

Evaluation Methodology for Software Based Leak Detection Systems

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American Petroleum Institute
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Manufacturing, Distribution and Marketing Department

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American Petroleum Institute

Evaluation Methodology for Software Based Leak Detection Systems

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As with any technical document, it is possible that there may be cases where further clarification or additional depth is warranted. If necessary, and within reason, UTSI International Corporation will issue a revision to these procedures. Please address comments to UTSI International Corporation, Pipeline Consulting Division, 1560 West Bay Area Boulevard, Suite 300, Friendswood, Texas, 77546, or send email to pipecons@utsi.com.

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Chapter One

Executive Summary

In December, 1992 the American Petroleum Institute (API), General Committee on Pipelines, approved a project to address the needs of pipeline companies regarding the evaluation of software-based leak detection systems. The purpose of the project was to define a uniform methodology which could be employed by pipeline companies as an aid for the evaluation of software-based leak detection systems. UTSI International Corporation was contracted by the API to define and develop the evaluation methodology to be consistent with the needs of pipelines and vendors and to supervise validation testing. Development of this methodology has been made possible through the cooperation of many pipeline companies and vendors of software-based leak detection systems.

Validation of the procedures was an integral part of the methodology development project. The Validation Process was designed to apply the concepts established during the project to real pipeline systems, and to evaluate the effectiveness of those concepts as an aid to the task of selecting a leak detection solution for a given pipeline system.

The procedures defined within this document have been developed under the premise that one uniform set of information, consisting of a description of the pipeline's physical configuration, samples of run-time or simulated data, and definition of the pipeline company's performance expectations will allow any software company to estimate expected leak detection system performance in a more efficient, and presumably a lower cost manner. Results from each vendor's analysis are to be compiled into a standardized format for presentation to the pipeline company so that interpretation of the vendor's product capabilities can be easily achieved.

A pipeline company wishing to evaluate a given vendor's leak detection system must provide the vendor with the following information related to the subject pipeline system or systems:

- A pipeline configuration file,
- Data files and supporting information for sample test scenarios, and
- A specification of the desired leak detection system performance.

The vendor will use the information in the configuration file to develop a suitable representation of the pipeline. The vendor's software-based leak detection system will then be installed to operate on the simulated pipeline, and tests will be performed using the operational data provided in the data files. Once the vendor has completed the analysis, a report will be prepared defining the observed performance of the software based leak detection system with respect to the performance metrics, configuration definition, and the representative data sets specified by the pipeline company.

This document contains step-by-step procedures for defining pipeline configurations, run-time data samples, and performance specifications. In addition, the procedures include a definition of the recommended vendor report format and suggestions for its interpretation.

Overview

Within the context of these procedures, it is assumed that leak detection systems are acquired for the primary purpose of detecting leaks if and when they occur. A natural extension of that primary purpose is to estimate the size and location of a leak, if one should be detected. An equally natural extension is to detect and respond to situations that might impair the ability of the leak detection system to perform its primary function. Thus the selection of a system for application on a specific pipeline involves evaluation of the expected leak detection performance, as well as operational features and functions that might add to the utility of the system but do not directly improve leak detection performance. The selection process might also include commercial and economic criteria such as system cost, support, ease of maintenance, and so forth. Since the commercial analysis process for any given project can vary significantly between operating companies, it is considered to be beyond the scope and intent of this document, and will not be addressed further herein.

The procedures presented herein acknowledge that there are physical limits to the size of leak that can be detected. Furthermore, the task of determining the best leak detection solution for a given pipeline always involves performance tradeoffs. In some cases, these tradeoffs must be made before the leak detection system is placed into operation. Ideally, a vendor could state exactly how their leak detection system would perform on a given pipeline configuration, prior to its installation. Often this is not possible due to unavailable or incomplete information about the physical pipeline and its operation.

The focus of these procedures is to establish an evaluation methodology that can be adapted to a wide range of pipeline systems and operating company requirements. The intent is to provide a vehicle that can be adapted to accommodate future changes in leak detection techniques or pipeline operations.

The evaluation procedure consists of the following six parts:

1. Gathering information and describing the physical pipeline,
2. Assembling case files and operational data samples,
3. Specifying and prioritizing performance metrics,
4. Analyzing and projecting leak detection system performance,
5. Reporting projected performance in a standard format, and
6. Appraising the performance of the leak detection system for the pipeline.

Parts 1, 2, and 3 are executed by the pipeline company. The pipeline configuration data, operational data and performance requirements are then submitted to the potential leak detection vendors, who execute parts 4 and 5, and provide their results to the pipeline company. The company then executes part 6 to determine the suitability of a given leak detection system for the target pipeline(s).

A keyword-oriented file structure has been developed to facilitate specification of the pipeline configuration. A data file format has also been defined, along with standards for specification of performance criteria and presentation of results. A discussion of the reliability, sensitivity, accuracy and

robustness performance metrics is provided as an aid to the pipeline engineer, along with a glossary of leak detection terminology.

The step-by-step procedures presented in Chapter Six require that the pipeline engineer be familiar with the supporting information contained within Chapters Two through Five. The supporting information is referred to throughout the procedures, and must be used for the preparation of information to be transmitted to the software based leak detection system vendor(s).

Chapter Two

Overview of Pipeline Leak Detection

Pipeline leak detection is treated herein as a classical problem in parameter estimation. In other words, the leak detection system estimates parameters based upon measurement data. The leak parameter estimates are then examined to decide if they warrant the issuance of an alarm to indicate the likely presence of an actual leak. Note that the estimated parameters depend upon the nature of the leak detection system. These might include the leak flow rate, amount of fluid lost, magnitude of pressure or flow disturbance at the leak site, most probable location of the leak, and so forth. Virtually all systems that make a statistical decision based upon a set of measurement data can be discussed within the framework of this model.

As represented in Figure 1, the detection problem is a step-wise process that logically separates each of the system's components in terms of their relationship to the desired result. The software based leak detection system relies on data values acquired from some reliable source, usually the real-time SCADA system, to provide a series of data sets representative of actual conditions at any given point in time. Once data for a given time period has been acquired, it is subjected to some pre-determined mathematical or statistical analysis process that generates additional data based on an assumed model of the pipeline and its associated parameters. Results from the analysis process are produced in the form of parameter estimates. These parameter estimates are in turn subjected to some probability law or decision criteria to determine if a leak does indeed exist. In the simplest case, a given set of data can represent one of two possible outcomes; the existence of a leak or the absence of one. Typically, the process requires an examination of many complex data interrelationships in order to provide acceptable results. Depending upon the nature of the leak detection system, this examination might be done over a small window in time or it could involve periods of several minutes or even hours. In some cases, the time required to make a decision might also depend upon the size of the leak, if one should occur.

The phrase "model of the pipeline" is used here and throughout this document in the most general sense. Some vendors and client companies tend to group software based leak detection systems into the two categories "model based" and "not model based", depending upon whether or not the system involves a fluid dynamics model. In fact, this is an incomplete characterization. Fluid dynamics models employ one or more of the basic equations of fluid mechanics, which include the equations of continuity, momentum, and energy. However, there are a number of software based leak detection methods, all of which are based upon some set of rules or "model" describing the pipeline operation. It is this set of rules that determines how such systems use the measurement data to make decisions.

