

Environmental Restoration Division
ORNL Environmental Restoration Program

**Leak Testing Plan for the Oak Ridge National Laboratory
Liquid Low-Level Waste System (Active Tanks)**

Vol. I. Regulatory Background and Plan Approach

Vol. II. Methods, Protocols, and Schedules

**Vol. III. Evaluation of the ORNL/LT-823DP Differential
Pressure Leak Detection Method**

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PREFACE

This document, the Leak Testing Plan for the Oak Ridge National Laboratory Liquid Low-Level Waste System (Active Tanks), comprises three volumes. The first two volumes address the component-based leak testing plan for the liquid low-level waste system at Oak Ridge, while the third volume describes the performance evaluation of the leak detection method that will be used to test this system.

Volume I, Regulatory Background and Plan Approach, describes that portion of the liquid low-level waste system at the Oak Ridge National Laboratory that will be tested; it provides the regulatory background, especially in terms of the requirements stipulated in the Federal Facilities Agreement, upon which the leak testing plan is based. Volume I also describes the foundation of the plan, portions of which were abstracted from existing federal documents that regulate the petroleum and hazardous chemicals industries. Finally, Volume I gives an overview the plan, describing the methods that will be used to test the four classes of components in the liquid low-level waste system.

Volume II, Methods, Protocols and Schedules, takes the general information on component classes and leak detection methods presented in Volume I and shows how it applies particularly to each of the individual components. A complete test plan for each of the components is presented, with emphasis placed on the methods designated for testing tanks. The protocol for testing tank systems is described, and general leak testing schedules are presented.

Volume III describes the results of a performance evaluation completed for the leak testing method that will be used to test the small tanks at the facility (those less than 3,000 gal in capacity). Volumes I and II are essentially a single document divided into two parts. Although Volume III is technically a separate document, it is included here because it completes the description of how the Oak Ridge system will be tested.

Some of the details described in Volumes I and II are expected to change as additional information is obtained, as the viability of candidate release detection methods is proven in the Oak Ridge environment, and as the testing program evolves. As significant changes occur, they will be documented and incorporated into a Detailed Leak Testing Plan and Schedules document, to be prepared at a later time.

**Leak Testing Plan for the Oak Ridge National Laboratory
Liquid Low-Level Waste System
(Active Tanks)**

Vol. I. Regulatory Background and Plan Approach

Dennis G. Douglas
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TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	v
LIST OF FIGURES.....	vii
LIST OF TABLES	viii
LIST OF ABBREVIATIONS AND ACRONYMS.....	ix
1 INTRODUCTION	1
1.1 Purpose and Scope	1
1.2 Background	1
2 FFA REQUIREMENTS AND EPA REGULATIONS AS THE BASIS FOR THE LEAK TESTING PLAN	3
2.1 The Federal Facilities Agreement	3
2.2 The EPA Regulations as the Basis for the Leak Testing Plan	4
3 DESCRIPTION OF THE LLLW SYSTEM	6
3.1 Overview of the LLLW System	6
3.2 Active Portion of the LLLW System Addressed in the Plan	14
4 OBJECTIVES AND ISSUES	17
5 PERFORMANCE STANDARDS FOR LLLW LEAK TESTING METHODS	23
5.1 Performance	23
5.2 Evaluation	28
6 LEAK TESTING PLAN	29
6.1 Small-Volume Collection and Accumulator Tanks	30
6.2 Larger-Volume Collection and Service Tanks	30
6.3 Pressurized Pipelines	33
6.4 Gravity-Fed Pipelines	33
7 LEAK TESTING SCHEDULE	36
8 CONCLUSIONS	37
REFERENCES	40

EXECUTIVE SUMMARY

A leak testing plan for a portion of the Liquid Low-Level Waste (LLLW) system at the Oak Ridge National Laboratory (ORNL) is provided in the two volumes that form this document. This plan was prepared in response to the requirements of the Federal Facilities Agreement (FFA) between the U.S. Department of Energy and two other agencies, the U.S. Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC). The effective date of this agreement was 1 January 1992.

The LLLW system is an interconnected complex of tanks and pipelines. The FFA distinguishes four different categories of tank and pipeline systems within this complex: new systems (Category A), doubly contained systems (Category B), singly contained systems (Category C), and inactive systems (Category D). The FFA's specific requirements for leak testing of the Category C systems is addressed in this plan. The plan also addresses leak testing of the Category B portions of the LLLW system. Leak testing of the Category B components was brought into the plan to supplement the secondary containment design demonstration effort that is under way for these components.

The approach that has been taken in preparing this plan, and that will be taken in executing it, is fully responsive to the requirements of the FFA. A key feature of the plan is that it is guided in part on relevant portions of current federal EPA regulations applicable to underground storage tanks and pipelines (UST systems) that store and transfer petroleum products and other hazardous substances. While the FFA does not require that the leak testing at ORNL follow these regulations, the regulations do provide the solid technical foundation for the testing program. In particular, the UST regulation provides clear and unambiguous *performance standards* for the conduct of release detection testing, and it provides a *schedule* for repeated testing of UST components. This plan, however, also recognizes that the EPA's UST regulation cannot be blindly applied to the LLLW system. This is because the operation of the LLLW system at ORNL is very different from the operation of a typical retail station. As a result, this plan makes some adjustments in the application of the regulation, as demanded by operational considerations.

Volume I of the leak testing plan reviews the background for the plan and describes how the EPA's UST regulation can be applied to the LLLW system. This volume provides an overview of the LLLW system, with a discussion of the tanks and associated pipelines that will be leak tested under the plan. Because the variety and complexity of the various components in the LLLW system preclude a single method or leak testing approach, Volume I describes several methods that are expected to be used. It also identifies primary and secondary methods for each component class, and the performance standards that will be used for each method. Volume II describes the testing of each component in detail. A component-type priority is established so that leak testing can be implemented in an orderly manner consistent with the needs and limitations of the facility.

For LLLW tanks with a capacity of less than 3,000 gal, the existing level sensor in these tanks (together with measurements of the temperature of the sensor) is identified as the primary release detection method. To allow cost-effective use of the existing instruments, the plan for this method utilizes (1) algorithms sufficient to compensate for environmental effects that influence the measurements and (2) a leak testing protocol applied to the data collection and analysis steps. Subject to further modeling and validation testing, it is expected that the existing level sensors can also be used to leak test the larger tanks, with leak detection algorithms and testing protocols appropriate for these larger tanks. It is planned that the LLLW tanks will be leak tested on a monthly schedule; the release detection method will be evaluated to ensure detection of a 0.2-gal/h leak, with a probability of detection (P_D) of not less than 95% and a probability of false alarm (P_{FA}) of no more than 5%.

There are two classes of pipelines: pressurized and gravity-fed. It is planned that an enhanced volume balancing method will be employed as a primary method for the gravity-fed lines. This method will use a controlled addition of minimal volumes of water to the line being tested. The performance of this method remains to be validated. The pressurized pipelines will be tested by a number of means, including volumetric methods, tracers, and volume balancing; the choice of method for a given line will depend upon whether that line can be isolated by means of valves. It is planned that the LLLW pipelines will be leak tested annually. Following the guidelines provided in the UST regulation, the pipelines will be tested using methods that result in performance sufficient to detect a *full-use equivalent* of 0.1-gal/h leaks with a P_D of not less than 95% and a P_{FA} of no more than 5%. Since the LLLW pipelines are used only intermittently and most are used infrequently, since the volumes transferred during use are small compared to retail station transfer rates, and since testing of most of these pipelines is very complex, performance standards and testing schedules must be developed by which lines can be tested in a manner equivalent to the way the lines covered in the regulation are tested.

Where it is both possible and practical, visual inspections of the various components will be used in lieu of more cumbersome testing methods. The use of visual inspections requires that suitable audit trails and other quality assurance procedures be developed and implemented.

The leak testing plan prioritizes implementation of the testing activities. The tanks are addressed first because of the volume of stored product and the consequences of a release. These are followed by the gravity-fed and pressurized pipelines. Development of a Detailed Leak Test Plan and Schedule (a document required by the FFA) and implementation of the release detection program for the tanks and pipelines will be accomplished in accordance with the schedule presented in a separate document.¹

¹ "Federal Facilities Agreement Plans and Schedules for Liquid Low-Level Radioactive Waste Tank Systems at Oak Ridge National Laboratory, Oak Ridge, Tennessee," Report No. ES/ER-17&D1, prepared by the Waste Management and Remedial Action Division, Martin Marietta Energy Systems, Inc., Contract No. DE-AC05-84OR21400, Oak Ridge, Tennessee, March 1992.

LIST OF FIGURES

	Page
Figure 1. Map showing the distribution of the LLLW system in the Bethel and Melton Valleys of the ORR.	7
Figure 2. Diagrammatic representation of the active portion of the LLLW collection, transfer, and waste treatment systems subject to leak testing.	8
Figure 3. LLLW drain piping in Building 3517.	10
Figure 4. Typical LLLW drain and transfer piping (Building 3517 illustrated).	11
Figure 5. Photograph of an LLLW collection tank showing penetrations.	12
Figure 6. Schematic diagram of a typical LLLW collection tank showing penetrations.	13
Figure 7. Histogram of the distribution of tank volumes in active portions of the LLLW system that require leak testing.	14
Figure 8. Typical underground storage tank system at a retail petroleum station (a) compared to a typical LLLW tank, which is relatively more complex (b).	18
Figure 9. Data from the leak-test feasibility demonstration in WC-2 conducted on 8-11 February 1991. (The solid line indicates tank volume measured by the level gauge; the dashed line indicates air temperature measured at X-10 "Met Tower.").	21
Figure 10. Noise histogram of data from a volumetric leak detection method.	24
Figure 11. Cumulative distribution functions from noise and signal-plus-noise histograms.	26
Figure 12. An illustration of the process of estimating P_D and P_{FA} from the cumulative distribution functions.	27
Figure 13. Summary of LLLW leak testing plan for small-volume tanks.	31
Figure 14. Summary of LLLW leak testing plan for larger-volume tanks.	32
Figure 15. Summary of LLLW leak testing plan for pressurized pipelines.	34
Figure 16. Summary of LLLW leak testing plan for gravity-fed pipelines.	35
Figure 17. Leak detection test plan and schedule.	36

LIST OF TABLES

	Page
Table 1. Top-level Description of Doubly Contained Tank Systems Addressed by Leak Testing Plan	15
Table 2. Top-level Description of Singly Contained Tank Systems Addressed by Leak Testing Plan	16

LIST OF ABBREVIATIONS AND ACRONYMS

- A_{eff} = effective cross-sectional area (of the surface of a liquid in a container)
- A/D = analog/digital
- API = American Petroleum Institute
- ASME = American Society of Mechanical Engineers
- ATG = automatic tank gauge
- $^{\circ}\text{C}$ = degrees Celsius
- CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
- CFR = Code of Federal Regulations
- df = degrees of freedom
- ΔP (or DP) = differential pressure
- DOE = Department of Energy
- EPA = Environmental Protection Agency
- ft = feet
- F & D head = flanged and dished head (for end caps of tanks)
- FFA = Federal Facilities Agreement
- $^{\circ}\text{F}$ = degrees Fahrenheit
- gal = gallon(s)
- gal/in. = gallons per inch
- gal/h = gallons per hour
- gal/volt = gallons per volt
- h = hour
- HOG = hot off-gas
- H/V = height to volume

Hz = Hertz
in. = inch(es)
in./°C = inches per degree Celsius
in./volt = inches per volt
LLW = low-level liquid waste
LLLWSIM = liquid low-level waste simulator
LVDT = linear voltage displacement transducer
MMES = Martin Marietta Energy Systems
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
PC = personal computer
P_D = probability of detection
P_{FA} = probability of false alarm
RTD = resistance temperature detector
SARA = Superfund Amendment and Reauthorization Act
SS = stainless steel
TDEC = Tennessee Department of Energy and Conservation
UST = underground storage tank
USTTA = (EPA) Underground Storage Tank Test Apparatus
V/H = volume to height

1 INTRODUCTION

1.1 Purpose and Scope

This document provides a preliminary leak testing plan for a portion of the Liquid Low-Level Waste (LLLW) system at the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee. The leak testing plan addresses two of four categories of tank and pipeline systems within the LLLW system. It provides a plan for leak testing the active, singly contained portions of the system, as specifically required by the Federal Facilities Agreement (FFA) for ORNL; it also provides a testing plan for the active, doubly contained portions of the system, to supplement the secondary containment design demonstrations for these systems.

The leak testing plan described here specifically addresses 42 tank and pipeline systems; that is, it provides candidate leak testing solutions for all of the currently active portions of the LLLW system. The FFA requires that a detailed leak testing plan and schedule be prepared and submitted. This document is a preliminary version of that detailed plan. The detailed plan and schedule will be submitted as described in the FFA Plans and Schedules document [1].

This leak testing plan uses a "systems engineering" approach. This approach provides for the implementation of a unified set of testing objectives, procedures, and schedules that are common to the portion of the LLLW system addressed by the plan, while providing for component-specific requirements and testing limitations to be incorporated into the plan.

Volume I of this plan describes the background and approach for testing the singly contained tanks and pipelines associated with the active portion of the LLLW system, as well as some of the active, doubly contained tanks and pipelines. Volume I also describes the common elements of the plan, such as the performance standards that will be required of the leak testing methods employed in the execution of this plan, component-category testing schedules, and a general view of the demonstration priorities. Volume II of this plan provides detailed descriptions of the leak testing methods to be used for each component, the leak testing protocols for each method and for each component of the LLLW system, and the testing schedule for each component.

1.2 Background

The Oak Ridge National Laboratory is located approximately 25 miles west of Knoxville, Tennessee, within the Oak Ridge Reservation (ORR). Operations at ORNL began in 1943 as part of the Manhattan Project. Since that time, the laboratory's role has expanded to include nuclear fuel reprocessing research, radioisotope production, and nuclear reactor concepts. More recently, the laboratory has increasingly engaged in multidisciplinary activities that include biological, environmental, energy, and materials research.

Many of the liquid waste materials generated in the course of the work at ORNL are collected by the LLLW system. This system, which in its present configuration was largely designed in the 1950s, is a complex assemblage of 96 tanks, associated pipelines, and ancillary equipment such as pumps and valves; the system is distributed between the Bethel Valley and Melton Valley areas of the ORR. The tanks that compose the LLLW system range in capacity from 40 to 170,000 gal and are used to collect, neutralize, concentrate, and store liquid wastes prior to disposal [2]. Although many of the tanks and transfer pipelines that compose the LLLW system have been removed from service [1,3], much of this system continues in active operation. The capacity of the tanks in the currently active portion of the LLLW system ranges from 40 to 50,000 gal. This system is composed of 42 separate tanks, with thousands of feet of networked piping connecting the LLLW source locations with the various tanks.

The Superfund Amendment and Reauthorization Act (SARA) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) has required that the Department of Energy (DOE) execute a Federal Facilities Agreement (FFA) with the Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC) for the Oak Ridge Reservation. The FFA for the ORR establishes new requirements for the tank systems at ORNL, including the preparation and implementation of a leak testing plan for the LLLW tanks. The objective of this leak testing plan is to provide guidance to ORNL for the design and implementation of a leak testing program for a portion of the LLLW system, so that that portion of the system can be brought into compliance with the requirements of the FFA. As noted above, this plan includes all 42 of the active tanks and their associated pipeline systems.

2 FFA REQUIREMENTS AND EPA REGULATIONS AS THE BASIS FOR THE LEAK TESTING PLAN

2.1 The Federal Facilities Agreement

The Federal Facilities Agreement [4] addresses the scope of the investigatory and remedial activities for the Liquid Low-Level Waste system at the Oak Ridge National Laboratory. While the LLLW system is distributed widely throughout both Bethel and Melton Valleys at ORNL, Section IX.A of the FFA divides the entire system into four essential categories. These are

- Category A:* new or replacement tanks and pipelines with secondary containment;
- Category B:* existing tanks and pipelines with secondary containment;
- Category C:* existing tanks and pipelines without secondary containment (e.g., singly contained); and
- Category D:* existing tanks and pipelines without secondary containment that have been removed from service.

The *Category B* grouping includes doubly contained portions of the system that do not require upgrade or replacement (because those portions fully meet the secondary containment requirements specified by the FFA) as well as doubly contained portions of the system that do require upgrade or replacement.

This leak testing plan addresses the *Category C* tanks and pipelines, as required by the FFA. It also addresses those tanks and pipelines in *Category B* to supplement the design demonstrations being prepared for those systems. The components of the LLLW system addressed in this plan comprise a total of 42 tanks ranging in capacity from 40 to 50,000 gal, plus the pipelines that connect the various tanks.

The FFA does not provide the technical requirements for leak testing the LLLW tanks. Section IX.F.2 of the FFA, *Structural Integrity Assessment(s) for Non-Secondarily Contained Tank System(s)* provides the most explicit guidance. In part, this section reads:

[The] DOE shall demonstrate . . . that the tank system(s) is not (or may be) leaking. This demonstration shall include: (a) volume balancing data for transfer lines and tank liquids level trend data, . . . or (b) data/information from alternate methods that accurately evaluates tank integrity.

Except for the clear requirement for volume balancing, this section is not explicit with respect to the types of "alternate [leak detection] methods" to be employed, nor does it specify the performance standards for the volume balancing method or for the "alternate methods."

