those who perform the emission calculations associated with fugitive emissions. This manual also discusses equipment categories, provides an overview of available emission estimation approaches, presents sample calculations for different calculation methods, discusses issues that affect the determination of fugitive emissions, and addresses data management.



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LIST OF ACRONYMS

AC	- actual concentration
API	- American Petroleum Institute
ASTM	- American Society for Testing and Materials
CFC	- chlorofluorocarbons
COS	- carbonyl sulfide
CS ₂	- carbon disulfide
FID	- flame ionization detector
HAP	- hazardous air pollutant
I/M	- inspection and maintenance
ID	- identification
LDAR	- leak detection and repair
MTBE	- methyl tert-butyl ether
NDIR	- nondispersive infrared
NSPS	- New Source Performance Standards
OEL	- open-ended line
OVA	- organic vapor analyzer
PID	- photo ionization detector
ppmv	- parts per million by volume
PRV	- pressure relief valve
RF	- response factor
SOCMI	- Synthetic Organic Chemical Manufacturing Industry
SV	- screening valve
TLV	- threshold limit value
TOC	- total organic compounds
TVA	- total vapor analyzer
U.S. EPA	- United States Environmental Protection Agency
VOC	- volatile organic compound



SECTION 1.0 INTRODUCTION

This manual has been prepared for the American Petroleum Institute (API) to provide a reference for screening and data management techniques for certain process equipment that have the potential to leak "fugitive emissions." These fugitive emissions are regulated by a number of federal, state, and local regulations that are designed to control the emissions of Volatile Organic Compounds (VOCs) and organic Hazardous Air Pollutants (HAPs). Screening is the procedure of using a handheld analyzer to gather VOC and HAP readings from process equipment such as valves, pumps, compressors, and connectors.

The primary objective of this document is to present methods that will assist in obtaining quality inspection and maintenance (I/M) data. An I/M program is the Leak Detection and Repair (LDAR) activity associated with components that screen above a regulatory-specified-threshold level. A variety of regulatory interpretations and applications of I/M methods have resulted in confusion regarding recommended or required methodology. This document was designed to reduce this confusion by clearly explaining monitoring options and in some cases providing recommendations. This guidance will assist with compliance with several different regulations affecting fugitive emissions. This guidance should also assist facilities to collect and manage data more efficiently.

This document is Volume I of a two volume set. The companion volume, Volume II, is designed to present the latest recommendations

for calculating fugitive emissions for petroleum industry facilities.

Note:

Some requirements identified in this document may not be applicable in all locations. Care should be taken when applying the recommendations in this document to ensure that these recommendations meet all local regulatory requirements and internal facility procedures to run an effective I/M program.

The remainder of this document is organized as follows:

- Section 2.0 discusses the compilation of a component inventory including a discussion of regulated equipment and component tracking recommendations;
- Section 3.0 identifies monitoring equipment that meet U.S. EPA Method 21 specifications;
- Section 4.0 discusses quality control;
- Section 5.0 explains the screening procedure;
- Section 6.0 addresses alternative measurement methods; and
- Section 7.0 includes the references.

SECTION 2.0

EQUIPMENT INVENTORIES

An accurate equipment inventory is essential for most inspection and maintenance (I/M) programs, as defined in this volume, and for determining the amount of emissions from equipment leaks, as provided in Volume II. This section identifies the process equipment that may be subject to equipment leak regulations and explains how to count and keep track of these components.

2.1 EQUIPMENT TYPES

The primary equipment types (or component types) that could be sources of fugitive emissions are:

- Agitators;
- Compressors;
- Connectors;
- Open-ended lines;
- Pressure relief devices;
- Pumps;
- Sampling connections;
- Valves; and
- Others.

Graphical depictions of these types of components are shown in Section 5.0 of this volume.