Leak Detection Performance

Determination of the presence or absence of a leak requires that the software based leak detection system has prior knowledge of the problem to be solved and some pre-determined criteria upon which to base its decision. In the most general sense, there are four possible outcomes each time the leak hypothesis is tested:

1. The system correctly indicates that there is no leak,

2. The system correctly indicates that there is a leak,
3. The system incorrectly indicates that there is a leak, and
4. The system incorrectly indicates that there is no leak (failure to detect).

Outcomes 1 and 2 constitute proper operation of the leak detection system whereas outcomes 3 and 4 constitute failure of the system. In the ideal system outcomes 3 and 4 never occur.

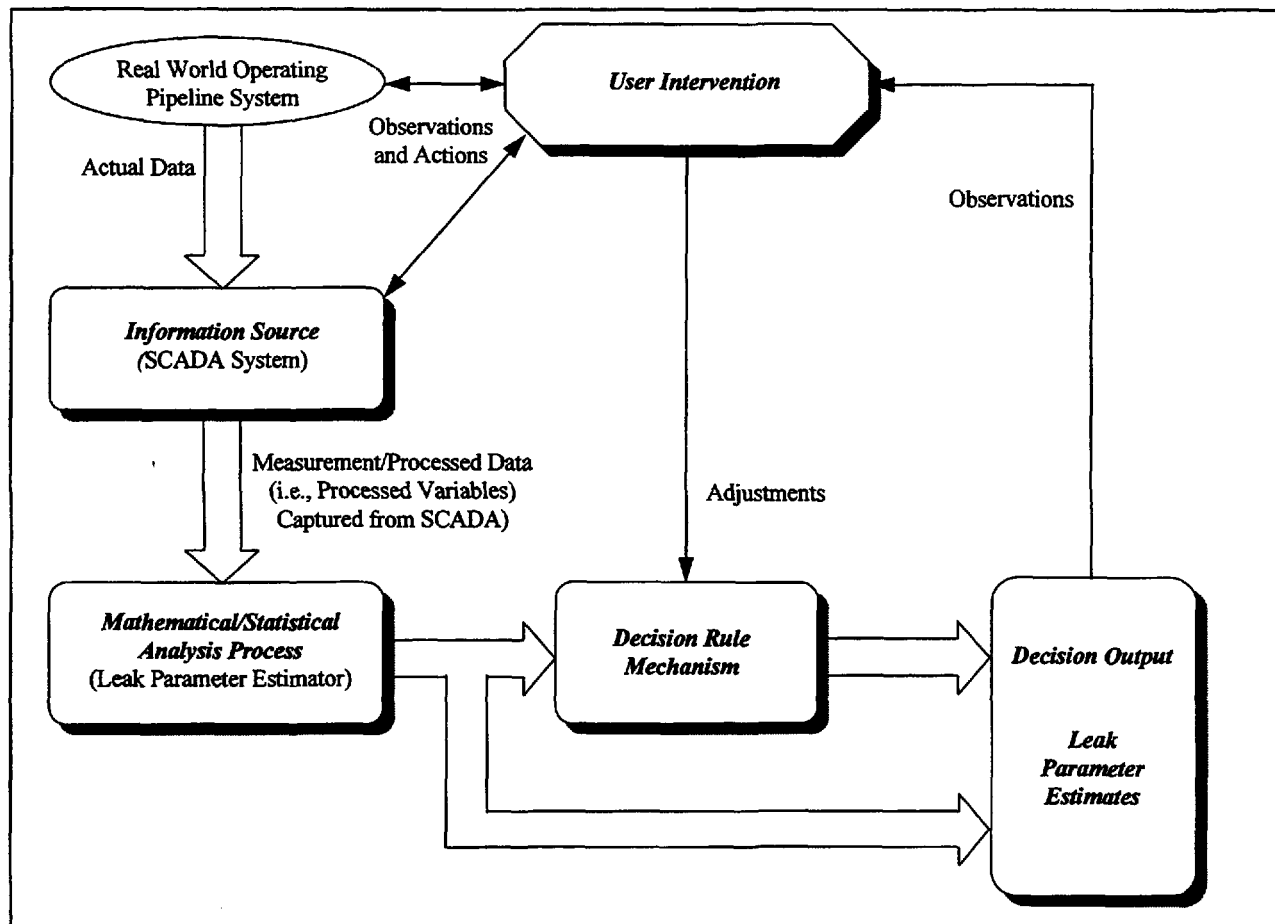


Figure 1: Generalized example of the software based leak detection process.

To further characterize the ideal leak detection system, one must recognize the importance of an accurate and timely response in the event that a leak occurs. With this in mind, the characteristics of an "ideal leak detection system" are easily stated. Such an ideal system would always and immediately detect any leak that might occur and it would never incorrectly declare a leak. Furthermore, it would always and immediately provide an accurate estimate of the location and size of any leak. Of course, there are no known software based leak detection systems that currently provide this ideal level of performance. Furthermore, certain characteristics of the "ideal leak detection system" impose conflicting requirements upon practical leak detection systems. For that reason, it is not likely that such an ideal system can ever be achieved in practice. Thus the task of determining the best leak detection solution for a given pipeline

always involves performance tradeoffs. In many cases these tradeoffs must be judged before the leak detection system is actually installed on the pipeline. In some cases, the leak detection system may be selected before the pipeline itself is placed into operation. Once installed, periodic adjustments of leak detection system parameters might be necessary to account for operational experience, configuration changes, and so forth.

Appraisal of Leak Detection System Performance

Determining the level of performance that can be expected from a software based leak detection system is a process that involves several factors, some of which may not be within the control of the pipeline company or the leak detection vendor. Many implementations assume that a certain degree of error will exist within the specification of the pipeline and with the measurements taken during operation, and provide algorithms to compensate for such inconsistencies. Additionally, some vendors require that the system be subjected to a tuning period during the installation process, so that adjustments to the configuration and the corresponding compensation algorithms can be made using real-time pipeline measurement information. Although this can sometimes be a tedious and time consuming process, it is generally accepted in the case of the more complex solutions, in that the ultimate outcome produces more accurate and reliable results.

Ideally a vendor, given accurate information, could state exactly how their software based leak detection system would perform on a given pipeline configuration, prior to its installation. In practice, this is sometimes difficult due to unavailable or incomplete information regarding the physical pipeline and its operation. The focus of this report is to identify a set of metrics that can be used to quantify performance projections, to suggest a method for the specification and prioritization of these metrics, and to define a procedure for the evaluation of leak detection system performance that can be adapted to a wide range of pipeline systems and operating company requirements.

Chapter Three

Output Data and Performance Metrics

This chapter deals primarily with the performance related aspects of software based leak detection systems. Selection of a software based leak detection system for a given application involves evaluation of the expected (or estimated) performance of the system, as well as operational features and functions that might add to the utility of the system but do not directly improve leak detection performance. The selection process for a specific pipeline system might also include commercial and economic criteria such as system cost, support, ease of maintenance, and so forth.