In Section IX.F.4, the FFA is clear with respect to the documentation necessary for compliance with the demonstrations and the subsequent leak testing program requirements, but it does not specify the maximum allowable leak test time, nor the interval between leak tests in the course of the program. In part, this section reads:

... the DOE shall submit a schedule for providing the results of leak detection tests together with a schedule for the periodic review and revision of the structural integrity assessments The demonstration shall be in writing and . . . certified [by a Tennessee-registered P.E.].

2.2 The EPA Regulations as the Basis for the Leak Testing Plan

To comply with the requirements described above in a meaningful way, the leak testing plan must provide quantitative parameters for the systems used for the detection of a leak. That is, it must specify (1) the methods to be used for testing the system, (2) the performance standards of the leak testing methods, and (3) the schedule for conducting the leak detection tests. To meet these needs, the leak testing plan described here draws upon regulatory standards, promulgated by the Environmental Protection Agency (EPA), which apply to the owners and operators of underground storage tanks containing petroleum products and hazardous chemicals. These regulatory standards are described in "40 CFR 280 - Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks" [5]. (This document is commonly referred to as the "UST regulation.")

The UST regulation, issued by the EPA on 23 September 1988, requires that tank systems containing petroleum products and hazardous chemicals be tested periodically for releases. (A hazardous chemical is any substance defined by CERCLA [6].) The regulations for testing underground storage tanks containing hazardous substances are similar to those for testing tank systems containing petroleum products.

It is noted that, at present, only the provisions of 40 CFR 280 Subpart A ("Program Scope") and Subpart F ("Release Response and Corrective Action for UST Systems Containing Regulated Substances") apply to tanks and pipelines containing radioactive wastes. Application of the remaining provisions of 40 CFR 280 (e.g., performance standards for leak testing methods, leak testing schedules, and other technical sections) to systems such as the LLLW was merely *deferred*; these systems are not exempt from the regulation. In the preamble to the regulation [Section IV.A.3(d)], the reason for the deferral is made clear:

... [commentors on the proposed regulation] stated that radioactive waste and materials tanks at nuclear facilities are regulated by the Nuclear Regulatory Commission (NRC) (10 CFR 50.34a) and that further regulation of these tanks under [40 CFR 280] would be duplicative and possibly inconsistent. . . . Because tanks containing radioactive wastes and other radioactive materials at nuclear facilities are regulated by the NRC, these tanks could be subject to overlapping

jurisdiction under [40 CFR 280] and the Atomic Energy Act of 1954. The Agency, however, lacks complete information on whether these regulations fully cover all appropriate areas addressed under [40 CFR 280]. The Agency, therefore, is deferring regulation of these tank systems until more information can be gathered.

The rationale for using the relevant parts of the UST regulation as the basis for the ORNL leak testing plan is straightforward: (1) 40 CFR 280 only defers regulation of LLLW systems—it does not exclude them from regulation; (2) it provides regulator- and industry-accepted (and industry-achieved) performance standards for leak detection methods used in underground storage tanks and pipelines; (3) the regulation provides industry- and regulator-accepted leak testing schedules for tanks and pipelines; and (4) application of relevant portions of the UST regulation to the LLLW system is consistent with the requirements of the FFA.

All systems that are used for leak testing must demonstrate that they meet a performance standard such as the EPA's [7]; this typically means that an evaluation must be performed. An evaluation usually entails 25 or more actual tests and analyses, over a wide range of operational and environmental conditions, during which the performance of the system is determined.

The UST regulation provides a *de minimis* exclusion for tanks with a volume capacity of less than 110 gal. The EPA noted that sections 9001 and 9003(a) of the Solid Waste Disposal Act of 1970 [8] authorized it to exclude from its regulations tanks containing *de minimis* amounts of regulated substances, and

. . . decided that the detriments of attempting to regulate these small tanks greatly outweigh any potential benefits from regulation of this class of tanks, and . . . therefore adopted this exclusion. [IV.A.2.d]

Although there is one tank in the LLLW system that might be excluded from the leak testing plan (tank F-201, which has a capacity of 40 gal), the *de minimis* exclusion provisions of the regulation will not be applied. There are a number of low-volume pipelines, however, that will be excluded from leak testing in this plan because they contain *de minimis* volumes and/or are used infrequently.

3 DESCRIPTION OF THE LLLW SYSTEM

The LLLW system at ORNL is complex, and a complete description of it can be found elsewhere (see [1], for example). This section of the leak testing plan provides a broad picture of the overall system and its operation, focusing on those portions of the LLLW system that are the subject of the plan.

3.1 Overview of the LLLW System

The function of the LLLW system is to safely handle the low-level radioactive liquid waste that is generated in the various research laboratories and operations buildings at ORNL. The LLLW system comprises 96 waste collection and storage tanks together with their associated piping and ancillary equipment. This network of tanks, lines, pumps, valve boxes and valves spans both the Bethel Valley and Melton Valley complexes at ORNL. A map that roughly illustrates the geographical extent of the active portion of the LLLW system is shown in Figure 1.

The earliest portions of the LLLW system were put into operation in 1943, and the system has continued to evolve over the years as new buildings have been constructed. Some parts of the LLLW system have been removed from service and some parts are presently in use. The active portion of the system comprises singly contained tanks and lines as well as doubly contained ones. The leak testing plan addresses the singly contained parts of the active portion, as well as the doubly contained tanks and lines.

The operation of the LLLW entails the movement of low-level aqueous waste products through the various pipelines and tanks that compose the system, from a generator facility to a long-term storage facility. Figure 2 shows a schematic diagram of the existing, active LLLW collection, transfer, and waste treatment system in the Bethel and Melton Valleys. There are 14 buildings in Bethel Valley and 7 in Melton Valley that generate low-level liquid wastes. The LLLW systems in these buildings and the network of tanks and pipelines that contain and move the wastes from the generator to the long-term storage facilities are subject to the leak testing plan presented here.

Generally, a generator facility will initially store its waste in local *collection tanks*. When the waste in these tanks reaches some predetermined level (typically, 60% to 70% of the volume capacity of the tank), the contents are pumped through underground pipelines to the *central waste collection header* (located in Bethel Valley), and then to interim service tanks at the evaporator facility. Here the wastes are concentrated and temporarily stored. When the volume in the concentrate tank reaches a certain level, the contents are pumped to long-term storage near the New Hydrofracture Facility (see Figure 1). (The distillate from the evaporator is pumped to the process waste facility; here, any remaining low-level radioactivity is stripped from the distillate and returned to the evaporator facility for reprocessing.) A discussion of the flow of these wastes from the generator building to the storage tanks is given below.

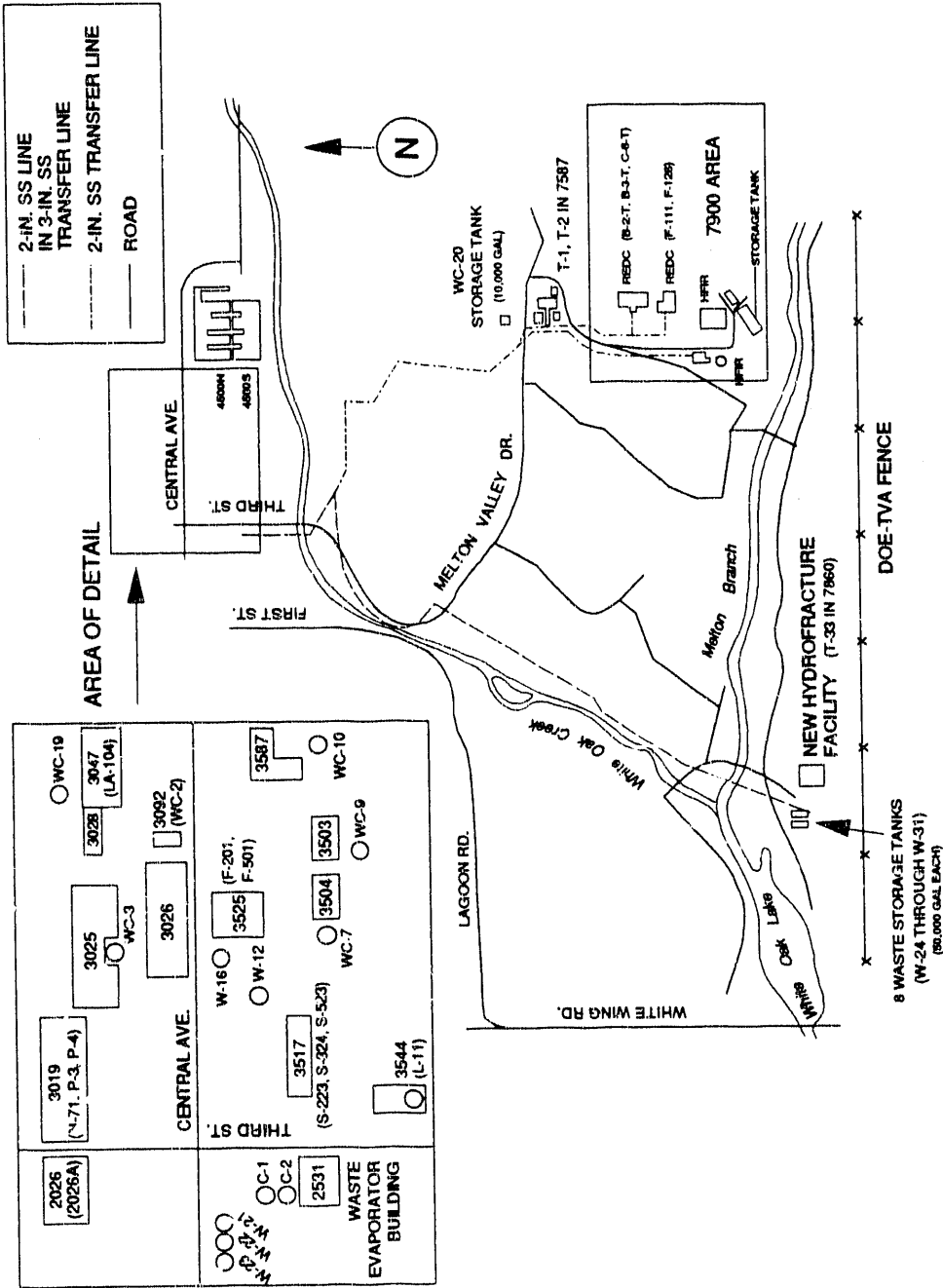


Figure 1. Map showing the distribution of the LLL W system in the Bethel and Melton Valleys of the ORR.

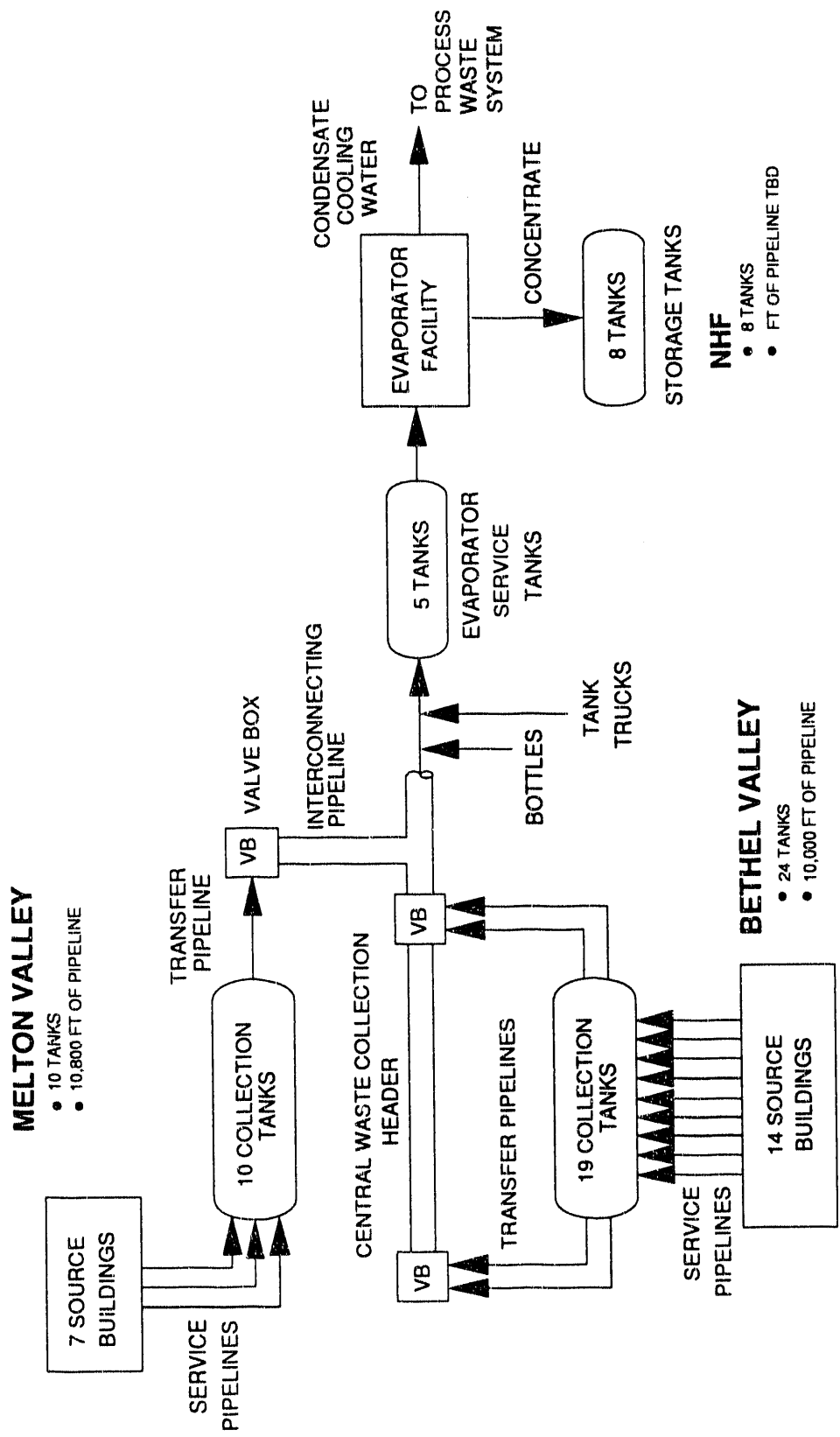


Figure 2. Diagrammatic representation of the active portion of the LLLW collection, transfer, and waste treatment systems subject to leak testing.

Typically, operators working at a "hot cell" in a building empty their waste solutions into a drain located in the hot cell. This waste, together with the wastes from other hot cells that may be operating in the same building, drains by gravity through an underground, singly contained drain pipe into a 500- to 1000-gal collection tank. A number of hot cell drains in a building may be connected to a central LLLW building drain. An example of a typical building's drain piping and collection tanks is given in Figure 3. This figure illustrates the drain piping from the various hot cells within Building 3517 (one of the generator buildings in Bethel Valley) leading to the building's collection tanks, S-223, S-523, and S-324, located immediately outside the building in an underground concrete vault. The figure shows that in Building 3517, there are 10 drains connected to the collection tanks by means of two main internal drain lines that run along a service tunnel located beneath the building and leading to tank S-523. As illustrated in Figure 4, the contents of tank S-523 are pumped by means of a steam jet to an interim tank, S-223. In this building, the wastes are pumped from S-324 or S-223 to the central waste collection header.

The collection tanks, like the drains, are underground, and are usually located outside and adjacent to the generator building. In some cases, the tanks are located in lined vaults; other tanks are buried in backfill. Figure 5 shows a photograph of collection tank S-523, located in Building 3517. It can be seen that the tank is mounted horizontally. Penetrations into this tank are numerous, and include one or more inlet lines, an outlet line, a vent line, a centrifugal pump, a "hot off-gas" (HOG) system that maintains the vapor space in the tank at a low-level vacuum (about -0.5 to -1.0 in. of water), and the piping and/or conduits for one or more level gauges. S-523 is located in an epoxy-lined vault that is located immediately outside Building 3517. Figure 6 is a schematic drawing of a typical tank, installed vertically in backfill. Five penetrations are shown. The wastes are pumped by means of a "steam jet" that draws the waste into the outlet line by means of high-pressure steam directed over a venturi syphon. There is a monitoring well adjacent to this tank. (Note that in these examples, there are no valves that allow isolation of component parts of the system. This lack of valving, which is common in the LLLW system, makes leak testing more complicated.)

The volume of liquid in the collection tank is monitored by means of one or more level gauges installed in the tank, which are in turn monitored by the tank's operator and "owner"; when the tank volume reaches a predetermined level (usually 60% or 70% of the tank's maximum capacity), the tank's contents are pumped to 50,000-gal service tanks at the evaporator facility in Bethel Valley. After the wastes have been through the evaporation process, the concentrate is stored temporarily in a 50,000-gal tank at the evaporator facility, and later pumped to any of several 50,000-gal tanks for long-term storage.