The seals on agitators, compressors and pumps are the source of equipment leaks associated with these equipment types; thus, the emissions from these equipment types are often described as from agitator seals, compressor seals and pump seals. In this volume and the companion volume (Volume II), this terminology (with or without seals) is often used interchangeably. For example, a leak could be described as coming from a "pump" or from a "pump seal." Due to the evolving nature of nomenclature, other terminology is also often used interchangeably to describe equipment types. For example, connectors can also be referred to as "fittings."

Subsequent sections of this report provide a description of these component types and information related to how these components leak.

2.1.1 Agitators

Agitators are used to stir or blend chemicals. Four seal arrangements are commonly used with agitators: packed seals, mechanical seals, hydraulic seals, and lip seals.

A packed seal consists of a cavity, called a *stuffing box*, in the agitator casing filled with a packing gland to form a seal around the shaft. There are several types of single mechanical seals, with many variations to their basic design and arrangement, but all have a lapped seal face between a stationary element and a rotating seal ring. There are also many variations of dual and tandem mechanical seals. Dual mechanical seals with the following characteristics are

considered to be leak free (and therefore typically do not require monitoring):

- Barrier fluids pressurized higher than the agitator cavity;
- A barrier fluid reservoir vented to a control device; and
- A pressure tight barrier fluid with a pressure alarm indicator.

In a hydraulic seal, an annular cup attached to the process vessel contains a liquid that contacts an inverted cup attached to the rotating agitator shaft. Although it is the simplest agitator shaft seal, the hydraulic seal is limited to low temperature/low pressure applications and can handle only very small pressure changes. A lip seal consists of a spring-loaded, non-lubricated elastomer element, and is limited in application to low-pressure, top-entering agitators.

Agitator seals can leak because of poor installation, aging, and deterioration of the seals themselves, thermal stress, and vibration.

2.1.2 Compressors

Compressors provide the force to transport gases through a process unit in much the same way that pumps transport liquids. There are centrifugal, reciprocating, and rotary compressors in use by industries affected by equipment leak regulations. The sealing mechanisms for compressors are similar to the packed and mechanical seals for agitators.

2.1.3 Connectors

Connectors are used to join sections of piping and equipment. Connectors can be flanges, screwed or threaded connectors, union connectors, tubing connectors, caps, plugs, etc.

Flanges are bolted, gasket-sealed connectors. Flanges are normally used for pipes with diameters of 2.0 inches or greater. The primary causes of flange leakage are poor installation, aging and deterioration of the gasket, thermal stress and vibration. Flanges can also leak if improper gasket material is chosen.

The non-flange connectors (screwed, union, tubing, caps, plugs, etc.) typically are used to connect piping and equipment having diameters of 2.0 inches or less. Emissions from these connectors can occur as the sealant ages and eventually cracks. Leakage can also occur as the result of poor assembly or sealant application, or from thermal stress or vibration on the piping and fittings.

2.1.4 Open-ended Lines

Some valves are installed in a system so that they function with the downstream line open to the atmosphere. A faulty valve seat or incompletely closed valve on such an open-ended line would result in a leakage through the open end. In some locations open-ended lines are prohibited. A cap, plug, or blind flange used to control leaks from open-ended lines can also leak from improper installation and aging and deterioration of the gasket or threads. Because these leaks are similar to those found in connectors, a potentially open-ended line that is

capped, plugged, or blind flanged is counted as a connector.

2.1.5 Pressure Relief Devices

Pressure relief devices are safety devices commonly used in petroleum and chemical facilities to prevent operating pressures from exceeding the maximum allowable working pressures of the process equipment. Note that when a pressure relief device functions as designed during an over-pressure incident and allows pressure to be reduced it is not considered an equipment leak. Equipment leaks from pressure relief devices occur when material escapes from the pressure relief device when it is in the closed position. These leaks can occur from the aging and deterioration of packing or sealing materials.

The most common pressure relief device is a spring-loaded pressure relief valve (PRV). The PRV is designed to open when the operating pressure exceeds a set pressure and to reseal after the operating pressure has decreased to below the set pressure.