Any appraisal of leak detection system performance involves an assessment of the various tradeoffs that must be made when the system is installed. In practice, real and potential costs are incurred for each incorrect alarm, missed alarm, late alarm, and/or any other deviation from ideal leak detection system performance. Any evaluation of costs and liabilities associated with improper alarming is beyond the scope of this document. In order to establish appropriate performance criteria, the client pipeline company must perform their own assessment and understand the implications of that assessment with respect to the various categories of leak detection performance.

Performance of a software based leak detection system is tantamount to its ability to recognize leak conditions rapidly and without failure, so as to minimize fluid loss, property damage and the risk of personal injury. But this definition of performance is too broad to be useful to determine projected performance of a leak detection system on a given pipeline or set of pipelines. To that end, it is first necessary to decompose the broad definition of performance into more specific components. With that goal in mind, a wide range of criteria used by pipeline companies and vendors in the specification of leak detection system performance have been examined. These performance criteria can be grouped into four categories, or metrics, that determine a system's *reliability*, *sensitivity*, *accuracy*, and *robustness*. A definition and discussion of each of these performance metrics follows.

Reliability

Reliability is defined as a measure of the ability of a leak detection system to render accurate decisions about the possible existence of a leak on the pipeline, while operating within an envelope established by the leak detection system design. It follows that reliability is directly related to the probability of detecting a leak, given that a leak does in fact exist, and the probability of incorrectly declaring a leak, given that no leak has occurred. A system is considered to be more reliable if it consistently detects actual leaks without generating incorrect declarations. Conversely, a system which tends to incorrectly declare leaks is often considered to be less reliable. This is particularly true in cases where it is difficult for the pipeline operator to distinguish between actual leaks and incorrect declarations. On the other hand, a high rate of incorrect leak declarations might be considered less significant if the pipeline operators have access to additional information that can be used to verify or disqualify a leak alarm.

Systems that limit or inhibit alarm generation in response to certain conditions of pipeline operation are not necessarily less reliable. Reliability pertains only to the functionality of the leak detection software without regard to SCADA system performance, availability of the pipeline instrumentation and

communication equipment, or any other factor beyond the control of the leak detection system vendor. Such factors involve a separate category of performance, namely robustness.

The reliability of a leak detection system usually depends upon a number of parameter settings (e.g. decision thresholds, filter characteristics, and so forth) as well as all of the suitable leak detection techniques employed for the operational characteristics of the target pipeline system. In some cases, a pipeline operator must decide whether to use settings that cause frequent alarms during normal pipeline operations, or to use other settings that are less likely to cause alarms, but might delay or even fail to alarm when a leak is present. Many systems also make automatic adjustments to decision thresholds and other parameters in order to reduce the likelihood of generating alarms during defined operating conditions. When such adjustments are made, a corresponding penalty is normally incurred in some other aspect of performance. For example, decisions based on longer observation intervals might make a particular system less susceptible to random instrumentation errors or disturbances caused by normal pipeline operations, but this performance gain is achieved at the expense of longer response time and the risk of greater fluid loss if a leak should occur.

Reliability can be managed through the use of operator response criteria and procedures. Such procedural methods, unless embodied within the leak detection software itself and performed automatically by the system, do not serve to discriminate between leak detection systems with regard to performance. On the other hand, if additional information is available from the leak detection, SCADA, or other systems, then reliability may be better managed.

Sensitivity

Sensitivity is defined as a composite measure of the size of leak that a system is capable of detecting, and the time required for the system to issue an alarm in the event that a leak of that size should occur. The relation between leak size and response time is dependent upon the nature of the leak detection system. In some cases, as illustrated in Figure 2, there is a wide variation in response time as a function of leak size. In other cases the response time is relatively independent of leak size, as depicted in Figure 3. However, there are no known systems that tend to detect small leaks more quickly than large leaks.

To further illustrate this definition of sensitivity, consider a hypothetical case involving four different leak detection systems (Red, Green, Blue, Yellow) with the following projected levels of sensitivity on a given pipeline:

- Red System: This system is capable of detecting a small leak within 5 minutes of the start of the leak.
- Green System: This system is capable of detecting a small leak within 15 minutes of the start of the leak.
- Blue System: This system is capable of detecting a large leak within 5 minutes of the start of the leak.
- Yellow System: This system is capable of detecting a large leak within 15 minutes of the start of the leak.

On the basis of these performance projections it is obvious that the Red System is the most sensitive and that the Yellow System is the least sensitive. However, comparison of the Green and Blue Systems is less apparent. It is possible that for one pipeline the Green System might be more appropriate, whereas for another pipeline the Blue System is more applicable. Since some leak detection systems manifest a strong correlation between leak size and response time, it is also possible that the two levels of sensitivity shown for the Green and Blue Systems could be manifested by the same leak detection system.