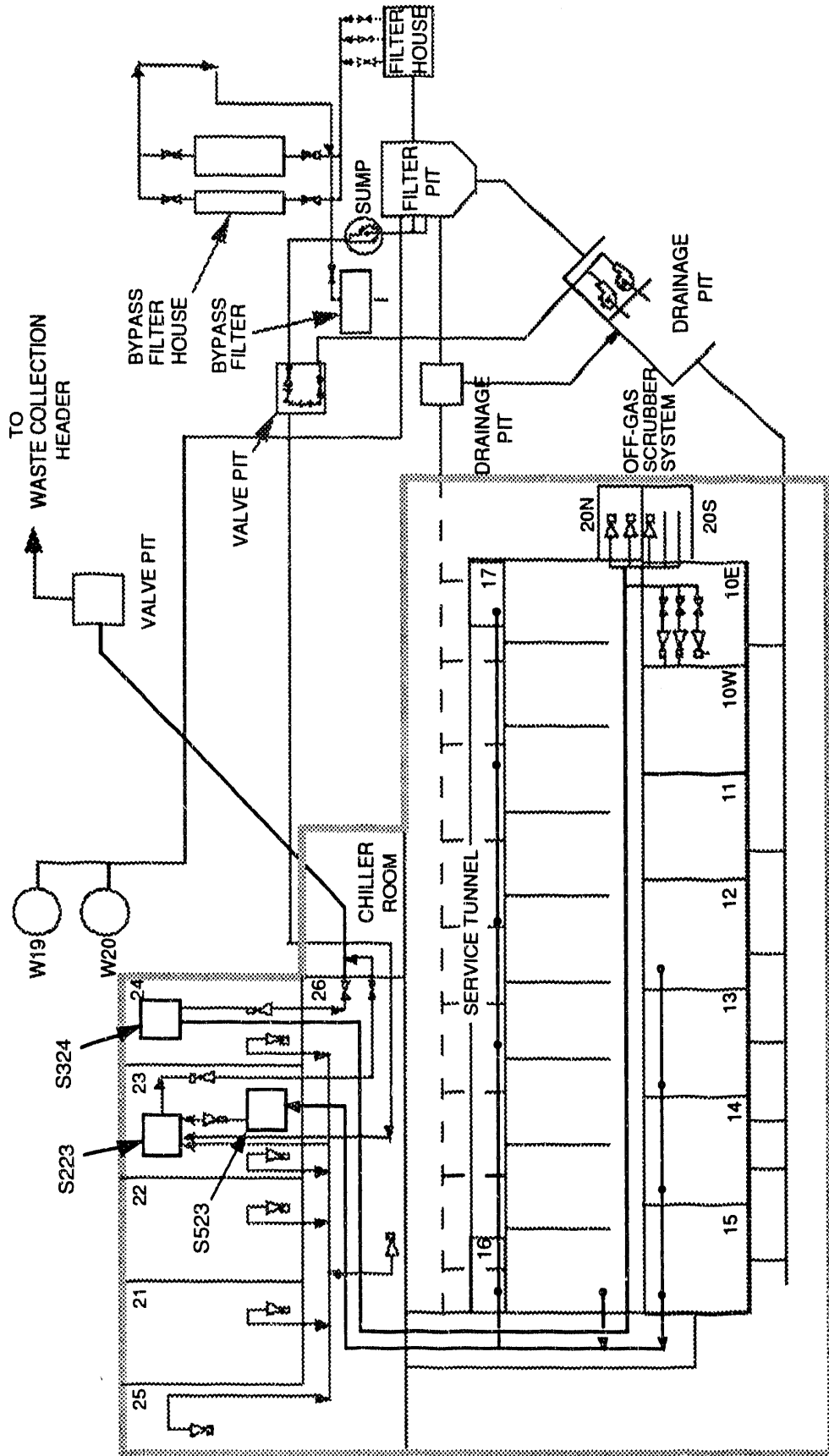


Figure 3. LLLW drain piping in Building 3517.

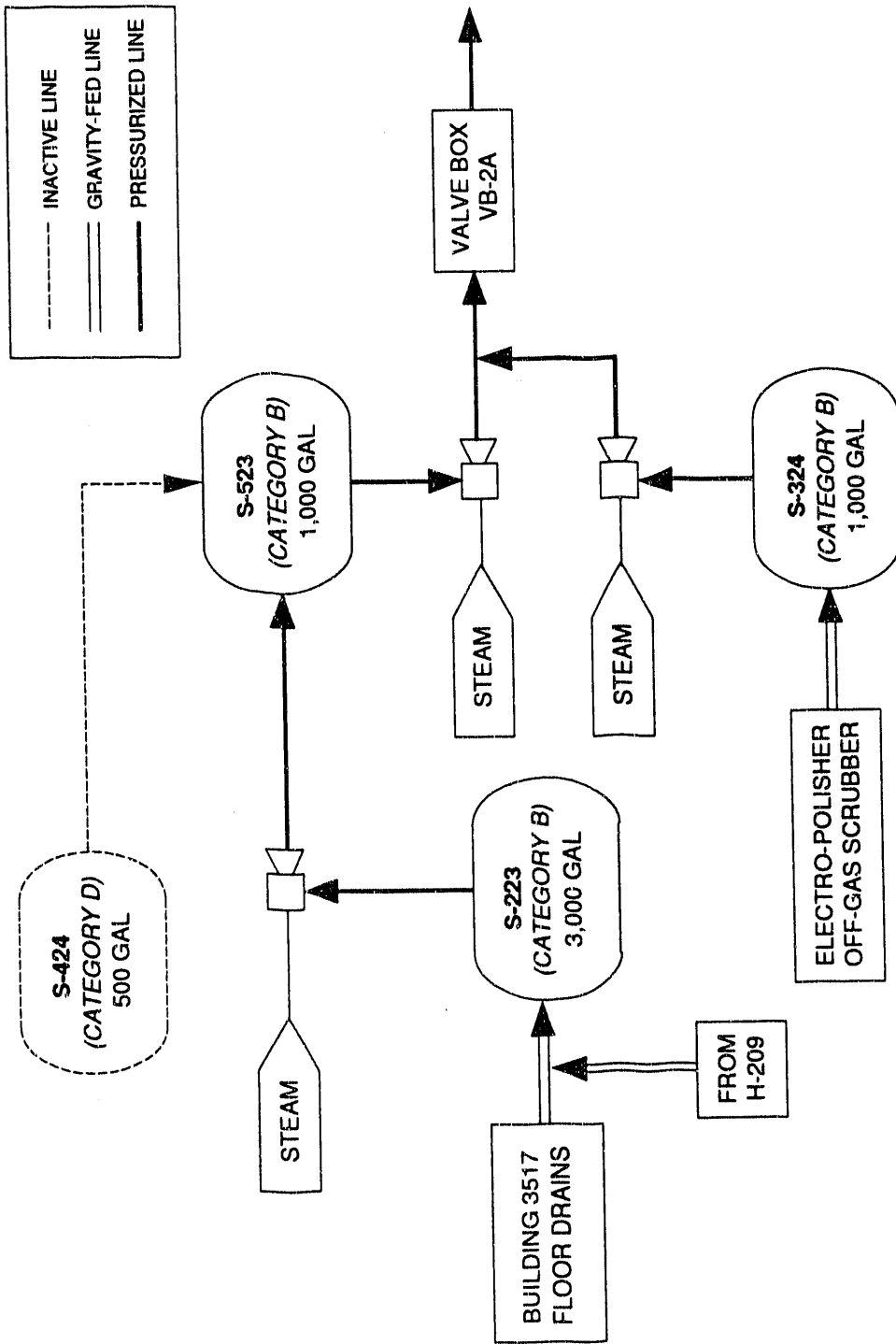


Figure 4. Typical LLLW drain and transfer piping (Building 3517 illustrated).

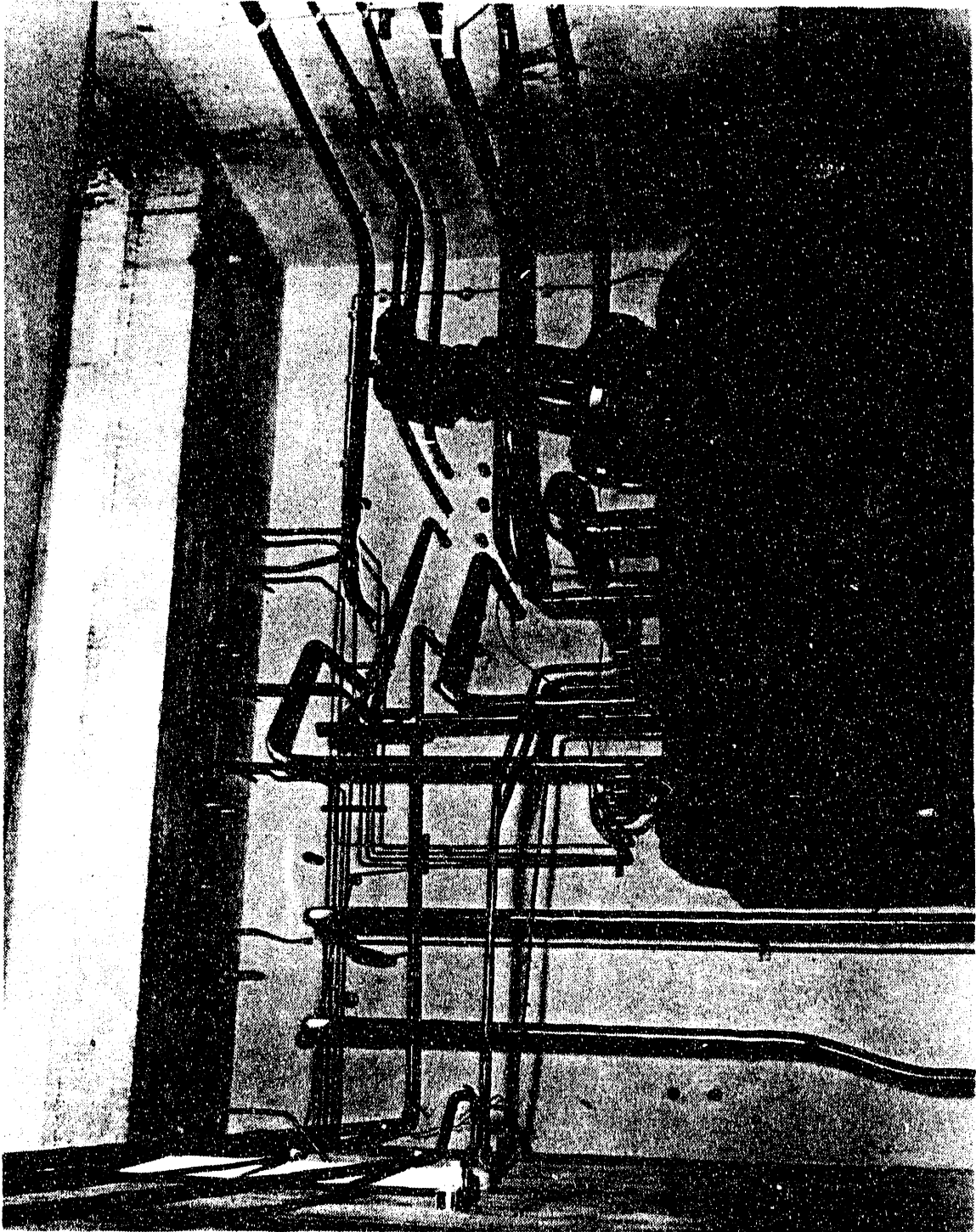


Figure 5. Photograph of an LLLW collection tank showing penetrations.

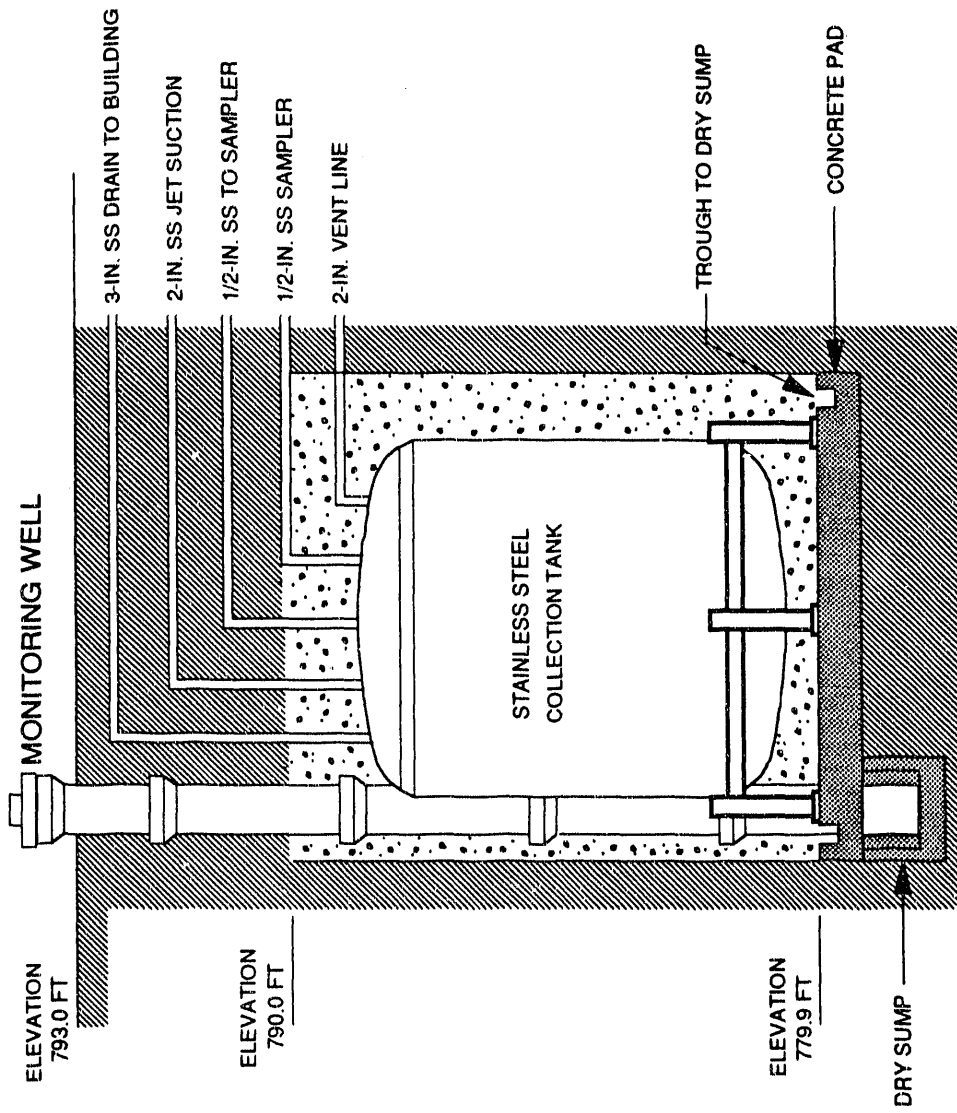


Figure 6. Schematic diagram of a typical LLLW collection tank showing penetrations.

3.2 Active Portion of the LLLW System Addressed in the Plan

This leak testing plan addresses 42 ORNL LLLW tanks that are in active service and their associated pipelines and ancillary equipment. These 42 tank systems comprise 27 doubly contained tanks and 15 singly contained tanks. Table 1 provides an overview description of the doubly contained tanks, and Table 2 describes the singly contained tanks. The pipeline data for groups of tanks within one area or served by one transfer line are expressed in terms of the total pipeline length associated with that grouping. The pipeline data shown in the tables are estimates, because these data are incomplete at the present time.

Figure 7 shows a histogram of the distribution of tank volumes for the systems shown in Tables 1 and 2. The abscissa of this graph shows tank volume, and the ordinate shows the number of tanks having that capacity; the "bin size" used for the histogram is 1,000 gal. For example, the plot shows that the leak testing plan will address eleven tanks with volume capacities of up to 1,000 gal, nine tanks with volume capacities between 1,000 and 2,000 gal, and so on. Figure 7 shows that the greatest number of tanks fall into the small-tank category — those less than 3,000 gal in capacity; in terms of volume, however, most of the stored waste is found in the large tanks. A comparison of the data in Figure 7 with that in Tables 1 and 2 shows that most of the stored waste is found in tanks having secondary containment, with only a small volume stored in the smaller tanks that are singly contained.

Volume II of this plan provides additional details about each of the tank systems.

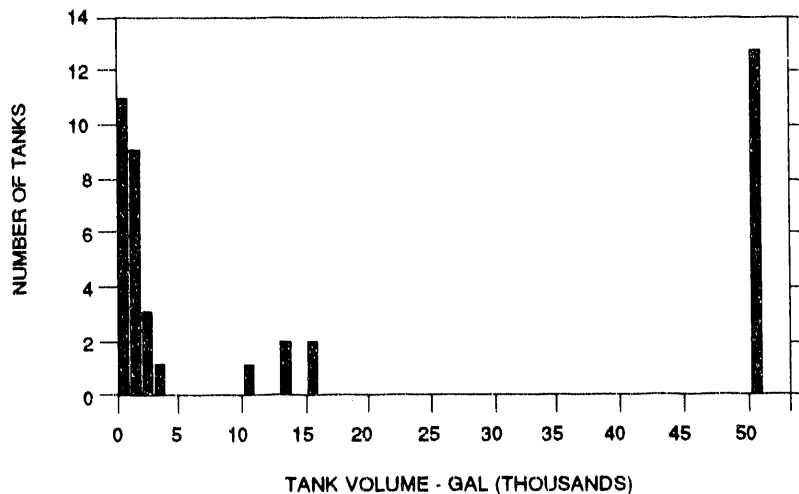


Figure 7. Histogram of the distribution of tank volumes in active portions of the LLLW system that require leak testing.