Another pressure relief device is a rupture disk. Rupture disks are sometimes used upstream of PRVs to control emissions during normal operations. These disks rupture when a set pressure is exceeded, thereby allowing the system to depressurize. Rupture disks do not permit emissions during normal operations. During normal operations it should be assumed that rupture disks do not have any fugitive emissions. However, as a caution, rupture disks are generally not advisable for small diameters due to restriction of flow.

2.1.6 Pumps

Pumps are used extensively in the petroleum industries for the movement of liquids. The centrifugal pump is the most widely used pump type in the petroleum industry; however, other types, such as the positive displacement (reciprocating) pump, are also used. Liquids transferred by pump can leak at the point of contact between the moving shaft and the stationary casing. Consequently, all pumps except the sealless types, such as canned-motor, magnetic drive, and diaphragm pumps, require a seal at the point where the shaft penetrates the housing in order to isolate the pumped fluid from the environment. Sealless pumps do not have fugitive emissions.

Packed and mechanical seals for pumps are similar in design and application to packed and mechanical seals for agitators. Packed seals can be used on both reciprocating and centrifugal pumps. Mechanical seals are limited in application to pumps with rotating shafts. The cause of pump seal leaks are similar to those described for agitators.

2.1.7 Sampling Connections

Sampling connections are fittings where samples are routinely taken for process and quality control purposes. A sampling connection has a specific function (to aid in sample taking) with specific types of emissions that are distinct from those described previously. A sampling connection can leak from a faulty valve seat or incompletely closed valve that is upstream of the sampling connection. A sampling connection

can also have emissions from the flushing of the line during the sampling process.

2.1.8 Valves

Except for connectors, valves are the most common process equipment type found in the petroleum industries. Valves are available in many designs, and most contain a valve stem that operates to restrict or allow fluid flow. Typically, the stem is sealed by a packing gland or O-ring to prevent leakage of process fluid to the atmosphere. Emissions from valves occur at the stem or gland area of the valve body when the packing or O-ring in the valve deteriorates. Some emissions could also occur from the valve housing, generally at the bonnet flange.

Bellows valves and rubber diaphragm valves have negligible emissions as long as there is not a break in the bellows or the diaphragm.

2.1.9 Others

Other component types can also be a source of fugitive emissions. These other types are usually small in number at a facility, and they might be unique to one sector of the petroleum industry. Other equipment types that are not listed above that may be considered as sources of fugitive emissions are: instruments, loading arms, stuffing boxes, site glasses, vents, dump lever arms, diaphragms, drains, hatches, meters, and polished rods. These component types can leak for a variety of reasons including improper installation, aging, deterioration, thermal stress, and vibration.

2.2 COUNTING COMPONENTS

An accurate inventory of components is essential for a precise determination of fugitive emissions as well as to ensure that all appropriate components are monitored. The first step in developing this inventory is to define the process unit boundaries. A process unit is the smallest set of process equipment that can operate independently and includes all operations necessary to achieve its process objective. All of the components, by component type, need to be specified within that process unit.

Components can, in some cases, be identified from process flow diagrams. However, process flow diagrams may not include all of the components that emit fugitive emissions, because all changes in the numbers of valves or connectors may not have been included on the flow diagrams. Therefore, it is usually necessary to systematically follow process streams while counting, categorizing, and labeling components as you go. Even after this systematic approach, it is recommended to divide the process unit into a grid to search for components (usually connectors) that were missed on the initial survey.

Some components will not be easily accessible. Many flanges are covered with insulation, and some components may be beyond the reach of a person on the ground. The exact definition of what is considered inaccessible differs among the various regulations controlling fugitive emissions from equipment leaks. Difficult to monitor (defined in the regulations) or covered components are often considered

inaccessible. Although monitoring requirements may differ for inaccessible components, an inventory of these components would be needed for emission calculation purposes if it is required to calculate all potential sources of fugitive emissions.

Some components will be unsafe to monitor. Unsafe-to-monitor equipment could be associated with high temperature or pressure operations or with process specific safety concerns. These unsafe-to-monitor components should be included as part of the inventory for fugitive emission calculations.