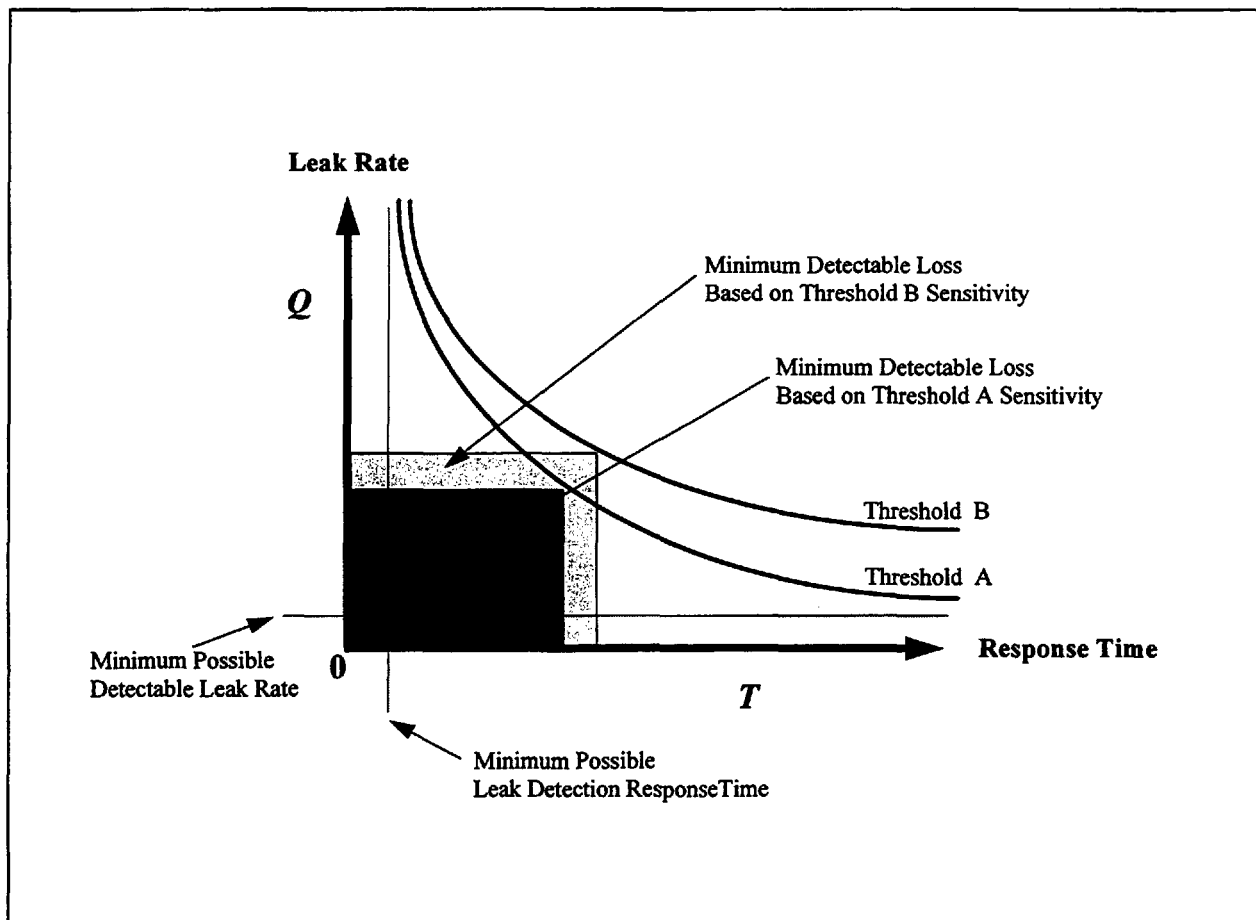


Figure 2: Examples of sensitivity curves based on different operating thresholds. These examples are typical of systems that operate on accumulated parameter errors (e.g., volume balance).

Frequently during the specification process, users attempt to define leak detection performance in terms of detecting a particular leak flow rate within a specified minimum period of time. Although sensitivity expressed in such terms certainly represents one aspect of performance, its importance can vary depending on the nature of the leak detection system and the operating characteristics of the target pipeline system. As shown in Figures 2 and 3, the correlation between leak size and response time can be highly dependent upon the leak detection techniques employed. It is also important to recognize that adjustments made in the interest of improving sensitivity can have a corresponding and not necessarily beneficial effect on other aspects of performance.

The examples shown in Figures 2 and 3 also serve to illustrate the concept of *minimum detectable leak size* and *minimum attainable response time* on any given pipeline. In practice, most systems can be set up to achieve various levels of sensitivity, provided the minimum detectable leak size and minimum attainable response time are not violated. The leak detection system vendor, and possibly the pipeline operator, can affect these characteristics by adjusting leak detection thresholds, filter characteristics or other parameters. Appropriate settings for these thresholds are usually dependent upon factors such as the SCADA system's scan time, instrument placement, fluid types, and so forth.

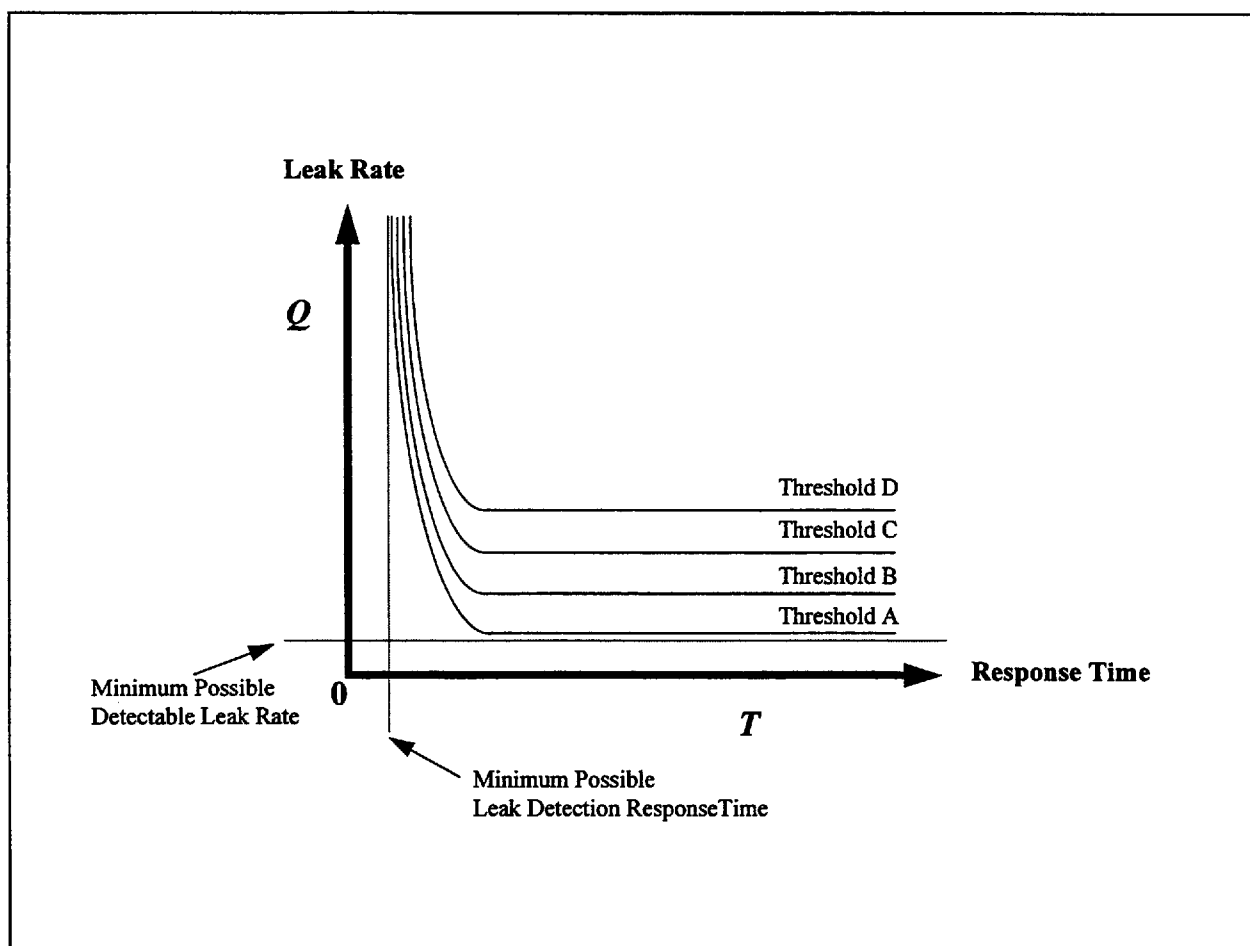


Figure 3: Examples of sensitivity curves typical of event oriented systems. Such systems might employ pattern recognition techniques to identify the onset of a leak.