Table 1. Top-level Description of Doubly Contained Tank Systems Addressed by Leak Testing Plan

Designation	Tank					Piping			
	Location	Capacity (gal)	Installed	Method of Burial	Material	% in Facilities Doubly Contained	% Underground Doubly Contained	Length of Buried Piping (ft)	
C-1	2531 (BV)	50,000	1964	IGV	304L SS	75	96	300 (est)	
C-2	2531 (BV)	50,000	1964	IGV	304L SS				
N-71	3019 (BV)	240	1954	AGV	304L SS	100	0	200 (est)	
P-3	3019 (BV)	197	1954	AGV	347 SS				
P-4	3019 (BV)	197	1954	AGV	347 SS				
S-223	3517 (BV)	3,000	1955	IGV	304L SS	100	98	250 (est)	
S-324	3517 (BV)	1,000	1955	IGV	304L SS				
S-523	3517 (BV)	1,000	1955	IGV	304L SS				
L-11	3544 (BV)	500	1974	AGV	SS	0	25	1047	
B-2-T	7930 (MV)	1,870	1965	IGV	304L SS				
B-3-T	7930 (MV)	1,870	1965	IGV	304L SS				
C-6-T	7930 (MV)	710	1964	IGV	304L SS	60 est	0	7,800 (est)	
F-111	7920 (MV)	125	1962	IGV	304L SS				
F-126	7920 (MV)	1,200	1962	IGV	304L SS				
WC-20	7567 (MV)	10,000	1976	IGV	304L SS				
W-21 / W-23	2537 (BV)	50,000 (ea)	1979	IGV	SS	100	100	9100 (est)	
W-24 / W-31	7830	50,000 (ea)	1980	IGV	SS	100	100	6200 (est)	
T-13	NHF	3,000	1979	IGV	SS	100	100	250 (est)	

Legend:

BV - Bethel Valley
 MV - Melton Valley
 SS - Stainless Steel
 BT - Buried Tank (backfilled)

IGV - In-ground vault
 AGV - Above-ground vault
 UNK - Unknown
 NHF - New Hydrofracture Facility

Table 2. Top-level Description of Singly Contained Tank Systems Addressed by Leak Testing Plan

Designation	Tank						Piping			
	Location	Capacity (gal)	Installed	Method of Burial	Material	% in Facilities Doubly Contained	% Underground Doubly Contained	Length of Buried Piping (ft)		
2026A	2026 (BV)	500	1962	IGV	304L SS	0	0	1,276		
WC-3	3025 (BV)	1,100	1951	BT	347 SS	0	0	136		
WC-19	3047 (BV)	2,100	1955	BT	347 SS	0	0	1,590		
WC-9	3503 (BV)	2,150	1952	BT	347 SS	0	0	154		
WC-7	3504 (BV)	1,100	1951	BT	347 SS	0	0	849		
F-201	3525 (BV)	40	1962	IGV	304L SS	0	0	367		
F-501	3525 (BV)	200	1962	IGV	304L SS	0	0			
HFIR	7910 (MV)	13,000	1961	BT	SS	0	0	3,000 (est)		
T-1	HFIR (MV)	15,000	1963	BT	304L SS	0	0			
T-2	HFIR (MV)	15,000	1963	BT	304L SS	0	0			
WC-10	3587 (BV)	2,300	1951	BT	SS	0	0	2,800 (est)		
LA-104	3047 (BV)	296	1960	IGV	304L SS	10	0			
WC-2	3092 (BV)	1,000	1951	BT	347 SS	0	0	1,100 (est)		
W-16	STF (BV)	1,000	1951	BT	347 SS	0	0	267		
W-12	3523 (BV)	1,000	1947	BT	SS	0	0	700 (est)		

Legend:
 BV - Bethel Valley
 MV - Melton Valley
 SS - Stainless Steel
 BT - Buried Tank (backfilled)
 IGV - In-ground vault
 AGV - Above-ground vault
 UNK - Unknown

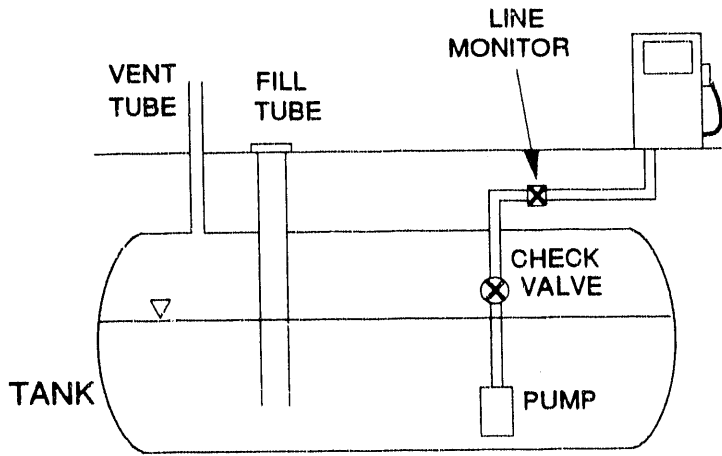
4 OBJECTIVES AND ISSUES

The objective of the leak testing plan is to provide guidance to the Oak Ridge National Laboratory for the design, implementation, and conduct of a leak testing program for those active portions of the LLLW system that require leak testing. In order for the LLLW system to achieve compliance with the FFA, the plan must be capable of being implemented at ORNL; therefore it must also be realistic and address the operational requirements and limitations of the system. A review of the LLLW system has identified a number of operational and system design issues that affect the leak testing. Some of these issues, and the actions taken in this plan to address and mitigate these issues, are discussed below.

- ***The LLLW system at ORNL is very different in scale, complexity and functional design from the traditional underground storage tank scenario found at retail petroleum stations and chemical facilities.*** Figure 8(a) illustrates the relative simplicity of an underground tank system located, for example, at a retail petroleum station. In the case of the retail station, the system has been designed to facilitate leak testing. Each part of the system can be isolated by means of valves. There are few penetrations to the tank, and pipeline lengths are short. This can be compared to Figure 8(b), as well as Figures 2 through 5, which illustrate the myriad tanks and lines at ORNL, where there is little or no valving, many penetrations, and great lengths of piping.

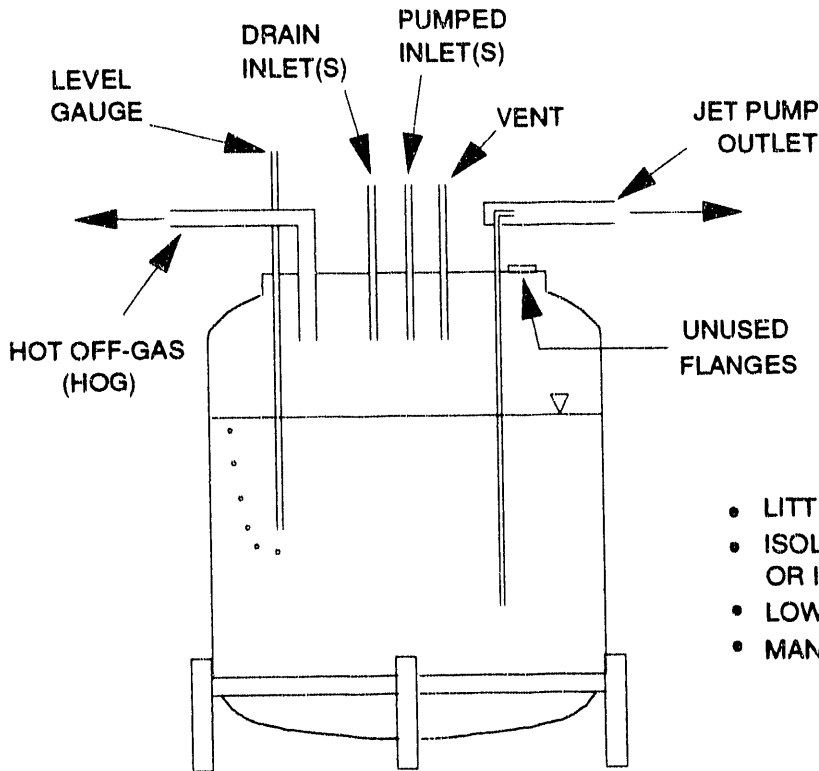
The leak testing plan recognizes the scale, complexity, and functional design of the LLLW system and approaches leak testing from a systems engineering point of view; objectives are established for the entire system, and then component-level solutions that achieve these objectives are developed for each component.

Unlike the case of underground storage tanks in the petroleum and chemical industries, one or two traditional leak detection methods will not suffice for the entire LLLW system. The implication here is that the plan must comprehend each of the differences unique to the specific components; therefore, leak testing solutions will be component-specific. The leak testing plan accommodates these differences by first identifying the differences and then providing a leak testing strategy and tactic for each component, as necessary.



(a)

- VALVES MAKE ISOLATION OF COMPONENTS EASY
- LIMITED PENETRATIONS
- INFLOWS CONTROLLABLE
- PIPING UNDER PRESSURE



(b)

- LITTLE OR NO VALVING
- ISOLATION DIFFICULT OR IMPOSSIBLE
- LOW VACUUM
- MANY PENETRATIONS

Figure 8. Typical underground storage tank system at a retail petroleum station (a) compared to a typical LLLW tank (b), which is relatively more complex.

- ***There are numerous "owners" of the various components that compose the LLLW system, and these owners have different LLLW instrumentation and operational procedures.*** The issue here is that while some owners have well-instrumented LLLW facilities that can be easily upgraded to incorporate a leak testing method, other owners are not as well-equipped and additional work will be required before leak testing can be routinely accomplished in their facilities. The implications here are similar to those in the case of the components; that is, the leak testing plan must recognize and accommodate these differences. To address this issue, the plan provides that early demonstrations of the leak testing capabilities of various methods will be made at the better equipped facilities; while this testing is going on, the less well-equipped facilities will be undergoing the modifications necessary for them to accommodate the various methods.
- ***The amount of waste products generated as a consequence of conducting leak tests must be kept to a minimum.*** This issue limits the scope of traditional leak testing approaches. One approach to testing a pipeline, for example, is to introduce a known volume of liquid and then, if it is a sealed line, monitor the change in temperature-compensated volume that occurs over time (a "volumetric" method) or, if it is an open line, measure and compare the volume of liquid that flows out of the other end of the pipeline (a "volume balancing" method). The problem in applying these methods to the LLLW system is that to accurately test all of the pipelines in this manner would introduce a large volume of water into the system. Disposition of these newly created waste products may pose serious waste management problems in an already burdened system. This issue has particular significance for the gravity-fed-pipeline portion of the system because volumetric or volume balancing methods appear to be two of the few viable testing options. The paragraph below discusses how the leak testing plan addresses this issue.
- ***The basic design of the LLLW system does not provide for leak testing.*** Unlike most petroleum and hazardous chemical storage systems, much of the LLLW system is unvalved; therefore, individual components of the system cannot easily be isolated. This has an impact on testing all parts of the system that are unvalved, but particularly the gravity-fed-pipeline portion of the system. This piping tends to be small in diameter (2 to 3 in.), with many drain inlets at different elevations within the buildings and laboratories, and many bends and connections in the buildings. Thus, while most of the piping connects to a single pipeline leading to the collection tank (which is usually outside the

building), the internal piping is distributed and generally inaccessible. In addition, the radiation hazards associated with these lines further limit access. The leak testing plan addresses these difficulties by recommending an enhanced volume balancing leak detection method using minimal quantities of distilled water introduced into the pipeline to test the arterial lines. The performance of the enhanced volume balancing method using distilled water, in terms of minimum detectable leak and probability of detection and probability of false alarm, will be determined during the demonstration phase. The viability of other methods, such as tracers, acoustics, and so on, will be assessed during the demonstration phase.

- **Maximum use of existing LLLW instrumentation for the conduct of leak tests is desirable.** Each of the collection and storage tanks in the LLLW system (and some of the pressurized pipelines) has *in situ* instrumentation used to monitor the product level in the tank (or pressure in the line). Because of the health hazards associated with working on the LLLW system, the potential environmental risk, and the cost considerations, it is desirable to make maximum use of the existing instruments where possible. The petroleum-tank and hazardous-chemical-tank industries use methods that have been *evaluated*—that is, subjected to a rigorous and standardized series of tests for the purpose of determining their *performance* in terms of minimum detectable leak and their probability of detection, P_D , and probability of false alarm, P_{FA} , against a specified leak rate. The existing level gauges in the LLLW system have not been evaluated; their performance is therefore unknown and must be determined before they can be used to show that ORNL is in compliance with the FFA.

During the preparation of the leak testing plan, the capabilities of the existing instrumentation were examined. It was determined that, subject to validation tests and an evaluation, both of which will be conducted during the demonstration phase, some of the existing instrumentation could be adapted for leak testing purposes. This is illustrated in Figure 9. The solid line in this figure represents the volume of waste liquid (right-side ordinate) measured in tank WC-2 (Bethel Valley) during an assessment experiment conducted at ORNL between 8 and 11 February 1991. (The volume was defined as the product of the level gauge data and the volume-to-height conversion factor, $\Delta V/\Delta h$.) It is evident that during the test period, the volume of waste product measured by

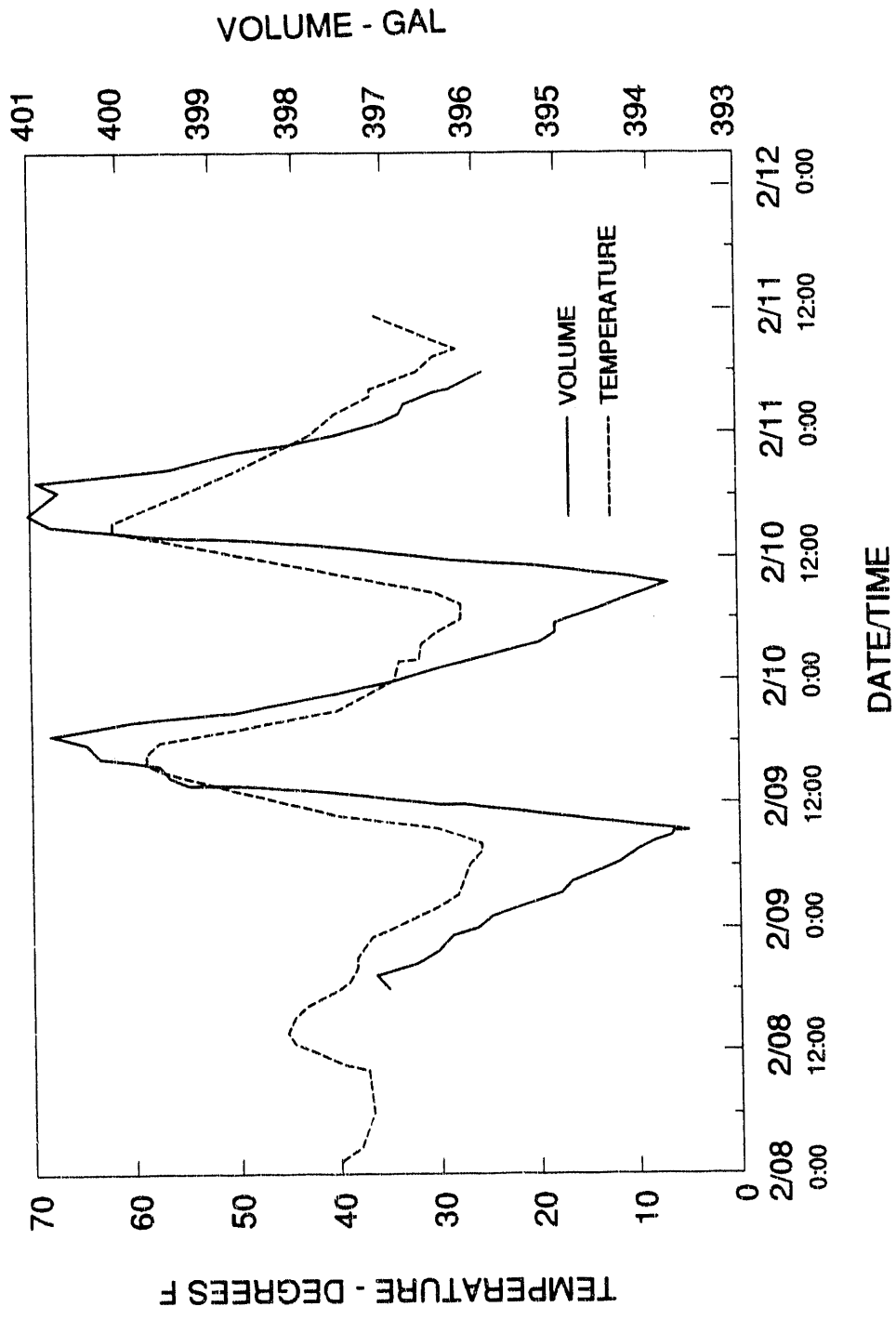


Figure 9. Data from the leak-test feasibility demonstration in WC-2 conducted on 8-11 February 1991. (The solid line indicates tank volume measured by the level gauge; the dashed line indicates air temperature measured at X-10 "Met Tower.")

the level gauge varied from about 394 gal to about 401 gal, and showed a daily variation. The dashed line in Figure 9 shows the air temperature (left-side ordinate) during the same experiment period, measured at ORNL's meteorological tower (X-10), which is more than 2,000 ft away from WC-2. These data show a strong positive correlation between air temperature and volume (liquid level) . This indicates that, if the level gauge data are compensated for variations in air temperature, the diurnal fluctuations in the level-gauge readings can be reduced significantly, thus improving the *precision* of the instrument. As discussed below, compensation and improved precision have a direct impact on the performance of a leak detection method (here, the level gauge), and are thus two factors that would have an impact on the use of this instrument as a leak detection method.