Note that more components may need to be counted for emission calculation purposes than need to be monitored as part of a leak detection and repair program (i.e., "unsafe-to-monitor," "heavy liquid service," etc.). Even though no monitoring may be required, it has been found that some of these components may leak, even if the emission rate is low. Average emission factors for these components can be applied when emission calculations are needed. In order to apply these average emission factors, component counts are needed. It may be advisable to utilize some unique codes in the component inventory to keep track of these special categories.

Other components may not need to be monitored or included in emission estimates. For example, leakless components (such as welded connectors), components not in VOC or HAP service, or components under a vacuum should be excluded from inventories and not

used for either monitoring or emission calculation purposes.

The components need to be counted according to the governing regulation. If emission calculations are being performed for submittal to a regulatory agency, it should be noted that each agency may differently define what constitutes a component. Therefore, it is critical to understand the regulations that govern the inspection and maintenance activities for each facility.

2.2.1 Agitators

Each agitator seal is associated with a single agitator housing penetration. Therefore, an agitator may have a single housing penetration equipped with either a single or double mechanical seal that is counted as one agitator seal. Some agitators, however, have a shaft that penetrates both sides of the agitator housing with a separate seal on both the inboard and outboard sides. This type of arrangement is counted as two agitator seals.

2.2.2 Compressors

Compressors can have housing penetrations and seals that are similar to agitators and are counted in the same fashion. A compressor may have a single housing penetration equipped with either a single or double mechanical seal that is counted as one compressor seal. However, if the compressor has a shaft that penetrates both sides of the compressor housing with a separate seal on both the inboard and outboard sides, it should be counted as two compressor seals.

Large compressors often include several other component types that are needed for the compressor to function. For instance, a compressor could also include valves on cylinders and multiple connectors on the compressor housing or piping. These other component types, although attached to the compressor, should be counted separately as components themselves and not included as a part of the compressor.

2.2.3 Connectors

A connector is typically defined for equipment leak purposes as any fitting used to join two pieces of pipe and/or components together, with the exception of welded connectors which are assumed to be leak free. This definition includes flanges, threaded connectors, unions, tubing fittings, caps, plugs, etc.

The definition of a connector may, however, vary by regulation. In some cases, connectors have been identified as only including flanges. In other cases, all types of connectors (threaded, union, tubing, etc.) are included. These other types of connectors have occasionally been found to leak. Therefore, if it is desired to develop the most accurate estimate of fugitive emissions, these other types of connectors should be included in component inventories.

There has been some confusion over how to count the many varieties of connectors. Much of this confusion arises from the use of aggregate component names that include multiple connectors. For instance, an elbow fitting is a

common fitting in petroleum facilities that would have a connector on each end of a 90 degree bend of pipe. (See Figure 2-1). Although many people think of an elbow as one fitting, there are actually two connectors, either of which can leak independently of the other. Similarly, a "Tee" fitting would be counted as three connectors. A spool piece or swage piece would be counted as two connectors. The most difficult fitting to explain is the union connector, which has two potential leak sites (one at the threads and one at the back of the collar nut) but is counted as a single connector.

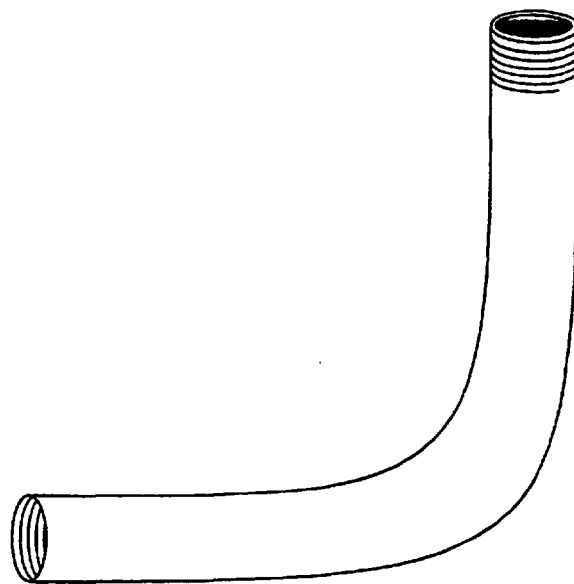


Figure 2-1. Threaded Connector Elbow

Heat exchangers have flanged ends and often have several screwed connectors. Some facilities and regulators count these components in inventories and others do not. Again, regulatory direction and facility operating practice for maintaining these components

should be followed. However, note that these flanged ends and screwed connectors have also been found to leak on occasion.