Accuracy

To this point we have focused on the philosophy of detecting and announcing a leak, but have not considered the additional information that might accompany a leak alarm. With reference to Figure 1, this additional information is derived by the leak parameter estimation process, and is made available to the user as ancillary data output from the software based leak detection system. Although the amount and nature of such information varies between vendors, it typically includes estimates of leak parameters such as *leak flow rate*, *total volume lost*, *type of fluid lost*, and *leak location* within the pipeline network. The validity of these leak parameter estimates constitutes a third measure of performance referred to as *accuracy*.

From a strictly mechanical point of view, leak rate depends upon the magnitude and shape of the perforation, pipe environment, fluid characteristics and pressure at the leak site. If the location of a leak is known, the leak flow rate can be used to determine resultant disturbances in pressure, flow rate, and temperature at other points on the pipeline. Software based leak detection systems, on the other hand, deal with quite the opposite situation. Although these systems approach their task in a wide variety of ways, the one thing they all have in common is that they must operate with no prior knowledge of the size or location of a leak, should one occur. Thus, a particular system might calculate a leak flow rate to compensate for a difference between observed and expected values of pressure or flow at certain points on the pipeline. This effective leak flow rate might then be used to estimate the location of the leak and/or the volume loss related to the leak. Another system, operating on the same pipeline, might estimate total fluid volume lost on the basis of metered volumes and calculated changes in line pack, without ever attempting to directly estimate leak flow rate or location.

Robustness

Robustness is defined herein as a measure of the leak detection system's ability to continue to function and provide useful information, even under changing conditions of pipeline operation, or in conditions where data is lost or suspect. A system is considered to be robust if it continues to function under such less than ideal conditions. On the other hand, if the system disables certain functions, it might then achieve better reliability, but would be considered less robust.

The distinction between reliability and robustness is significant. Reliability is a measure of performance within a specified operational envelope. Robustness is a measure of the effective size of the operational envelope. For example, consider the following hypothetical leak detection systems:

- System I: This system employs a sensitive leak detection algorithm. The system is normally very reliable, but will frequently generate alarms during certain normal pipeline operations.
- System II: This system employs an alternative algorithm which is somewhat less sensitive than that of System I, but generates only a fraction of the alarms.
- System III: This system employs the same sensitive leak detection algorithm as System I, but inhibits leak detection during pipeline operations that can cause it to generate alarms.
- System IV: This system normally employs the same sensitive leak detection algorithm as System I, but switches to the less sensitive algorithm of System II when it senses conditions that generate alarms.

In this example, the designers of System I have sacrificed a degree of reliability in order to maintain a high level of sensitivity, whereas the designers of System II have chosen to sacrifice a degree of sensitivity in order to achieve a high level of reliability. By simply disabling the leak detection function under certain conditions, the designers of System III have sacrificed a degree of robustness in order to achieve higher levels of reliability and sensitivity. The example of System IV represents an attempt to selectively trade sensitivity and/or reliability in order to achieve a more robust system.

Although techniques vary between different software based leak detection methodologies, most attempt to achieve an acceptable tradeoff between reliability, sensitivity, accuracy, and robustness by sensing conditions of pipeline operation that cause alarms and making temporary parameter adjustments or disabling certain functions as required. Prior to the selection of a methodology for a given pipeline system, it is important that the pipeline company understand the way all operating conditions are handled by that methodology. This understanding will help the pipeline company to determine if a particular solution is consistent with the target pipeline's operational characteristics, as well as the company's expectations.

The reliability of a pipeline's communication, SCADA, and instrumentation systems can also have a dramatic effect on the utility of a software based leak detection system. A more robust system is one that is less likely to exhibit loss of functionality during periods of partial data outages caused by instrument failures, communication anomalies, routine maintenance, and so forth. Systems that continue to operate during outage periods or transient conditions on the pipeline might employ different settings for thresholds, filter characteristics, and other parameters. This usually results in some degradation of the system's sensitivity, accuracy, and/or reliability. In such cases, robustness is enhanced at the expense of other aspects of performance.

Other Factors Affecting Leak Detection Performance

Aside from operational considerations and the physical topology of a pipeline, there are other factors that affect leak detection performance. Although a composite of these factors is represented within the various performance classes, some warrant independent discussion. The following paragraphs present a brief discussion of such factors, and their relationship to leak detection performance. Background information related to these items is expected to be transferred to the vendor via either the configuration file describing the pipeline, or the data file containing representative runtime information upon which to base a study.

Instruments located along the pipeline provide the fundamental information used by a software based leak detection system to monitor and analyze the operation of the physical pipeline system. Therefore, for optimum performance on a given pipeline, it is important that the characteristics and physical locations of the existing pipeline instrumentation be consistent with the needs of the system(s) under consideration. The performance of an instrument can be characterized in terms of its *accuracy*, *repeatability*, and *measurement precision*. Instrument characteristics are normally specified by the instrument manufacturer, and will vary based upon the quality of the instrument and how it is maintained.

Instrument accuracy denotes the measurement performance of the instrument relative to that of an ideal device. It may be expressed absolutely as the worst case measurement error over the range of the instrument, or it may be expressed relatively as a fraction of the instrument's full scale reading. The repeatability of an instrument is a measure of its ability to consistently return the same reading for a given set of measurement conditions. Repeatability may also be expressed absolutely as a worst case discrepancy, or relatively as a fraction of the full scale reading. Instrument precision, or resolution, is a measure of the smallest change that can be reflected in the output of the instrument. Precision depends upon the resolution of the analog-to-digital converter used to acquire readings, and/or the transducer itself.

Software based leak detection methodologies are sensitive to instrument characteristics and placement. Instrumentation requirements should be reviewed with each leak detection system vendor under consideration. While it is generally true that instruments of great accuracy, precision, and repeatability will improve performance over instruments of lesser characteristics, it is also true that some leak detection techniques are much less dependent upon instrument characteristics than others. Furthermore, estimates of an instrument's actual field operation, along with descriptions of the pipeline company's calibration guidelines and SCADA data processing techniques, will be more useful to a vendor of software based leak detection systems than the instrument manufacturer's published specifications.

Consistent and reliable SCADA system performance is of critical importance to a software based leak detection system, regardless of the methodology employed. If the quality of the data is bad, or if the data acquisition frequency is inadequate, the ability of the software to recognize a potential or actual leak condition is compromised. In addition to the physical description of the pipeline system, definition of the pipeline company's SCADA system, and its performance characteristics, are of critical importance to the leak detection vendor. This definition provides the vendor with background information necessary to determine if an existing SCADA system will be adequate to support the needs of their software. SCADA performance characteristics that can have a negative affect on leak detection include slow or irregular update rates, time skew in acquired data from opposite ends of the pipeline, and communication system reliability. These, like many of the other factors, have different effects depending on the leak detection method under consideration, and therefore, must be discussed with each vendor to determine their impact on that method's functionality.

Specification and Prioritization of Performance Metrics

Within the framework of the proposed leak detection system evaluation methodology, each performance metric is evaluated in terms of a system's ability to satisfy a set of related criteria. Vendors might assist in the development of performance criteria that are relevant to their particular leak detection systems, but ultimately it is the pipeline company that must establish specific criteria for a particular pipeline. In so doing, the company must first define their leak detection goals for the pipeline and then specify corresponding criteria relative to the performance metrics of reliability, sensitivity, accuracy and robustness. These performance criteria constitute one set of information that the company would then provide to a potential vendor in order to determine if that vendor's system is an acceptable leak detection solution.