5 PERFORMANCE STANDARDS FOR LLLW LEAK TESTING METHODS

5.1 Performance

Any device or system built to measure some quantity makes that measurement with some finite accuracy and precision. Accuracy is an absolute term and refers to how closely the measured quantity is to the actual value of that quantity. Precision is a relative term and refers to the repeatability of successive measurements. The performance of a given measurement device or system is determined by either its accuracy or its precision, or both. The performance of a tank gauge used for making simple level measurements, for example, is primarily dependent on the accuracy of the gauge; gross level changes need to be measured accurately (but infrequently) so that the volume can be computed. If this same gauge is used for leak detection tests, it is necessary to measure small changes in level over a relatively short time period; thus, the performance of the system becomes primarily dependent upon the precision of the gauge. The EPA requires that the performance of a release detection system be measured in terms of the system's probability of detection (P_D) and probability of false alarm (P_{FA}) in detecting a leak of a specified rate. The discussion below describes how accuracy, precision, P_D , and P_{FA} are related, and how P_D and P_{FA} will be determined for the LLLW internal leak detection methods.

The performance of a leak detection system is assessed by means of the "signal" and "noise" measured by that system; these statistics are determined from the output of the system with and without the signal present. The "signal" is the time signature of the leak; for example, the signal associated with a volumetric leak detection system is the flow rate (i.e., volume change with time) of the LLL wastes, defined at a constant pressure, through a hole in the tank or pipeline. The "noise" associated with a volumetric system is the sum of the volume changes in a nonleaking tank that could be mistaken for the signal, that is, the output of the system without the signal present.

A noise histogram, prepared from actual test results from a volumetric leak detection system deployed in a nonleaking tank, is shown in Figure 10. The frequency distribution is essentially the same as the histogram, except that the values on the Y axis of the histogram are divided by the total number of tests to arrive at a fractional representation of results. The frequency distribution thus describes the fraction of the total number of test results in a defined interval or bin; the data in Figure 10 are plotted in 0.01-gal/h bins centered on a volume rate of 0.0 gal/h ($-0.005 \text{ gal/h} \leq \text{volume rate} \leq +0.005 \text{ gal/h}$). The central value of the noise histogram is a measure of the accuracy of the system; the width of the distribution is a measure of the system's precision. The likelihood of exceeding a specified noise level is described by the integral of the frequency distribution, which results in a cumulative frequency distribution. If the signal is constant over time, independent of the noise and additive with it, the signal-plus-noise distribution can be estimated directly from the distribution of the noise only. For this case, the

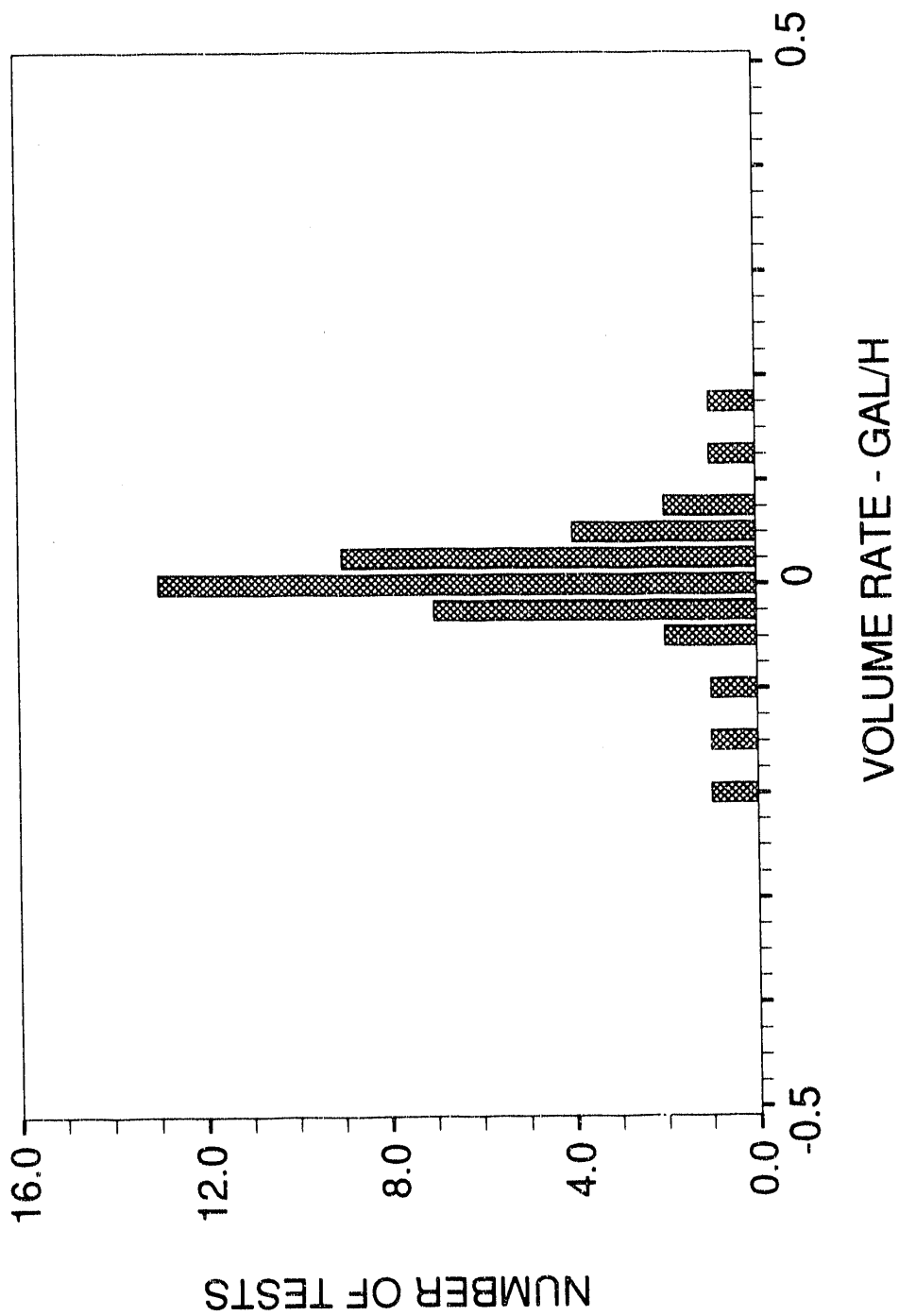


Figure 10. Noise histogram of data from a volumetric leak detection method.

signal-plus-noise distribution has the same shape as the distribution of the noise only, but the mean of the noise distribution is shifted by an amount equal to the signal strength. An example of cumulative frequency distributions for a noise distribution and a signal-plus-noise distribution for a -0.10 gal/h leak detected by a volumetric system is shown in Figure 11.

A leak detection method will indicate the possibility of a leak in the pipe or tank under test whenever the volume rate measured by the method exceeds some predetermined threshold value.* The threshold value is chosen to achieve an acceptable compromise between false alarms and missed detections. Threshold selection requires that the noise and signal-plus-noise cumulative frequency distributions be defined. Together, these are used to estimate the performance of the system in terms of P_D and P_{FA} . P_{FA} is determined from a vertical line drawn at some volume rate (the candidate threshold); the ordinate at which this line intersects the noise distribution is the P_{FA} of the system for that threshold. The P_D is determined from the intersection of the threshold line with the signal-plus-noise cumulative frequency distribution. This process is illustrated in Figure 12; a candidate threshold of 0.05 gal/h is considered in this figure. It is seen from Figure 12 that the threshold line intersects the noise distribution at an ordinate value of about 0.1, giving a P_{FA} of about 10%; the P_D is about 84%. In this case, the leak detection method would not meet the performance standard described in the UST regulation for tank (or line) tightness testing methods (i.e., 95%/5% at 0.1 gal/h). The performance of the system at other leak rates can be estimated by shifting the signal-plus-noise cumulative frequency distribution left or right as necessary, and considering other thresholds. (The performance of the hypothetical system described here, against a 0.2-gal/h leak rate is about 93%/5% [P_D/P_{FA}] at a threshold of about 0.13 gal/h; this method would not meet the performance standard required for a monthly test method).

The threshold is usually chosen to balance the P_D and P_{FA} in such a way that there is an acceptable compromise between economic and environmental risks. If the threshold is low (i.e., if very small leaks are to be detected), the P_D will be high, but so will the P_{FA} . On the other hand, if the threshold is high, there exists less chance of false alarm but also a greater probability of missed detections (because the P_D is lower). Thus, any adjustment made to the threshold for the purpose of improving the P_D carries with it an increased probability of false alarm. Conversely, any adjustment made to the threshold for the purpose of lowering the P_{FA} automatically implies a decreased probability of detection.

*Note that the leak test *threshold* is different from the leak test *criterion*. The criterion is a portion of the performance standard; the threshold is a value used to achieve the requisite performance. Also note that even if the tank system "fails" a test (that is, if the results of a single test exceed the given detection threshold), a leak is not declared until the testing protocol has been fully completed and continues to indicate a leak. The protocol will prescribe the conditions for conducting a leak test and the test results necessary to "declare" the leak. The ORNL protocol will require that, if a system fails a first test, one or two more tests be conducted in series to confirm the initial finding; if the system passes a subsequent test, it is deemed to be "tight."

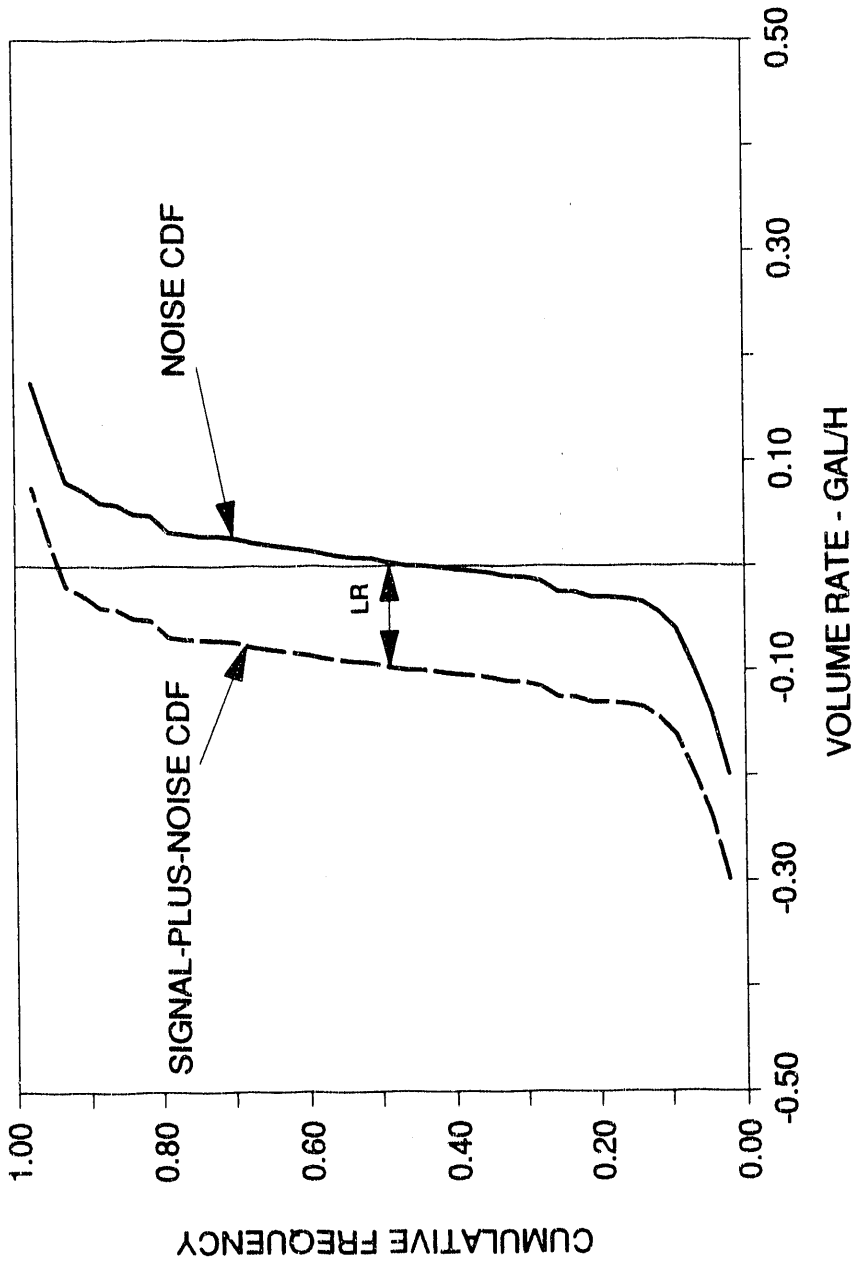


Figure 11. Cumulative distribution functions from noise and signal-plus-noise histograms.

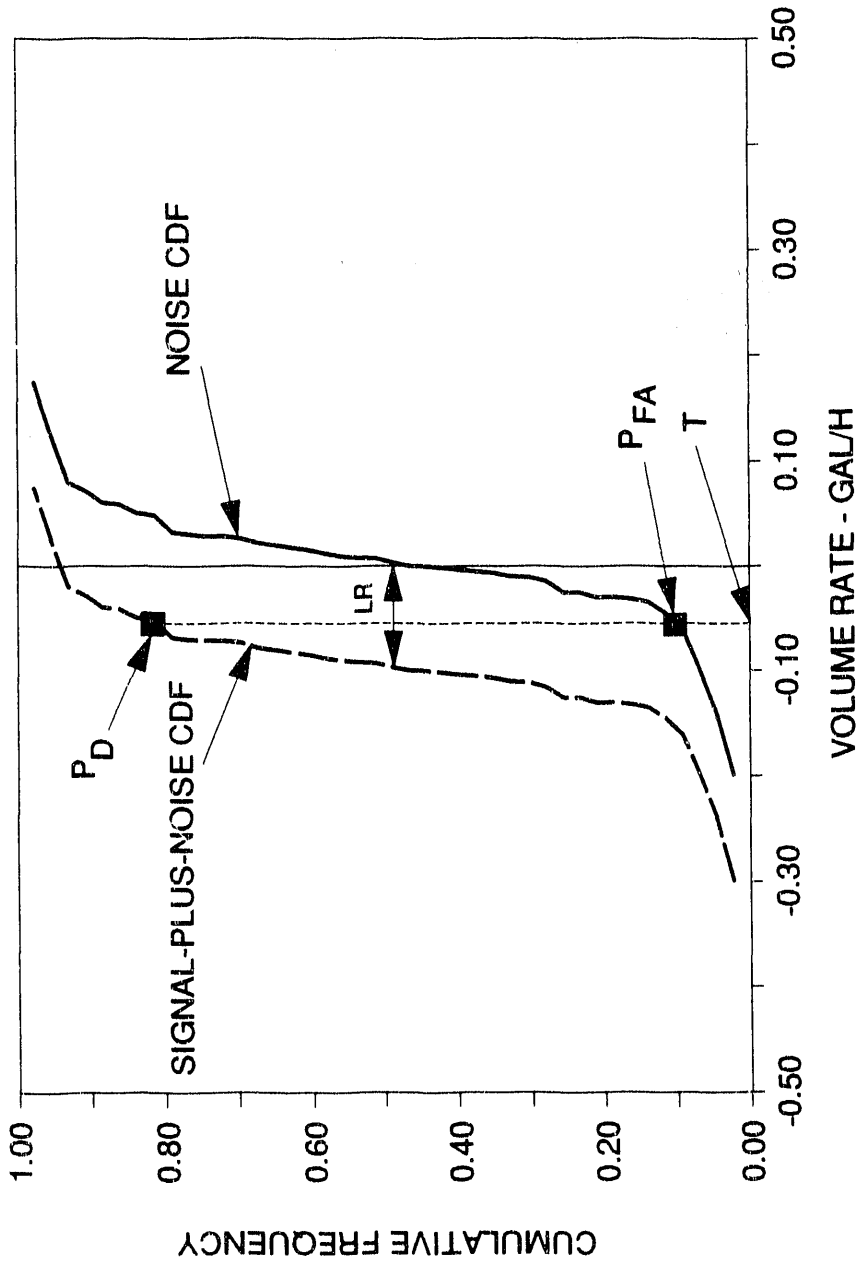


Figure 12. An illustration of the process of estimating P_D and P_{FA} from the cumulative distribution functions.

5.2 Evaluation

As described above, performance estimates for a given leak detection method are made from the results of tests conducted with that method. The EPA places special significance on a particular type of test called an *evaluation*, and requires an evaluation of leak detection methods used to achieve compliance with the UST regulation. Evaluation tests are conducted in accordance with standardized EPA-published test procedures (or an equivalent procedure) and serve to formally establish the performance of the method. An evaluation document prepared at the conclusion of the evaluation testing certifies the performance of the method.