2.2.4 Open-ended Lines

Open-ended lines are generally easy to count. Some confusion does occur when a potentially open-ended line is controlled with a cap, plug, or blind flange. Such a controlled potentially open-ended line is counted as a connector, because that is the effective leak sealing mechanism.

2.2.5 Pressure Relief Devices

The most common pressure relief device is a spring-loaded pressure relief valve (PRV). Another pressure relief device is a rupture disk. Both pressure relief valves and rupture disks should be counted in the same fashion as valves. It is recommended that the flange on the upstream side of pressure relief devices be counted as a separate component from the pressure relief device. The downstream flange should also be counted as a separate component if the downstream line is not exposed to the atmosphere (such as a line connected to a different process vessel).

2.2.6 Pumps

Like agitators, each pump seal is associated with a single pump housing penetration. Therefore, a pump may have a single housing penetration equipped with either a single or double mechanical seal that is counted as one pump seal. Some pumps, however, have a shaft that penetrates both sides of the pump housing with a separate seal on both the inboard and

outboard sides. This type of arrangement is counted as two pump seals.

2.2.7 Sampling Connections

Each uncontrolled sampling connection should be counted uniquely. Sampling connections can have emissions reduced by using a closed-loop system or collecting purged process fluid and transferring it to a control device or back to the process.

The distinction between sampling connections and other open-ended lines is dependent on both the configuration and use. An open-ended line that is used for routine sampling would be counted as both an open-ended line and a sampling connection. If equipped with a cap or plug, the same system would be counted as a connector (threads of the cap or plug) and a sampling connection. On the other hand, an open-ended line that is used as a drain or a high point vent would not be counted as a sampling connection.

2.2.8 Valves

Valves are most commonly defined for counting purposes as including the stem seal, the packing gland, and the connection between the parts of a multi-part valve body (like the bonnet flange). This definition should provide the most accuracy in calculating emissions, because it is the same definition that was used in the bagging studies from which the average factors and the emission correlation equations were developed (Ricks, 1993; Ricks, 1994; Webb, 1993). Most regulatory agencies also use this definition for valves.

Although not supported by methods used to develop emission factors and emission correlation equations, some regulatory agencies may define a valve for inspection and maintenance purposes as including the flanges on either side of the valve. Figure 2-2 shows the locations of these flanges on some valves. Regulations may provide conflicting definitions of a valve, or may not provide a definition at all. The result is that facilities across the nation may differ in their counting practices. Some include the flanges on either side as part of the valve, and some facilities count these flanges as separate components. Therefore, one needs to refer to regulations for the appropriate action.