There are three steps involved in determining the appropriate leak detection performance criteria for a particular pipeline. The pipeline company must first identify any *legal, contractual or regulatory requirements* relating to leak detection. A minimum set of performance criteria must be established to meet these obligations.

The next step is to *characterize the pipeline* in terms of its possible leak mechanisms and the likelihood that one of these will result in a leak. A number of diverse factors are involved in this characterization. These include, but are not necessarily limited to:

- Length and volume of the pipeline,
- Pressure, temperature, and flow rate envelope,

- Terrain over which the pipeline travels,
- Type of fluids transported,
- The installed pipe,
- Pipeline operating procedures,
- Pipeline maintenance procedures, and
- External factors such as nearby roadwork, construction, or land development activity.

The final step in developing performance criteria is to perform an assessment of definite and potential costs associated with incorrectly declared leak alarms, missed alarms, late alarms, and any other deviation from ideal leak detection system performance. This assessment, when considered alongside the regulatory requirements and the leak potential characterization of the pipeline, should provide a basis from which the pipeline company can establish a set of leak detection objectives. The task of defining the appropriate leak detection performance criteria can then be reduced to a process of prioritizing each performance metric in terms of its level of importance, and further defining a set of specific performance criteria which illustrate the desired objectives.

The format for presenting performance metrics and the related specific performance criteria to software based leak detection vendors is divided into two tables as presented in Figure 4. In the first table, each performance metric is ranked based on its level of importance to the pipeline company. Ranking of the four (4) performance metrics simply involves assignment of a numerical rank (1, 2, 3, or 4) to each, with the most important performance metric being assigned a rank of one (1).

The second table contains definitions of specific performance criteria related to each performance metric, and may be optionally left blank or deferred to the vendor to complete. In this table, each performance metric may be characterized by a set of performance criteria to be evaluated under certain operating conditions on the pipeline. These criterion may be specified in either qualitative or quantitative terms. Pipeline companies are encouraged to provide qualitative specifications for performance criteria, and quantitative specifications where possible. Even though many of the performance criteria are difficult, or even impossible, to completely separate from others, this mechanism provides the pipeline company with a means to identify and rank the specific elements of performance important to them, and relevant to their operational needs and leak detection goals.

It must be noted that the performance criteria identified in Figure 4 are specified in qualitative terms rather than quantitative terms, and are only a representative sample of criteria that might be established under a given set circumstances. This is not an all-inclusive list that would apply to every pipeline, nor is it a recommended list with application to any particular pipeline. Since the needs of each pipeline company differ, it is only necessary to specify those performance criteria that are representative of the pipeline's specific needs.

Performance Metric	Level of Importance (Rank 1-4)
Sensitivity	
Reliability	
Robustness	
Accuracy	

Performance Metric	Qualitative Performance Criteria Specification
Sensitivity	Minimum detectable leak rate
	Minimum detectable leak volume
	Maximum volume loss prior to alarm
	Response time for a large leak
	Response time for a small leak
Reliability	Incorrect leak alarm declaration rate (overall)
	Incorrect leak alarm declaration rate (steady state flow)
	Incorrect leak alarm declaration rate (transient conditions)
	Incorrect leak alarm declaration rate (static conditions)
Robustness	Loss of function due to pressure outage(s)
	Loss of function due to temperature outage(s)
	Loss of function due to flow measurement outage(s)
	Loss of function due to pump state changes
	Loss of function due to valve state changes
	Loss of sensitivity due to pump state changes
	Loss of sensitivity due to valve state changes
	Startup stabilization period
Accuracy	Leak location error
	Leak flow rate error
	Leak volume error

Figure 4: Tabular format for the ranking of the level of importance for each performance metric, and an optional table for qualitative or quantitative specification of performance criteria related to each metric.

Features and Functions

As an integral part of many software based leak detection systems, there exist numerous features and functions that may not necessarily affect leak detection performance, but add value to the presentation and use of information produced by the leak detection system. Pipeline companies frequently require that certain features and functions accompany a software based leak detection system. As part of the specification process, the pipeline company might also desire to indicate which features and functions are of specific interest to them. An applicable tabular format for this purpose, as shown in Figure 5, consists of two (2) columns to specify individual features and/or functions and to indicate the importance of each to the pipeline company.

Feature or Function Specification	Provide Additional Information (Yes/No)
Volume Balance/Imbalance Processing	
Line Pack Calculations	
Pressure Profiling	
Thermal Modeling	
Instrument Error Analysis	
Pump Modeling	
Batch and Product Tracking Capability	
Batch Interface Profiling	
Custody Transfer Tracking and Management	
Pig and Scraper Tracking	
Support for Drag Reduction Agents	
Support for Slack Line Flow	
Data Trending and Archiving	
Warm Start Capability	
Instrument Maintenance Scheduling	

Figure 5: Specification table for software based leak detection system features and functions.

A pipeline company's need for information about a particular feature or function should be indicated by one of two possible choices as follows:

- The company would like additional information about a particular feature/function, or
- The company is not interested.

The features and functions listed in Figure 5 are presented solely for illustrative purposes. This list is not all-inclusive, nor does it constitute a recommendation of any sort. Depending upon the nature of the leak detection system, certain of these features are routinely provided whereas others might not be available under any circumstance. It is important that the pipeline company exercise care in preparing such a list, since the inclusion of unnecessary features might impact both the cost and the utility of the system.

Chapter Four

Pipeline Configuration Data Requirements

To perform a meaningful analysis of the performance of a particular leak detection system on a given pipeline, a leak detection system vendor must have adequate knowledge about the physical configuration of the pipeline. The vendor will use this knowledge of the pipeline to develop their response to the pipeline company's request for estimated performance projections. Since different leak detection methodologies require varying amounts of supporting information and detail, the evaluation procedure has been organized to allow for variations in the magnitude of information produced, provided that the pipeline company has a predetermined software based leak detection method in mind. In any case, it is the responsibility of the pipeline engineer to describe the physical pipeline system to whatever degree of detail is required by the desired methodology. In cases where the pipeline company has no predetermined methods in mind, a complete description of the pipeline must be provided so that any available methodology can be considered.

In this document a standard, keyword record oriented file format is defined to facilitate the transmission of pipeline physical configuration information to leak detection system vendor companies. The configuration file structure defined herein is designed to permit a complete and accurate description of any pipeline and all elements of the pipeline that are significant to a leak detection system. It is intended to provide an efficient, universally accepted standard for transmission of pipeline configuration data. A properly constructed configuration file can be used directly by a leak detection system vendor to develop a model of the pipeline suitable for off-line testing with captured (or simulated) operational data provided by the pipeline company.

A generalized discussion of pipeline network topology and the corresponding configuration file structure is provided in this section. Complete definitions of all configuration file record types are provided in Appendix B.