Each of the methods to be used at ORNL in the execution of this leak testing plan will need to be evaluated. This is true for the existing instruments at ORNL that may be adapted for use as leak detection methods and for other leak testing methods that may be installed at ORNL. An evaluation is necessary for the existing ORNL level gauges to certify their performance as leak detection methods for the ORNL wastes. An evaluation of other methods (that may have been previously evaluated for use in petroleum tanks) will be necessary since the evaluation documents currently held by these methods are not likely to include operation in aqueous solutions.

As part of the demonstration phase, the leak testing methods will be evaluated by means of a procedure that is equivalent to the EPA's standardized test procedure. The evaluation tests and the results of these tests will be made part of the leak testing demonstrations. Vista Research, Inc., a contractor to Martin Marietta Energy Systems (MMES), will conduct the evaluation of the various methods. The evaluations will be carried out either at ORNL or at EPA's Underground Storage Tank Test Apparatus (USTTA) in Edison, New Jersey. The choice of evaluation site depends upon the particular geometric requirements of the method.

6 LEAK TESTING PLAN

The leak testing plan for the ORNL LLLW system must be consistent with the requirements of the FFA. The provisions and goals in the plan must be technically achievable, and the plan must address the issues described above. Furthermore, the plan must be structured so that it can be implemented and its goals accomplished within the time frame and budget allocated to it, consistent with the priorities assigned to each segment of the plan. The leak testing plan for the ORNL LLLW system includes these elements: specification of the performance of the leak testing methods to be used, identification and specification of the components to be tested, the leak testing schedule for each component, and the priorities for implementing the plan. These elements are discussed below in general terms; Volume II of this plan provides specific details.

Based upon the findings of the work described above, the substance of the leak test plan is summarized in the following points:

- Each component of the LLLW system that must be tested for leaks (tank, inlet piping, and outlet piping) requires an implementation that is specific to that component.
- Each volumetric method used to test LLLW system components must be evaluated, so that its performance is known and documented.
- In terms of performance, the volumetric leak testing methods used at ORNL will detect a specified leak rate with a P_D of no less than 95% and a P_{FA} of no greater than 5%.
- Each component will be tested on a regular basis: at least once per month for tanks and once per year for pipelines.
- Methods used for monthly tests will detect leaks of 0.2 gal/h; methods used for annual tests will detect leaks of 0.1 gal/h.
- Volume balancing is one method that can be used, to the extent that the performance of this method meets the performance standard or can be used for monthly reconciliation.
- Both internal and external leak detection methods can be used.
- Visual methods can be used, where inspections are possible and practical.

Based upon this summary, the general leak testing plan for the ORNL LLLW system is described below. In these descriptions, the components of the LLLW system that are subject to leak testing are identified by class. Volume II of this plan provides the specific details for each component in its respective class.

6.1 Small-Volume Collection and Accumulator Tanks

Figure 13 summarizes the leak testing plan for the small-volume tanks that are part of the LLLW system—tanks that have a volume capacity of less than about 3,000 gal. Leak testing of these tanks will be accomplished primarily by means of a differential-pressure level sensor. As shown in Figure 13, it is planned that each tank subject to this method will be tested monthly. Except for tank L-11, which will be inspected visually, the tanks will require between 4 and 24 h for a complete test; the actual length of a test will be related to the volume capacity of the tank (smaller tanks will require less time than larger ones). This will be described in the test protocol. Testing these tanks by means of the differential pressure method requires some time; therefore, leak testing is scheduled for weekends, when it will have minimum impact on operations at ORNL. The principal advantage of using the differential pressure method for testing the subject tanks at ORNL is that an existing level sensor is presently installed in most of the tanks within the scope of this plan. Thus, a leak testing feature can be readily incorporated into the management of these tanks. In addition to the plan for the small tanks illustrated in Figure 13, at least one of the tanks, L-11, can be visually inspected. Since a visual inspection is a direct means of determining the integrity of a tank, it will be employed in the case of L-11.

6.2 Larger-Volume Collection and Service Tanks

The leak testing plan for the larger of the Category B and C LLLW tanks (those with volume capacities between 3,000 and 50,000 gal) that are subject to leak testing is shown in Figure 14. These larger tanks may require a different method than the smaller tanks. This is because, for tests lasting less than 24 h, the differential-pressure level-sensor method used in the smaller tanks may not adequately compensate for the net environmental factors affecting measurements in the larger tanks. The primary method that is planned for leak testing the larger tanks is an enhanced version of the small tank method, with test periods of 48 to 72 h. In other tanks, leak testing will be done by means of an electronic tape, together with a test protocol developed for this sensor. While the performance of this method has yet to be determined, it is expected that the tank environment is sufficiently benign to allow leak testing with the tape, without ancillary liquid temperature information. Monthly testing of the subject tanks will be performed.

Any methods that are used at ORNL will have to be evaluated prior to implementation. Evaluations will be accomplished in such a way that the implementation phase is consistent with the FFA Plans and Schedules document [1].

Number of Components Included

24 tanks ranging in capacity from 40 to 3,000 gal*

Methods

Primary: existing differential-pressure level gauges

Secondary: enhanced volume balancing

Tanks with secondary containment have release detectors.

Testing Frequency/Leak Rate Specification

Monthly at 0.2 gal/h

Estimated test duration: 4 to 24 h

Performance Validation/Evaluation

- Validation and evaluation to be performed off site, followed by on-site validation and demonstration
- Method-validation measurements must be made
- Method evaluation (performance determination) was completed November 1991

Priority

- Number one priority due to number of singly contained tanks, ease of method implementation, age of tanks
- Waste Management- (WM-) owned tanks first because of computing capability, other owner to follow demonstrations in WM-owned tanks

Potential Problems/Solutions

No major problems identified; some level gauges only need modification for atmospheric temperature measurement. Other level gauges need various modifications, including additional data acquisition capability.

* One tank, L-11, will be inspected visually; it is not included here.

Figure 13. Summary of LLLW leak testing plan for small-volume tanks.

Number of Components Included

17 tanks ranging in capacity from 10,000 to 50,000 gal

Methods

Primary: multiple dip-leg differential pressure sensor

Secondary: electronic "tape" without temperature compensation

All tanks have secondary-containment release detectors.

Testing Frequency/Leak Rate Specification

Monthly at 0.2 gal/h

Estimated test duration: 24 to 72 h

Performance Validation/Evaluation

- Method-validation measurements are necessary
- Method evaluation (performance determination) is necessary
- Evaluation to be performed on site, using field evaluation procedures
- Validation and demonstration to be accomplished on site

Priority

Number two priority due to large volume of stored quantities, age of tanks

Potential Problems/Solutions

Large volumes imply that a very precise method is needed to detect small volume rates with acceptable performance. Multiple dip-leg differential pressure sensor will provide adequate performance. If thermal effects in LLLW are small, uncompensated electronic tape may be adequate. Long test durations may be necessary for the required performance to be achieved in LLLW tanks.

Figure 14. Summary of LLLW leak testing plan for larger-volume tanks.

6.3 Pressurized Pipelines

There are two types of pressurized pipelines in the LLLW system. The more common type includes those whose contents are moved by means of a steam jet or centrifugal pump acting from some "up-stream" location that pressurizes the line in the course of forcing the waste along the line. The second type can be described as "double-walled" lines; typically, the annular space in these pipelines is pressurized (with nitrogen) to a pressure that greatly exceeds the pump-produced pressure in the inner pipeline (which is carrying the waste). In a further division of the pipeline system, some of the piping is equipped with valves so that sections of it can be isolated from the remainder of the LLLW system; most of the piping does not include valving.

An initial estimate shows that there are at least 15 major pressurized pipelines in the LLLW system that require leak testing, comprising almost 20,000 ft of singly and doubly contained piping. Even while the details of the piping system are being finalized, the leak testing of the pressurized components can be planned. This is summarized in Figure 15. This figure shows that the primary leak detection method for pipelines that have valves will be a volumetric one, while for pipelines without valves it will be enhanced volume balancing. Since the performance of these methods has yet to be evaluated, several secondary leak detection methods are being planned for validation and assessment. These include tracer techniques, acoustics, and others. Annual leak testing of the pressurized lines is planned.

6.4 Gravity-Fed Pipelines

Figure 16 summarizes the leak detection plan for the gravity-fed pipelines. It is estimated that there are approximately 8,000 ft of gravity-fed piping in the LLLW system that require leak testing. Most of it is drain piping that runs from floor drains in various buildings' hot cells to the collection/service tanks near those buildings. The primary leak detection method planned for these pipelines is an enhanced volume balancing method using distilled water. Annual leak testing is planned.

Number of Components Included

Based upon Tables 1 and 2, it is estimated that there are at least 15 major pressurized pipelines subject to leak testing; the doubly contained portion of these pipelines is greater than 10,000 ft in length; the singly contained portion totals an estimated 10,000 ft.

Methods

Primary: Volumetric method (using extant LLL wastes) for pipelines with valves and centrifugal waste pumps; enhanced volume balancing (using extant LLL wastes) for unvalved pipelines with centrifugal pumping; external methods (e.g., tracers, acoustics) for jet-pumped pipelines.

Secondary: External methods (e.g., tracers, acoustics).

Testing Frequency/Leak Rate Specification

Annually at 0.1 gal/h

Estimated test duration: 4 to 24 h

External methods: annual testing

Tracers: detect presence of tracer chemical outside pipeline, no leak rate specified; estimated test time up to one week per line.

Performance Validation/Evaluation

All internal methods used will require off-site validation and evaluation, followed by on-site validation and demonstration.

Priority

Number three priority due to frequency of use, volumes of transferred wastes

Potential Problems/Solutions

Jet-pumped pipelines introduce additional waste as a result of steam condensate following venturi; this makes these pipelines difficult to test with internal methods and may require use of external methods. External methods would test the various pipelines serially and would be time-consuming and costly. The fraction of the total number of pressurized pipelines requiring external methods has yet to be determined.

Figure 15. Summary of LLLW leak testing plan for pressurized pipelines.

Number of Components Included

Based upon Tables 1 and 2, it is estimated that there are 25 major gravity-fed pipelines subject to leak testing; these pipelines total more than 8,000 ft in length.

Methods

Primary: Enhanced volume balancing (using distilled water)

Secondary: External methods (e.g., tracers, acoustics)

Testing Frequency/Leak Rate Specification

Annually at 0.1 gal/h; "annual equivalent" at 0.1 gal/h possible for low-use pipelines and performance of leak detection method

Estimated test duration: One week per line

Performance Validation/Evaluation

Enhanced volume balancing method requires off-site validation and evaluation, followed by on-site evaluation and demonstration.

Priority

Number four priority due to frequency of use, volumes of transferred wastes

Potential Problems/Solutions

Gravity-fed lines are particularly difficult to test with traditional leak detection methods because they are unvalved and operate at atmospheric (or slightly lower) pressure. However, most of these lines are operated only infrequently and have low flow rates. The performance of an enhanced volume balancing method has yet to be determined.

The portion of the gravity-fed lines that lie within a building perimeter may not be testable if the enhanced volume balancing method demonstrates inadequate performance. If other methods (e.g. visual inspections) are impractical, an exclusion will be recommended due to the *de minimis* volume of LLL wastes.

Figure 16. Summary of LLLW leak testing plan for gravity-fed pipelines.

7 LEAK TESTING SCHEDULE

A schedule for the development, demonstration, and implementation of the ORNL LLLW leak testing plan is shown in Figure 17. This figure (which appears as Figure 6.4 in the FFA Plans and Schedules document for ORNL [1]) reflects the estimated technical effort required and incorporates the schedule priorities described above.

Full implementation of the leak testing plan for the ORNL LLLW collection tanks will occur in two phases. The first phase will focus on the collection and storage tanks. The second phase focuses on the pipelines.

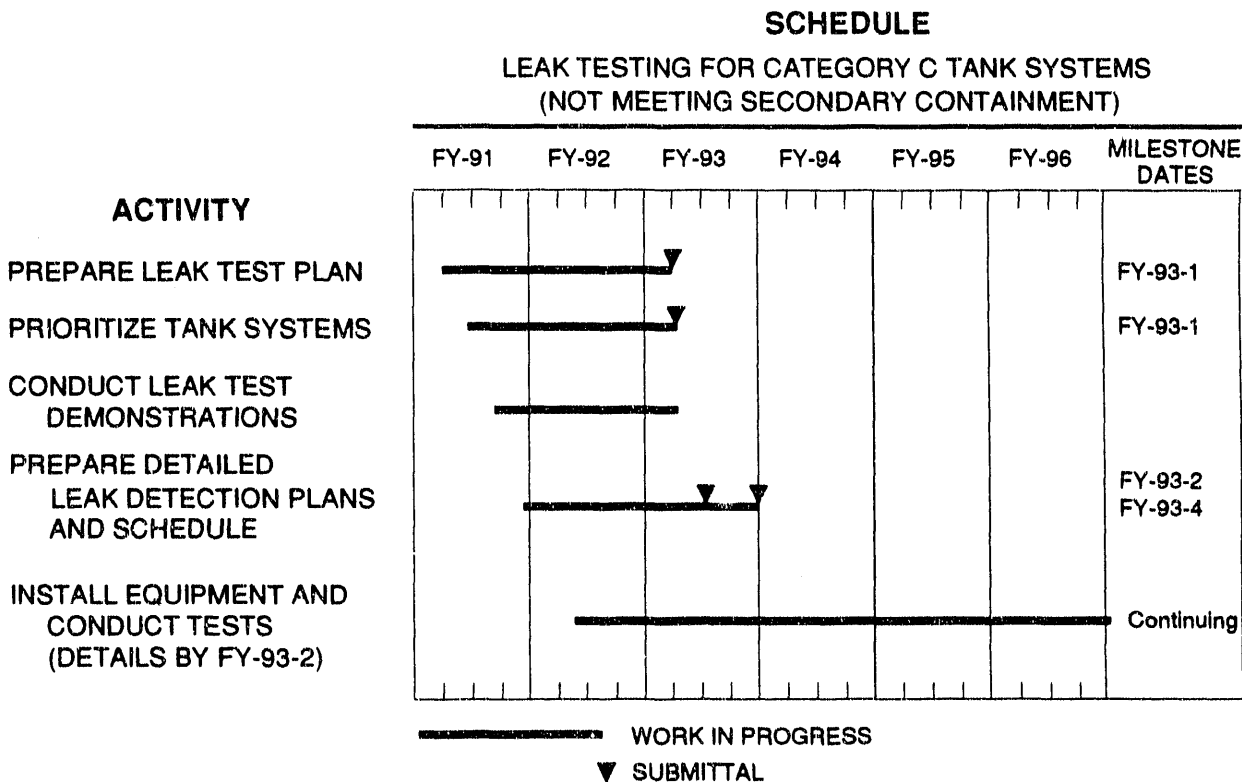


Figure 17. Leak detection test plan and schedule.

8 CONCLUSIONS

A preliminary leak testing plan for a portion of the ORNL Liquid Low-Level Waste system has been described. This plan is designed in such a way that it is consistent with the requirements and intent of the Federal Facilities Agreement (FFA). The elements in the plan are technologically achievable, and can be implemented in a timely and cost-effective manner. Further, the approach described in this plan provides the same degree of protection to the LLLW system as is required by the EPA for tank systems containing hazardous substances.

A key feature of the plan is that it is based in part on relevant portions of current federal regulations applicable to underground tanks and pipelines that store and transfer petroleum products and other hazardous substances (i.e., "40 CFR 280 - Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks" [5]). This regulation has *deferred* LLLW systems from immediate compliance, but has not *excluded* them. There are three advantages to basing the plan on this federal regulation. First, the UST regulation has been accepted by industry and is being implemented by most state and local regulators. Second, the regulation provides quantitative performance standards by which to gauge the effectiveness of leak detection methods; it also provides a testing schedule for making the necessary measurements. Third, since the regulation is founded on existing technology, the physics of many of the leak testing methods applicable to the LLLW system are well understood, and the methods themselves can be demonstrated and implemented.

The leak testing plan addresses the individual components of the LLLW system. This is necessary because of (1) the variability in volume capacity among the many tanks, (2) the variability in the way these tanks are installed, (3) the variability in the size and configuration of inlet and outlet piping, and (4) the variability in transfer methods. Even among the common components, no single leak testing approach can be universally imposed because the tanks and lines have different "owners," each of whom has unique operational requirements, available instrumentation, and transfer procedures. Furthermore, some tanks and lines experience infrequent, low-volume flow, while others have more frequent flow, at higher flow rates.

In developing this leak testing plan, a substantial effort has been made to take advantage of existing instrumentation within the LLLW system, and existing practices, wherever possible and practical. This has advantages for the EPA, the Tennessee Department of Environment and Conservation, and ORNL in terms of time and cost. If specialized instruments had to be procured and then installed in each component, each new installation would require an individual installation design and installation plan, together with substantial site work. To the extent that existing instruments can be adapted for the leak testing function, the time and work associated with installing the new equipment are mitigated; this results in significant cost savings. The benefits of using existing equipment are especially apparent when one considers the engineering problems and health hazards implicit in dealing with low-level radioactive wastes.