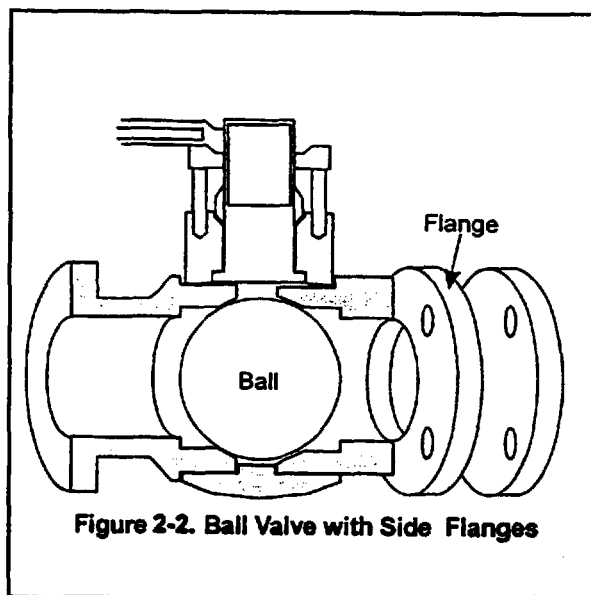


Figure 2-2. Ball Valve with Side Flanges

2.2.9 Others

Other component types such as instruments, loading arms, stuffing boxes, site glasses, vents diaphragms, drains, hatches, motors, and polished rods may also need to be counted to develop a complete inventory of potential fugitive emission sources. Again, one needs to refer to regulations for appropriate counting of these other types of components.

2.3 COMPONENT TRACKING

Keeping track of components, their periodic inspection results, and the repairs performed, requires a component identification system, as well as a consistent system for data collection, management, and reporting. In designing its component tracking system, each facility should consider such factors as facility complexity, internal management practices, and procedures and regulatory requirements.

2.3.1 Component Identification

Certain information is recommended for component identification. A method to identify the components is also needed. These recommendations are explained in this section.

2.3.1.1 Recommended Information. It is recommended that each component to be monitored be uniquely identified. The identification is more than just a numbering or tagging scheme. The following items can be used to uniquely identify components:

- Process unit descriptions;
- Equipment ID;

- Type of equipment (i.e., pumps, valves, etc.);
- Type of service (i.e., gas/vapor, light liquid, or heavy liquid);
- Primary material being transported in the line; and
- Unique location descriptions (to allow for repeat monitoring of targeted components).

The service type of a component identifies the general type of material carried in the process lines under normal conditions (as opposed to conditions of leakage as fugitive emissions). Gas/vapor service indicates that the piece of equipment contains process fluid that is in the gaseous state at operating conditions. An example of the distinction between normal and leakage conditions is liquefied butane in a process line that escapes as a fugitive emission. The service type for a component leaking this material is light liquid service. The distinction between light liquid service and heavy liquid service is defined differently in different regulations. In addition to the service type, the percent of VOCs and HAPs in the lines will directly impact if certain regulations apply. Please refer to the specific applicable regulation for details.

2.3.1.2 Tagging. Some method is required to uniquely identify components. One of the most common methods to identify components is called "tagging," which involves placing some identifier directly on the component. Facilities use a variety of tagging strategies. Some elect to physically tag each component. Others tag only some major pieces of equipment and identify the others by associations. Yet, others

might only tag leaking components, following inspection, to identify components for repair. These various tagging schemes might entail unique identifiers on diagrams similar to process flow diagrams. Inspectors locate, monitor, and repair components based on any combination of tags and diagrams used in their facility.

If tagging is used, several methods are in use to maintain the identity of each individual component. Currently, most facilities are using some type of metal or plastic tags. The tag will have a unique identifying code for each component. The code can be either alphabetically-based, numerically-based, or a combination of alpha-numeric characters. The code may have identifiers for the:

- Process unit;
- Area of the process unit;
- Type of equipment being tested;
- Chronological placement of the tags; and
- Process fluids in the process streams.

Metal and plastic tags have the advantage of being a low cost method of identifying components uniquely. All types of tags have the disadvantage of being influenced by the occasionally harsh petroleum industry environment of corrosion, erosion, grease, paint, or dirt. Embossed metal or plastic tags probably currently have the best resistance to this harsh environment. Physical tags might also get lost or misplaced following some maintenance activity.

Other methods for identifying components uniquely are also in use today. Some facilities use bar codes. The bar codes are similar to those used in grocery stores to automate pricing and checkouts. A wand can be passed over these bar codes that accepts the coded information (name of component, location, etc.) and records it in a database. Then the inspection and repair results are recorded separately. Use of bar codes, and some other new tag types, does ensure that a component was indeed visited by inspection teams. However, bar codes are also subject to the degrading influence of the potentially harsh petroleum industry environment including being difficult to read if covered by grime, rain, snow, and even morning dew.