Elements of a Network of Pipelines

For the purposes of this document, a *network* of pipelines is defined as an array of pumps, valves and pipe all under the ultimate control of a single SCADA system master station. Within a given network there may be one or more distinct *pipelines*, each of which is normally bounded by flow measurement instrumentation and has the capability of operating independently of all the other pipelines. Within each pipeline there may be one or more *sections*, each of which is usually associated with an independent survey or measure of linear position along the primary pipeline right-of-way. Finally, within each section there may be several pipe segments and stations. An example of this structure and associated nomenclature is depicted in Figure 6.

Each pipeline is represented as an array of *nodes* and *volume elements*. Nodes are defined on a pipeline at all points of significance to the leak detection system. In general, this includes the endpoints of all volume elements, all points where measurement instruments used by the leak detection system are located, and all points required to adequately profile the elevation of the pipeline. Volume elements include all elements of the pipeline conduit itself.

Upper Case Pipeline Company (a network of three pipelines)

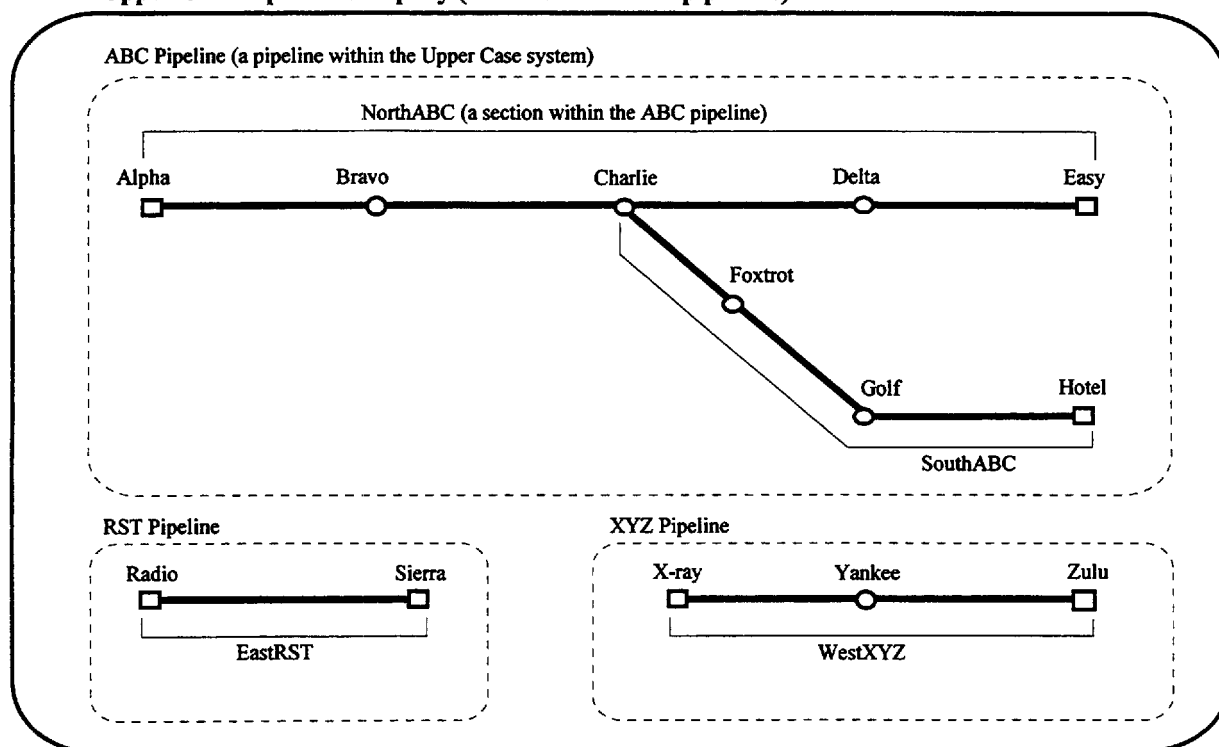


Figure 6: Pipeline topology representation.

The most obvious *dual-ported volume elements* are pumps, volumetric flow meters, and pipe segments. Less common devices that must be treated as volume elements include strainers, separators, pulsation dampeners and so forth. Valves, even though they displace a negligibly small amount of fluid, must also be treated as volume elements because they have the capability of controlling flow between two points. Valves are treated as an adjacent pair of nodes (i.e. a dual-ported element of zero volume) for the purposes of this document.

A pipe *segment* is defined to be a contiguous length of conduit containing no other volume elements, and across which there is no significant change in pipe inside diameter, pipe outside diameter, pipe wall thickness, pipe wall roughness, burial status of the pipe, pipe coating or pipe insulation. Fluid may be delivered from the pipeline and/or received into the pipeline at the endpoints of a segment but not at any point within a segment. The pipeline configuration file structure described in this document includes keyword record types which permit the user to specify all the various types of dual-ported volume elements.

Pump stations and other complex installations on a pipeline can always be represented as a combination of dual-ported volume elements. However, there are many cases in which the leak detection vendor will not require this level of detail, provided that the station is bounded by measurements that can be used to drive the leak detection system. In such cases, simple booster stations can be represented as dual-ported volume elements. More complex junctions and stations with multiple inlets or outlets constitute *multi-ported volume elements*. The pipeline configuration file structure described in this document does not provide a keyword record type for specification of a single volume element with an arbitrary number of ports. Even the most complex such cases can always be represented as a combination of dual-ported elements.

Boundary nodes represent the points of intersection between all significant volume elements within the pipeline. Specifically, boundary nodes exist at the following locations:

- Any point where fluid can be delivered from the pipeline and/or received into the pipeline,
- Any point where there is a significant change in pipe inside diameter, pipe outside diameter or pipe wall thickness,
- Any point where there is a significant change in the coating, insulation or burial status of the pipe (e.g. where the pipe enters or exits a body of water), and
- The inlet or outlet of a pump unit, volumetric flow meter, pipe segment or any other volume element.

The pipeline configuration file structure described in this document employs keyword record types which permit the user to specify the various types of volume elements. Boundary nodes are implicitly defined as a part of the volume element specifications. Thus there is no requirement for a keyword record type to specify boundary nodes.

Control nodes include blocking valve, control valve, regulator valve, and check valve sites on a pipeline. All active valves must be specified in the pipeline configuration file. Some vendors also require the specification of inactive valves, since they employ formulas to model the slight pressure drops associated with these devices. The file structure described herein includes keyword record types to specify valve sites as control nodes.

Measurement nodes include all points on a pipeline where instrumentation is attached to the pipeline in order to make measurements that are used by the leak detection system. All measurement nodes must be fully specified in the pipeline configuration file. The file structure described in this document includes keyword record types that can be used to define the various measurement nodes required for leak detection.

Elevation nodes include all points that must be defined in order to adequately represent the elevation profile for leak detection purposes. The number of points required in the elevation profile is dependent upon the nature of the pipeline and the type of leak detection system that might be employed. The file structure defined herein provides a keyword record type that can be used to specify the elevation profile, regardless of the nature of the pipeline or leak detection system.