Based upon the preliminary findings in this plan, existing instruments that are believed to be adaptable to the leak testing function include the differential-pressure level gauges found in the small-volume tanks (less than 3,000 gal), the conductivity level gauges found in some of the tanks, and possibly the pressure-monitoring instruments used on some of the longer pressurized pipelines. In some cases, visual inspection is possible, providing an external release detection method. The larger tanks may require new instrumentation or modifications to the small-tank method or protocol. The gravity-fed pipelines and some of the pressurized pipelines will require the application of specialized leak detection methods. All methods of testing for leaks, those that use existing instruments and those that do not, will have to be validated and evaluated during the leak test demonstrations to be conducted at ORNL.

A major element of the leak testing plan is *quantitative measurement of leak rate* from all testable components of the system, *using test methods whose performance has been formally evaluated* and documented in terms of detecting specified leak rates with a probability of detection of at least 95% (0.95) and a probability of false alarm of no more than 5% (0.05). Another major element of the plan is that the test results are *measured against specific leak detection criteria*. These elements clarify the requirements of the FFA, which is vague with regard to specific leak testing approaches and performance standards. For all of those components that can be tested with methods reporting a leak rate, the plan implements leak-rate detection criteria adopted from the UST regulation. Another major element of the plan is that the quantitative measurement of leak rate from each of the component parts of the LLLW system is *consistent with the technology developed to help the UST industry* comply with federal regulations for underground storage tanks. Thus, the plan takes advantage of the technological developments in the UST arena and applies them to the LLLW system.

Another element of the LLLW leak testing plan is the *scheduling of the leak tests*. The testing schedule for the LLLW system will be based upon the UST regulation. Both the large and small tanks will be tested monthly. (As indicated by the FFA, an enhanced volume-balancing method may also be employed on the tanks.) Transfers of liquid waste in the pressurized pipelines (e.g., those lines between the collection and storage tanks) are not regular and tend to be infrequent; annual testing is planned.

The gravity-fed-pipeline portion of the LLLW system will initially be tested with an enhanced volume balancing method. Because of the waste management issues associated with large-scale volume balancing tests, such testing will use minimal quantities of water. As for the collection tanks, the performance of the volume balancing method will be established during the demonstration period. To the extent that the performance of the enhanced volume balancing method proves to be inadequate because of low flow volumes of extant wastes, it is expected that external leak detection methods will be employed. Since many of the gravity-fed pipelines carry very infrequent, very low-volume flows, the testing schedule developed for each pipeline will be based upon utilization. Pipelines that lie within a building perimeter may not be testable if the enhanced volume balancing method demonstrates inadequate performance. This is because the

external methods are unlikely to be able to detect leaks that lie within concrete walls or floors. In this case, if the pipeline is small, with infrequent flows, a leak testing exclusion will be recommended because the pipeline contains a *de minimis* volume of waste.

Volume I of the leak testing plan has described a program tailored for the ORNL LLLW system. The plan is built upon existing federal regulations and leak testing technologies that have been proven in the underground storage tank industry, together with the specific needs and operational requirements at ORNL. The plan emphasizes the use of existing instrumentation where possible, so that implementation may be both timely and cost-effective. When implemented, the ORNL LLLW leak testing plan can become a model for other sites with similar waste management systems. It will feature quantified leak rate determination using instruments with known performance, testing with specific leak detection criteria, and a rigorous test schedule for each of the testable components of the system. Implementation of the leak testing plan will begin with a number of leak test demonstrations for particular components of the system. These demonstrations will serve to illustrate the leak testing methods, validate the performance of the methods, and prove their utility. The demonstration phase will be followed by regular leak testing of the various components of the system, in accordance with the testing schedules for those components.

Volume I has provided the background for the leak testing plan at ORNL and described the approach to be taken. Volume II provides detailed descriptions of the leak testing methods to be used for each component, and the leak testing protocol and testing schedule for each component of the system.

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**Leak Testing Plan for the Oak Ridge National Laboratory
Liquid Low-Level Waste System
(Active Tanks)**

Vol. II. Methods, Protocols, and Schedules

**Dennis G. Douglas
Joseph W. Maresca, Jr.**

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	v
LIST OF FIGURES.....	vii
LIST OF TABLES	viii
LIST OF ABBREVIATIONS AND ACRONYMS.....	ix
1 INTRODUCTION	1
2 OVERVIEW OF LEAK DETECTION METHODS	3
2.1 Volumetric Methods	3
2.2 Volume-to-Height Conversion Factor	4
3 LEAK DETECTION METHODS FOR THE LLLW SYSTEM AT ORNL	5
3.1 LLLW Tanks	5
3.1.1 Leak Detection Methods for Small Tanks	5
3.1.2 Leak Detection Methods for Large Tanks	8
3.2 Protocol for Conducting a Leak Test	8
3.3 Leak Testing Schedule.....	11
4 PIPELINES	13
4.1 Leak Detection Systems for Gravity-Fed Pipelines.....	15
4.2 Leak Detection Systems for Pipelines That Transfer Liquid under Pressure...	17
4.2.1 Volumetric Tests	17
4.2.2 Pressure Tests.....	18
4.2.3 Acoustic Tests	18
4.2.4 Tracers.....	19
4.3 Recommendations.....	21
5 CONCLUSIONS	23
REFERENCES	26
Appendix A: TANK CHART CALCULATIONS FOR HORIZONTAL TANKS.....	27
Appendix B: LEAK TESTING PLAN	39

EXECUTIVE SUMMARY

A leak testing plan for a portion of the Liquid Low-Level Waste (LLLW) system at the Oak Ridge National Laboratory (ORNL) is provided in the two volumes that form this document. This plan was prepared in response to the requirements of the Federal Facilities Agreement (FFA) between the U.S. Department of Energy and two other agencies, the U.S. Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC). The effective date of this agreement was 1 January 1992.

The LLLW system is an interconnected complex of tanks and pipelines. The FFA distinguishes four different categories of tank and pipeline systems within this complex: new systems (Category A), doubly contained systems (Category B), singly contained systems (Category C), and inactive systems (Category D). The FFA's specific requirements for leak testing of the Category C systems is addressed in this plan. The plan also addresses leak testing of the Category B portions of the LLLW system. Leak testing of the Category B components was brought into the plan to supplement the secondary containment design demonstration effort that is under way for these components.

The approach that has been taken in preparing this plan, and that will be taken in executing it, is fully responsive to the requirements of the FFA. A key feature of the plan is that it is guided in part on relevant portions of current federal EPA regulations applicable to underground storage tanks and pipelines (UST systems) that store and transfer petroleum products and other hazardous substances. While the FFA does not require that the leak testing at ORNL follow these regulations, the regulations do provide the solid technical foundation for the testing program. In particular, the UST regulation provides clear and unambiguous *performance standards* for the conduct of release detection testing, and it provides a *schedule* for repeated testing of UST components. This plan, however, also recognizes that the EPA's UST regulation cannot be blindly applied to the LLLW system. This is because the operation of the LLLW system at ORNL is very different from the operation of a typical retail station. As a result, this plan makes some adjustments in the application of the regulation, as demanded by operational considerations.

Volume I of the leak testing plan reviews the background for the plan and describes how the EPA's UST regulation can be applied to the LLLW system. This volume provides an overview of the LLLW system, with a discussion of the tanks and associated pipelines that will be leak tested under the plan. Because the variety and complexity of the various components in the LLLW system preclude a single method or leak testing approach, Volume I describes several methods that are expected to be used. It also identifies primary and secondary methods for each component class, and the performance standards that will be used for each method. Volume II describes the testing of each component in detail. A component-type priority is established so that leak testing can be implemented in an orderly manner consistent with the needs and limitations of the facility.

For LLLW tanks with a capacity of less than 3,000 gal, the existing level sensor in these tanks (together with measurements of the temperature of the sensor) is identified as the primary release detection method. To allow cost-effective use of the existing instruments, the plan for this method utilizes (1) algorithms sufficient to compensate for environmental effects that influence the measurements and (2) a leak testing protocol applied to the data collection and analysis steps. Subject to further modeling and validation testing, it is expected that the existing level sensors can also be used to leak test the larger tanks, with leak detection algorithms and testing protocols appropriate for these larger tanks. It is planned that the LLLW tanks will be leak tested on a monthly schedule; the release detection method will be evaluated to ensure detection of a 0.2-gal/h leak, with a probability of detection (P_D) of not less than 95% and a probability of false alarm (P_{FA}) of no more than 5%.

There are two classes of pipelines: pressurized and gravity-fed. It is planned that an enhanced volume balancing method will be employed as a primary method for the gravity-fed lines. This method will use a controlled addition of minimal volumes of water to the line being tested. The performance of this method remains to be validated. The pressurized pipelines will be tested by a number of means, including volumetric methods, tracers, and volume balancing; the choice of method for a given line will depend upon whether that line can be isolated by means of valves. It is planned that the LLLW pipelines will be leak tested annually. Following the guidelines provided in the UST regulation, the pipelines will be tested using methods that result in performance sufficient to detect a *full-use equivalent* of 0.1-gal/h leaks with a P_D of not less than 95% and a P_{FA} of no more than 5%. Since the LLLW pipelines are used only intermittently and most are used infrequently, since the volumes transferred during use are small compared to retail station transfer rates, and since testing of most of these pipelines is very complex, performance standards and testing schedules must be developed by which lines can be tested in a manner equivalent to the way the lines covered in the regulation are tested.

Where it is both possible and practical, visual inspections of the various components will be used in lieu of more cumbersome testing methods. The use of visual inspections requires that suitable audit trails and other quality assurance procedures be developed and implemented.

The leak testing plan prioritizes implementation of the testing activities. The tanks are addressed first because of the volume of stored product and the consequences of a release. These are followed by the gravity-fed and pressurized pipelines. Development of a Detailed Leak Test Plan and Schedule (a document required by the FFA) and implementation of the release detection program for the tanks and pipelines will be accomplished in accordance with the schedule presented in a separate document.¹

¹ "Federal Facilities Agreement Plans and Schedules for Liquid Low-Level Radioactive Waste Tank Systems at Oak Ridge National Laboratory, Oak Ridge, Tennessee," Report No. ES/ER-17&D1, prepared by the Waste Management and Remedial Action Division, Martin Marietta Energy Systems, Inc., Contract No. DE-AC05-84OR21400, Oak Ridge, Tennessee, March 1992.

LIST OF FIGURES

	Page
Figure 1. (a) Volume and temperature during demonstration; (b) correlation between level and temperature.	7
Figure 2. Leak-test algorithm and protocol for small LLLW tanks.	9, 10
Figure 3. Category chart of pipelines that will be tested for leaks.	13
Figure 4. Schematic diagram of volume-balancing method.	15
Figure 5. Acoustic leak detection/location.	19
Figure 6. Summary chart showing LLLW components, primary leak test methods, and schedules.	24

LIST OF TABLES

	Page
Table 1. Summary of Tank Characteristics and Leak Detection Protocols	12
Table 2. Test Duration Required for the Difference between Input Volume to the Line and Output Volume to a 64-in.-Diameter Tank to Exceed 1.645 Times the Precision of the Level Sensor (1.645 x 13.962 gal/in.) (All calculations assumed a slope of 1%.)	16
Table 3. Estimate of Hole Size, Volume of Liquid to Be Added for Test, and Test Duration.....	17
Table 4. Demonstration Experiments Required before a Method Can Be Considered for Leak Testing	22

LIST OF ABBREVIATIONS AND ACRONYMS

- A_{eff} = effective cross-sectional area (of the surface of a liquid in a container)
- A/D = analog/digital
- API = American Petroleum Institute
- ASME = American Society of Mechanical Engineers
- ATG = automatic tank gauge
- $^{\circ}\text{C}$ = degrees Celsius
- CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
- CFR = Code of Federal Regulations
- df = degrees of freedom
- ΔP (or DP) = differential pressure
- DOE = Department of Energy
- EPA = Environmental Protection Agency
- ft = feet
- F & D head = flanged and dished head (for end caps of tanks)
- FFA = Federal Facilities Agreement
- $^{\circ}\text{F}$ = degrees Fahrenheit
- gal = gallon(s)
- gal/in. = gallons per inch
- gal/h = gallons per hour
- gal/volt = gallons per volt
- h = hour
- HOG = hot off-gas
- H/V = height to volume

Hz = Hertz
in. = inch(es)
in./°C = inches per degree Celsius
in./volt = inches per volt
LLLW = low-level liquid waste
LLLWSIM = liquid low-level waste simulator
LVDT = linear voltage displacement transducer
MMES = Martin Marietta Energy Systems
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
PC = personal computer
 P_D = probability of detection
 P_{FA} = probability of false alarm
RTD = resistance temperature detector
SARA = Superfund Amendment and Reauthorization Act
SS = stainless steel
TDEC = Tennessee Department of Energy and Conservation
UST = underground storage tank
USTTA = (EPA) Underground Storage Tank Test Apparatus
V/H = volume to height

1 INTRODUCTION

This document provides a preliminary leak testing plan for a portion of the Liquid Low-Level Waste (LLLW) system at the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee. The leak testing plan addresses two of four categories of tank and pipeline systems within the LLLW system. It provides a plan for portions of the system, as required by the Federal Facilities Agreement (FFA). It also provides a testing plan for the active, secondarily contained tanks and pipelines to supplement the secondary containment design demonstration for these systems.

The LLLW system is comprised of several different types of components that require leak testing. Different types of components, or similar components with significantly different volume capacities or other characteristics, can require different leak testing methods. That different methods are needed is a consequence of the instrumentation (or performance) requirements, the configuration of the LLLW system, the environmental effects, operational constraints, or a combination of these factors. The various requirements and limitations affect the choice of method. For example, consider the primary release detection methods planned for the small and large tanks. In the LLLW system the small tanks, and some of the large tanks, are presently instrumented with differential-pressure sensors for making level measurements. It would be cost-effective if these sensors could be used to test all of the tanks. Although it has been established that the differential-pressure method can be used to test the small tanks [1], preliminary modeling efforts indicate that this method, if applied in exactly the same way in terms of configuration and protocol, may not be appropriate for the large tanks, at least if only a single dip leg is used. This is because, in a large tank, thermal gradients in the liquid product can be large enough that they affect the performance of the method. Thus, a modification to the small tank method (or at least another test protocol) may be required for the large tanks. One candidate is an extension of the small tank method using two dip legs. To cite another example, it was learned during the development stages of the leak testing plan that some of the pipelines in the system are valved off and then pressurized with nitrogen (or water) prior to transfers. A leak detection method can be developed from this "in-place" form of testing, and it would be useful if this method, after it had been developed and evaluated, could be used on all the pipelines. Most of the gravity-fed lines, however, cannot be isolated from the remainder of the system, and therefore cannot be pressurized. Thus, another method, such as volume balancing, must be used for the gravity-fed lines.

The EPA has described four different categories of release detection methods that are commonly used to test underground storage tank systems for leaks. These are: volumetric, nonvolumetric, inventory control, and leak-effects monitoring [2]. Each category may include a number of different types of methods. In all the methods in the first three categories, tests are conducted through measurements made inside the tank or pipeline, while leak-effects monitoring is an external procedure. Thus, the early portion of the leak testing program at ORNL entails assessing the needs and limits of the diverse components of the LLLW system and matching these components with an appropriate leak detection method. Where necessary, the best "match" may entail the development of suitable methods or the evolution of existing methods to help

answer the LLLW leak testing questions. The later portion of the leak testing program entails the implementation of the methods, including the establishment and maintenance of records from the tests of the various tanks and lines.

Volume I of this leak testing plan described the various portions of the LLLW system that will be tested, together with a description of the leak detection method(s) planned for the different types of LLLW components. Volume II gives an overview of particular facets of the leak testing to be accomplished at ORNL, including the specific methods and schedules to be used on the various components of the system, the protocols for the testing, and a discussion of the algorithms used by the various leak detection methods.

This plan specifically addresses 42 tank systems that are actively being used for the storage and transfer of low-level liquid wastes and that require leak testing; this includes the arterial pipelines associated with the tanks. The FFA requires that a detailed leak testing plan and schedule for these systems be prepared and submitted. This document is a preliminary version of that detailed plan. The detailed plan and schedule will be submitted as described in the FFA Plans and Schedules document [3].

2 OVERVIEW OF LEAK DETECTION

The leak detection methods to be used for testing the LLLW system will be designed to determine whether there exists in a tank or pipeline a leak that can release the LLLW liquids into the environment. Each method will be evaluated so that its performance, in terms of the probability of detection and probability of false alarm against a specified leak rate, has been established. The leak detection tests that are accomplished under this plan will be performed so that the quantities measured by the internal methods are related to a flow rate out of (or into) the tank or pipeline.

Most commercial leak detection systems are internal methods, based on measurement of the change in volume (inferred from product level) over the duration of the test, that is, a volume rate measurement. While the details of individual volumetric systems vary, the leak testing plan calls for using volumetric methods for a significant portion of the LLLW system. Subsection 2.1, below, illustrates some of the considerations necessary in using a volumetric method; the emphasis in this section is on tanks, but most of the discussion also applies to pipelines.