Another version of bar codes is also on the market. These bar codes are called "2D" tags. These tags can include much more information than is stored with the standard bar codes similar to those used in grocery stores. For example, historical information, or specific hazard information can be stored on these same tags.

A method that appears to be less subject to the damages of a petroleum industry environment is the use of "hotel keys." These hotel keys have encoded information holepunched into a metal tag. The hotel keys are read by a hotel key reader to identify the name of the component, etc.

Other identification methods are under development. Potential exists for data to be stored on electronic chips (or "buttons") that can be downloaded to data retrieval equipment in the field. The buttons could contain the identifying

information. Radio frequency identification systems also have potential to transmit component information to data readers. Future identifiers may give exact location descriptions based on global mapping formats.

Regardless of the tagging strategy used, it must be decided at the start of the tagging process how and which components will be tagged. Most regulations require unique identifying information for each component subject to inspection and repair in the form of a "logbook," but do not necessarily require physical tagging of components. The exact method for identifying components should be selected by facilities in line with their size, complexity, and compliance documentation system in place. For example, if regulations do not require routine inspection of connectors, then some sort of identifying tag for all of the non-connector components would be a manageable alternative. If it is required to inspect and repair connectors, then the tagging of components becomes much more difficult.

If facilities choose to tag every single component, including every individual connector, field accessible information could be maximized. However, it can be extremely costly to place that many tags and manage them over time. Furthermore, replacing these tags after repairs affecting process lines can sometimes be very difficult. After some repairs, buckets of tags might become available that have to be put back in exactly the right locations. This would require accurate process flow diagrams that indicate where each component (by tag ID) is located with reference to specific equipment.

Facilities that choose not to put tags on each connector could identify them in their databases based on the distance from a tagged valve or pump. For example, the valve could have the code PUB4482. The first connector beyond the valve could have the code PUB4482-A. The second connector could have the code of PUB4482-B, and so forth. The location of these connectors is maintained either in a database or process flow diagram.

The selection of a tagging method and which components to tag must be made individually by each facility. Decisions should be based on regulatory requirements, ease of implementation, ease of inspection and repair, initial cost, and replacement cost.

2.3.2 Data Collection

Once an identification method has been established, the method to collect inspection and repair information must be resolved. The options for screening instruments are discussed in the next section. Data collected are gathered either on hard-copy sheets, or by a data logger, or sometimes by a combination of both.

An example data sheet for the collection of screening data is shown in Figure 2-3. These sheets require the name of the process unit, the date of the inspection, the inspector's name, the component ID, the background screening value, the measured screening value, and comments. There are many variations of these data sheets. Information on repair attempts and post-repair values, failure code, and repair code are often recorded on the same sheet or a supplemental sheet.

Hard-copy data sheets have the advantage of being less costly initially than the purchase of data loggers. However, typically these data sheets require more time to complete in the field and to load into a data management system than using data loggers. The costs for the additional time required to record information on the hard-copy sheets should be evaluated against the additional costs for the data loggers.

Data loggers are hand-held or wearable computers that are carried into the field. Rather than writing data in a log, inspectors can directly enter readings into the device's memory, which can later be transferred directly to a database. Some data loggers are being built into the analyzer itself or can be linked with the analyzer. These data loggers do not require that the screening values be keyed into the system. The screening values are automatically recorded with the press of a button. Care needs to be taken to ensure that the recorded screening values represent a maximum screening reading taken over a time period of at least two times the response time rather than an instantaneous reading. Comments still can be typed into the device. Other data loggers require a reading to be made by the inspector from the analyzer and then keyed in by the inspector into the machine.

Data loggers have many advantages over hard copy sheets. In the past, two inspectors were frequently used for inspections; one to operate the instrument, the second to record the information on the hard-copy sheets. With data loggers it is possible to perform this work with a single inspector. Frequently, the use of data loggers is much quicker than using hard-copy sheets because much of the required information