Elements of the Pipeline Configuration File

The configuration file is a record-oriented ASCII text file. It is composed of a set of records describing the network topology, pipeline geometry, fluid properties, and all pertinent pipeline instrumentation for leak detection purposes. The first field of each record in the configuration file is a keyword. The keyword identifies the record type, which establishes the meaning of the parameters that are provided in the remaining fields of the record. Specific keyword record types are defined for the following purposes:

- To describe the organization of distinct pipelines within a network,

- To describe the organization of sections within a pipeline,
- To describe all the physical elements of a pipeline (e.g. pumps, valves, meters, and so forth) that are pertinent to leak detection,
- To define the elevation profile of a pipeline,
- To assign engineering units or scale factors, and
- To assign device state decode definitions.

By properly employing the various record types it is possible for the user to build a file that defines the structure of a pipeline or network of pipelines, describes the physical properties of the pipeline, and completely specifies the characteristics of every physical element of the pipeline that may be pertinent to the evaluation of leak detection system performance. A list of available keywords follows:

ambient	Identifies a record describing the position and characteristics of a real-time ambient air, soil or water temperature measurement.
assign	Identifies a record used to assign engineering units to data entries in the pipeline SCADA data base and other parameters.
blkValve	Identifies a record describing a three-state blocking valve.
chkValve	Identifies a record describing a two-state check valve.
ctrlValve	Identifies a record describing a control valve.
dataQuality	Identifies a record used to assign data quality attributes.
decode	Identifies a record used to define device states corresponding to particular values in the SCADA database.
default	Identifies a record used to define default values for certain parameters.
device	Identifies a record used to define certain dual-ported volume elements.
dNode	Identifies a record describing a real-time fluid density measurement.
dTable	Identifies a record used to define the relation between density, pressure, and temperature for a specific fluid.
endNetwork	Identifies a record used to terminate the definition of a <i>network ... endNetwork</i> block within the configuration file.
endPipeline	Identifies a record used to terminate the definition of a <i>pipeline ... endPipeline</i> block within the configuration file.

endSection	Identifies a record used to terminate the definition of a <i>section ... endsection</i> block within the configuration file.
eTable	Identifies a record defining the location and elevation of a point or set of points on the pipeline.
fluid	Identifies a record describing the properties of a specific fluid.
fNode	Identifies a record used to identify the type of fluid at a point in the pipeline.
network	Identifies a record used to initiate the definition of a <i>network ... endNetwork</i> block within the configuration file.
pipeline	Identifies a record used to initiate the definition of a <i>pipeline ... endPipeline</i> block within the configuration file and to assign the values of standard pressure and temperature for the corresponding pipeline.
pNode	Identifies a record describing a real-time fluid pressure measurement.
port	Identifies a record describing a port or connection between two sections within a pipeline.
qNode	Identifies a record describing a real-time flowrate and/or volumetric flow measurement.
regValve	Identifies a record describing a pressure regulator valve.
section	Identifies a record used to initiate the start of a <i>section ... endSection</i> block within the configuration file.
segment	Identifies a record used to define the location and physical parameters of a distinct segment within a pipeline.
station	Identifies a record used to define a simple station volume.
tNode	Identifies a record describing a real-time fluid temperature measurement.
vNode	Identifies a record describing a real-time fluid viscosity measurement.
vpTable	Identifies a record used to define the relation between vapor pressure and temperature for a specific fluid.
vTable	Identifies a record used to define the relation between viscosity, pressure, and temperature for a specific fluid.

A definition of the record structure associated with each of the keywords is provided in Appendix B. A complete definition of each record field is provided for all keyword record types along with an example of how each record type might appear in a typical pipeline configuration definition.

Structure of the Pipeline Configuration File

The pipeline configuration file is organized into *blocks*. The *network*, *pipeline*, *section*, *endNetwork*, *endPipeline*, and *endSection* record types are used to establish blocks within a configuration file. The three block types also serve to establish three distinct *levels* within a configuration file. Thus the configuration file blocks are directly analogous to the actual elements of the typical pipeline structure depicted in Figure 6.

Of the three block types, the *network ... endNetwork* block occurs at the highest level. All records that serve to describe the configuration of a particular pipeline network must be included within the corresponding *network ... endNetwork* block. As previously noted, a network of pipelines is defined as an array of pumps, valves and pipe all under the ultimate control of a single SCADA system master station. Although unlikely, it is technically possible to define more than one such network within a single configuration file.

The *pipeline ... endPipeline* blocks occur at the second level and must each be embedded within a *network ... endNetwork* block. All records that serve to describe the configuration of a particular pipeline must be included within the corresponding *pipeline ... endPipeline* block. One or more pipelines may be defined within a given network. Each distinct pipeline is normally bounded by flow measurement instrumentation and has the capability of operating independently of all the other pipelines.

The *section ... endSection* blocks occur at the third or lowest level and must each be contained within a *pipeline ... endPipeline* block. All records that describe elements within a particular section of a pipeline must reside within the corresponding *section ... endSection* block. One or more sections may be defined within each pipeline. Each section is usually associated with an independent survey or measure of linear position along the primary pipeline right-of-way. Aside from short stubs and other minor diversions, it is assumed that the survey measurement of position varies monotonically across the section and that widely separated points within a section cannot be assigned the same survey measurement value. In other words, if two points within the same section are physically separated by five miles they cannot be assigned the same survey mile post number.

In building a configuration file, it is imperative that the proper structure be maintained. Each block must be opened with a *network*, *pipeline*, or *section* record and terminated with an *endNetwork*, *endPipeline*, or *endSection* record as required. All *pipeline ... endPipeline* blocks must be embedded within a *network ... endNetwork* block. Furthermore, all *section ... endSection* blocks must be embedded within *pipeline ... endPipeline* blocks. Failure to maintain proper structure will invalidate the configuration file.

Scope of Configuration File Record Types

As currently structured, there are three levels corresponding to the three block types that can occur in a configuration file. The scope of each record type (or keyword) includes one or more of these levels as follows:

```

network
  assign
  dataQuality
  decode
  default
  fluid
  dTable
  vpTable
  vTable
  pipeline
    assign
    default
    section
      ambient
      assign
      blkValve
      chkValve
      ctrlValve
      default
      device
      dNode
      eTable
      fNode
      pNode
      port
      qNode
      regValve
      segment
      station
      tNode
      vNode
    endSection
  endPipeline
endNetwork

```

The definitions provided in Appendix B indicate the scope of each record type, and it is required that the appropriate configuration file structure be maintained. In a valid configuration file, all record types must occur within their valid scope (i.e. at an appropriate level). For example, all *pNode* records must occur within a *section ... endSection* block. Record types that occur outside their valid scope will invalidate the configuration file.

Establishing Connectivity between Volume Elements

It is the responsibility of the pipeline engineer to insure that the configuration file data properly establishes connectivity between the various volume elements on the pipeline. To this end, each record type used to define a node on the pipeline includes a *refPost* field for the purpose of assigning an identifier to that node. Furthermore, each record type used to define a volume element on the pipeline