2.1 Volumetric Methods

Product-level fluctuations in a tank (the fundamental measurement made by a volumetric method) can occur as a result of level changes caused either by a leak and/or by numerous effects not related to a leak. The latter are ambient fluctuations (i.e., ambient noise) that can be as large as or larger than the smallest leaks to be detected. In a partially filled tank, the ambient noise may be caused by long waves in the tank which periodically move the product back and forth, primarily along the long axis of the tank (i.e., seiching); by volume changes produced by thermal expansion or contraction of the product; by evaporation or condensation at the product surface; and by structural deformation. In addition, instrument effects (i.e., system noise) such as thermal drifts can also be present. The accuracy, or "performance," achieved by a method usually depends on the magnitude of these fluctuations and on how well that method can minimize or compensate for these non-leak-related volume changes and "apparent" volume changes.

The basic strategy in a volumetric test is as follows: (1) before taking measurements, observe appropriate waiting periods so as to avoid the problems associated with structural deformation of the tank and with the thermal instabilities that develop just after LLL wastes have been introduced into the tank (or pipeline); (2) measure product-level change over the duration of the test; (3) measure product temperature over the same period; (4) convert measurements to volume changes; (5) subtract out the thermally induced volume contribution and/or compensate for instrument effects; (7) estimate the volume rate; and (8) declare the tank leaking if the slope (volume rate) exceeds a specific threshold value. The assumptions in this scenario are that the effects of evaporation and condensation are small, and that the groundwater table is below the bottom of the tank. Interpretation of the test result (i.e., the size of the leak) is discussed below.

The performance of a test method is based simply on the ability of the method to accurately measure the flow rate that occurs during a test. The flow rate through a hole depends, in general, on the hydrostatic pressure exerted on the hole, on the physical properties of the hole, and on sediment particulates in the tank and the backfill material outside the tank that may retard

flow through the hole. The hydrostatic pressure is, in turn, a function of the level and density of product in the tank, the level and density of the groundwater table outside the tank, and the location of the hole.

Changes in the volume of product can be caused by any of several phenomena, but principally the following.

- *Expansion and contraction of the product due to temperature changes.* Volume changes result from thermal expansion and contraction of the liquids as the temperature changes. In the case of the LLLW system, thermal effects are thought to be small compared to those experienced at a retail station because the coefficient of thermal expansion of the LLLW products is about 1/6 that of petroleum products.
- *Evaporation and condensation of product at the product surface and along the tank walls.* The volume changes due to this phenomenon can be important for tests conducted in a partially filled tank.

The tank itself may also undergo a change in volume during the test. The most important of these changes is structural deformation of the tank. Deformation, which occurs whenever the hydrostatic pressure relative to the bottom of the tank changes, is the result of an instantaneous change in product level and consists of a time-dependent relaxation of the tank system. Deformation can result in volume changes large enough to mask a leak, and, under some test conditions, can also affect the magnitude of the measured leak rate. This effect is most significant immediately after a large-volume transfer into or out of a tank, when the temperature difference between the product in the tank and the backfill and/or surrounding environment is largest. At ORNL, the solution to this problem is to allow for a waiting period before leak testing is initiated. The waiting period is especially important for the LLLW tanks, since so many of them are located in vaults, without a surrounding backfill that would offer resistance to the deformation. Fortunately, because most LLLW tanks experience large volume changes only infrequently, it is expected that deformation will not present a significant limitation to the leak testing at ORNL.

2.2 Volume-to-Height Conversion Factor

An underlying assumption of a volumetric test is that product-level changes in a tank, whether produced by a leak or by any other volume change (such as the thermal expansion or contraction of the product), can be interpreted as product-volume changes. An accurate estimate of the volume-to-height conversion factor is required in order to convert the product-level changes to product-volume changes. The volume-to-height conversion factor is defined by

$$A_{\text{eff}} = \frac{\Delta V}{\Delta h} \quad (2.1)$$

where A_{eff} is the effective cross-sectional area of the product surface and ΔV is the volume change produced by a product-level change, Δh . For the vertical LLLW tanks, A_{eff} is a constant; for the horizontal tanks it will vary with the level in the tank. Appendix A provides calculations of the tank strapping tables for the horizontal tanks in the LLLW system.

3 LEAK DETECTION METHODS FOR THE LLLW SYSTEM AT ORNL

As noted in Volume I, the portion of the LLLW system to be tested for leaks can be divided into four distinct types of components: tanks smaller than 3,000 gal, tanks larger than 3,000 gal, pressurized pipelines, and gravity-fed pipelines. The pipelines can be further divided according to whether they are capable of being isolated from the remainder of the system (i.e., whether they are valved or unvalved), and whether they are double-walled or single-walled. The pressurized pipelines have an additional subdivision, according to whether the tank supplying the line is pumped by means of a centrifugal pump or a steam jet. Each of these types of components and their subdivisions presents distinctly different technical problems for leak testing and, therefore, each requires a different leak testing solution. The sections below provide information about the leak detection methods that are planned for each of the component types within the LLLW system.

3.1 LLLW Tanks

This preliminary leak testing plan addresses a total of 42 LLLW tanks that range in volume capacity from 40 to 50,000 gal. Twenty-five of these tanks have capacities of 3,000 gal or less and seventeen tanks have capacities greater than 3,000 gal. It is planned that two different volumetric methods will be used to test these two different types of tanks for leaks¹. The use of two different methods is based on a review of the instruments currently installed in the LLLW tanks, on the environmental effects occurring in tanks, and on a conservative estimate of the instrument precision necessary to perform the tests satisfactorily. This review found that the existing level sensors had sufficient precision to measure small changes in "small" tanks over a modest period of time, but that they lacked the requisite performance for the larger tanks—for tests of less than 24-h duration. The rationale for separating the methods at the 3,000-gal value included consideration of the precision of the existing instrumentation and the geometry and sizes of the various tanks. This is discussed in Subsection 3.1.1.

3.1.1 Leak Detection Method for Small Tanks

The smaller tanks will be tested by a method based upon a differential pressure measurement of liquid level in the tank. This measurement is made by an instrument called a "DP cell" or a " Δp " device. The DP cell measures liquid level by sensing the pressure produced by the head of liquid, with respect to the pressure in the vapor space of the tank. As the depth of the liquid increases, the pressure increases. The output of the device is proportional to the measured pressure. The liquid level can therefore be determined from a measurement of the output made by a calibrated sensor.

1. Tank L-11, which could be tested using the small tank method described later in this report, can also be examined visually. Since visual inspections can directly indicate the presence of a leak, this method will be employed for this tank (and for others where direct inspection is safe and practical).

As configured at ORNL, the DP cell infers the liquid level in the tank by measuring the mass of the liquid in a vertical column above the outlet of a "bubble" tube that is placed into the tank. In a container with constant cross-sectional area, and where the bubble tube extends to the bottom of the container, the outlet of the DP cell is independent of level (volume) changes that result from thermally induced expansion and contraction of the liquid. That is, the DP cell is self-compensating for thermally produced volume changes in the liquid; this is *approximately* true for the LLLW tanks. The advantage of such a sensor for making leak tests (whose goal is to detect when the tank's contents leak from the tank into the environment) is that it can be used for that purpose without the need for the complicated process of measuring the temperature of the liquid in the tank, followed by temperature compensation of the level to account for the effects of changes in volume. Since there are presently no temperature-sensing instruments installed in the LLLW tanks, a mass measurement method suitable for doing leak tests in those tanks provides an obvious advantage.

The DP cell itself, however, is not without a pronounced temperature dependency. This was illustrated in Figure 9 of Volume I of this report, which showed how the volume in tank WC-2 varied with (air) temperature. Another example is shown in Figure 1(a), which illustrates the volume of product in tank WC-9 and the air temperature measured during a demonstration of leak detection methods conducted at ORNL during the period 13 to 16 September 1991. In both of these figures, the lines indicate the liquid volume measured by the Δp device, and the points indicate the air temperature at the site as measured by the "X-10 met tower" in Bethel Valley. It can be seen from these data that the DP cell "measures" large level (volume) fluctuations as the temperature of the DP cell itself varies. (That the correlation is between level and *DP cell* temperature rather than between level and *LLLW liquid* temperature is clear when the tank environment is considered. The LLLW tanks are all deeply buried or in vaults that are heavily insulated from diurnal temperature fluctuations. Therefore, since the LLLW liquid temperature is not changing in daily cycles, the observed changes are properly associated with temperature changes of and around the DP cell.)

Figure 1(b) shows a scatter plot of the measured level in WC-9 and the air temperature during the September demonstration. This figure was prepared using the geometry of WC-9 and the volume-to-height coefficient for this tank (23.88 gal/in.). The recorded volume measurements were converted to liquid depth, or height. This plot shows that there is a very close correlation between level and temperature. A linear regression through the data shows that the *influence coefficient* between these two quantities is about 0.008 in. per degree Fahrenheit, or about 0.014 in. per degree Celsius. Similar influence coefficients have been determined from other ORNL demonstration data, and are being obtained in the course of the evaluation of the DP method; this finding indicates that the temperature effects on the DP cell itself can be reliably compensated for. The degree to which this compensation can be accomplished will influence the performance of the instrument in its function as a leak detection method; this is discussed in a separate report [1].

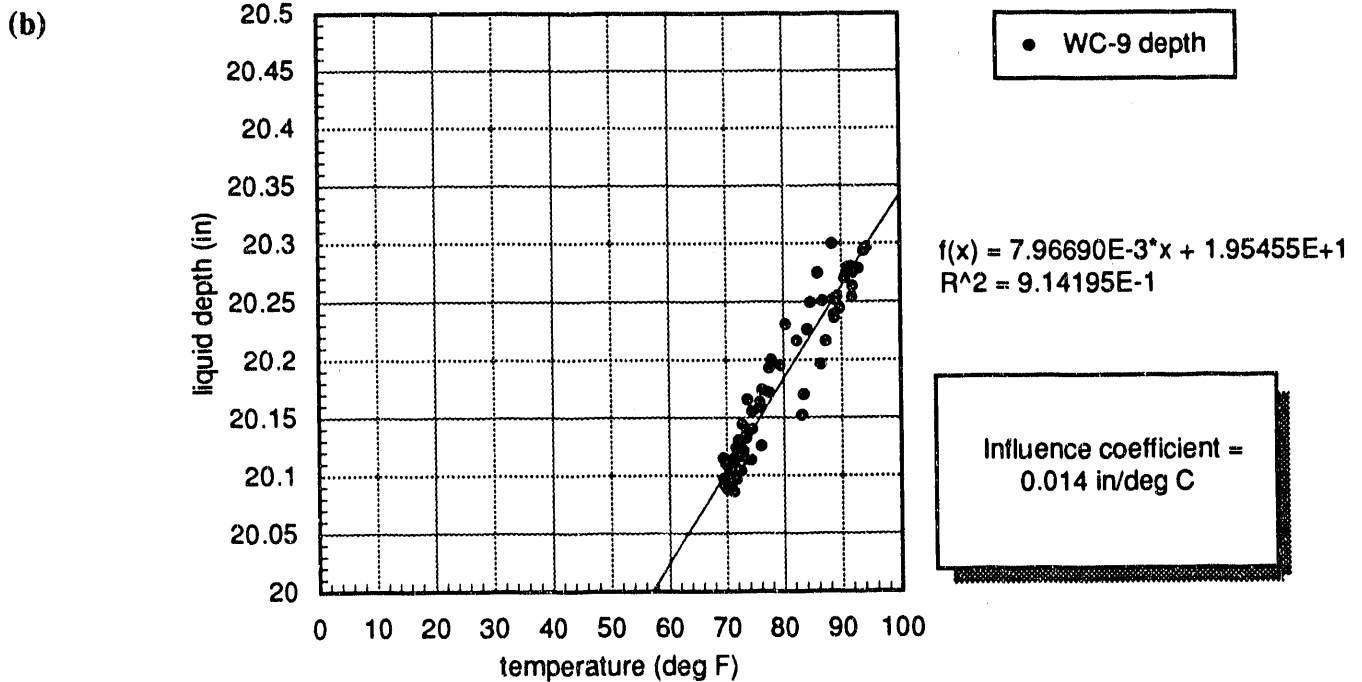
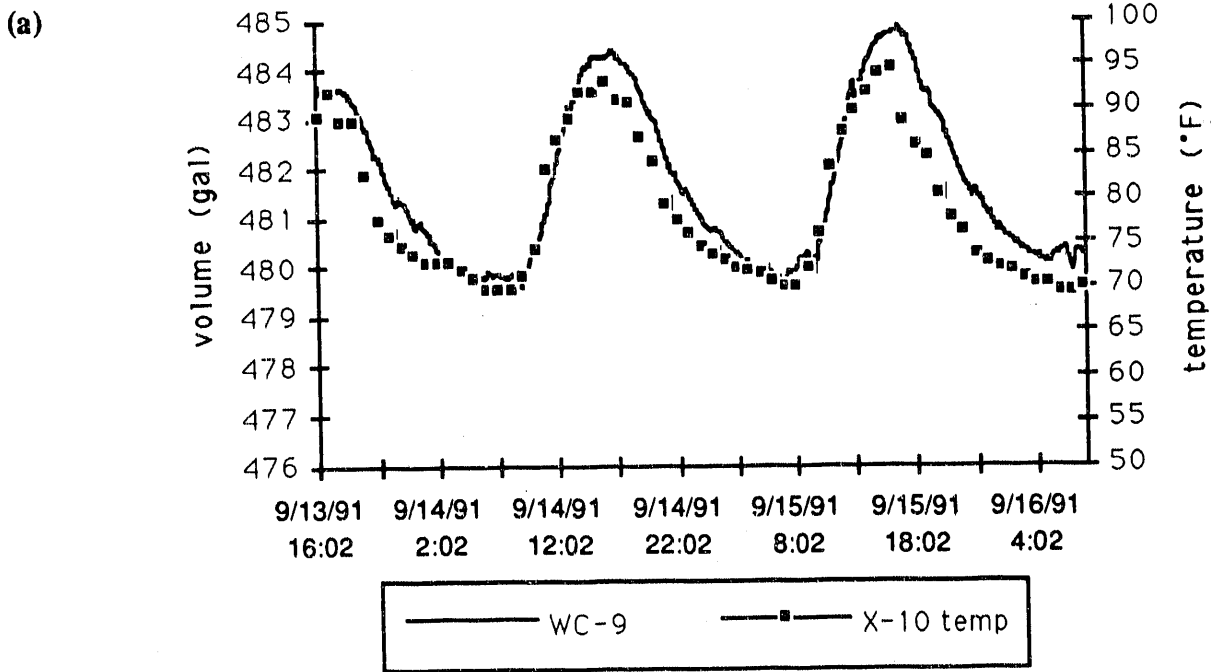


Figure 1. (a) Volume and temperature during demonstration; (b) correlation between level and temperature.

3.1.2 Leak Detection Methods for Large Tanks

The 17 large tanks will be tested by either of two methods: (1) a method based upon the differential-pressure sensor described above (but using multiple dip legs or a modified test protocol, or both), or (2) a method that uses a conductivity probe attached to a tape that is lowered from the top of the tank (i.e., the Robertshaw instrument). Where the modified DP-cell method cannot be used, the Robertshaw tape sensor will be substituted. The protocol for this method remains to be developed and validated.

Insofar as the choice of method is concerned, the "large" tanks are distinguished from the "small" tanks by their volume-to-height (V/H) ratios. As will be shown later, the tanks considered to be large have V/H ratios in excess of 100 gal/in. (at mid-tank), while the small tanks have V/H ratios significantly less than 100 gal/in. Since the candidate leak testing methods at ORNL sense level *change*, since changes in level must be interpreted as changes in volume, and because the large tanks have very large values of V/H, the method to be used in the large tanks must have very good resolution and good precision. Based upon the manufacturer's specifications, the Robertshaw device appears to have the requisite precision. Furthermore, since the liquids in the large LLLW tanks are transferred only infrequently, they are expected to be in thermal equilibrium (nominally) and thus not subject to significant level changes due to thermal expansion effects. Accordingly, it is expected that the Robertshaw device can be used to leak test LLLW tanks up to 50,000 gal in capacity.

Demonstrations at ORNL are presently being planned for the purpose of validating the use of the DP cell and Robertshaw methods for testing the larger tanks. It is expected that, following successful validation and evaluation of these methods in the course of the demonstrations, both the DP cell and the Robertshaw device will be installed in the subject tanks, and the testing program for these tanks will be implemented.

3.2 Protocol for Conducting a Leak Test

A flow chart that illustrates the various steps and procedures that comprise the protocol for testing the LLLW tanks for leaks is given in Figure 2. Before a leak test is initiated, it is important to minimize external factors that can affect the outcome of the test. Accordingly, the testing protocol begins with a waiting period, during which all tank activity is suspended until after the end of the leak test. During this period, the operators/owners using the tank are asked to suspend additions to and transfers from the tank. In addition, outside activities such as air sparging to clear the level gauge are also suspended. This waiting period gives the tank and its contents an opportunity to settle down, thereby maximizing the quality of the leak test data.

To reduce the chances that runoff could affect the test, the protocol requires that there be a dry period of 24 h before a test is initiated and that no rain fall during the test. This is because it is known that in some cases the vault sumps in some of the tanks collect runoff during periods of rainfall. It is also suspected that some of the pipelines in the LLLW system may leak rain runoff into the LLLW system. Waiting 24 h after a period of rainfall and before beginning a leak test reduces the opportunity for inflows that are not related to an actual leak. The rain-delay period of 24 h is based upon the experience of operators at ORNL, and can be increased or decreased as necessary.

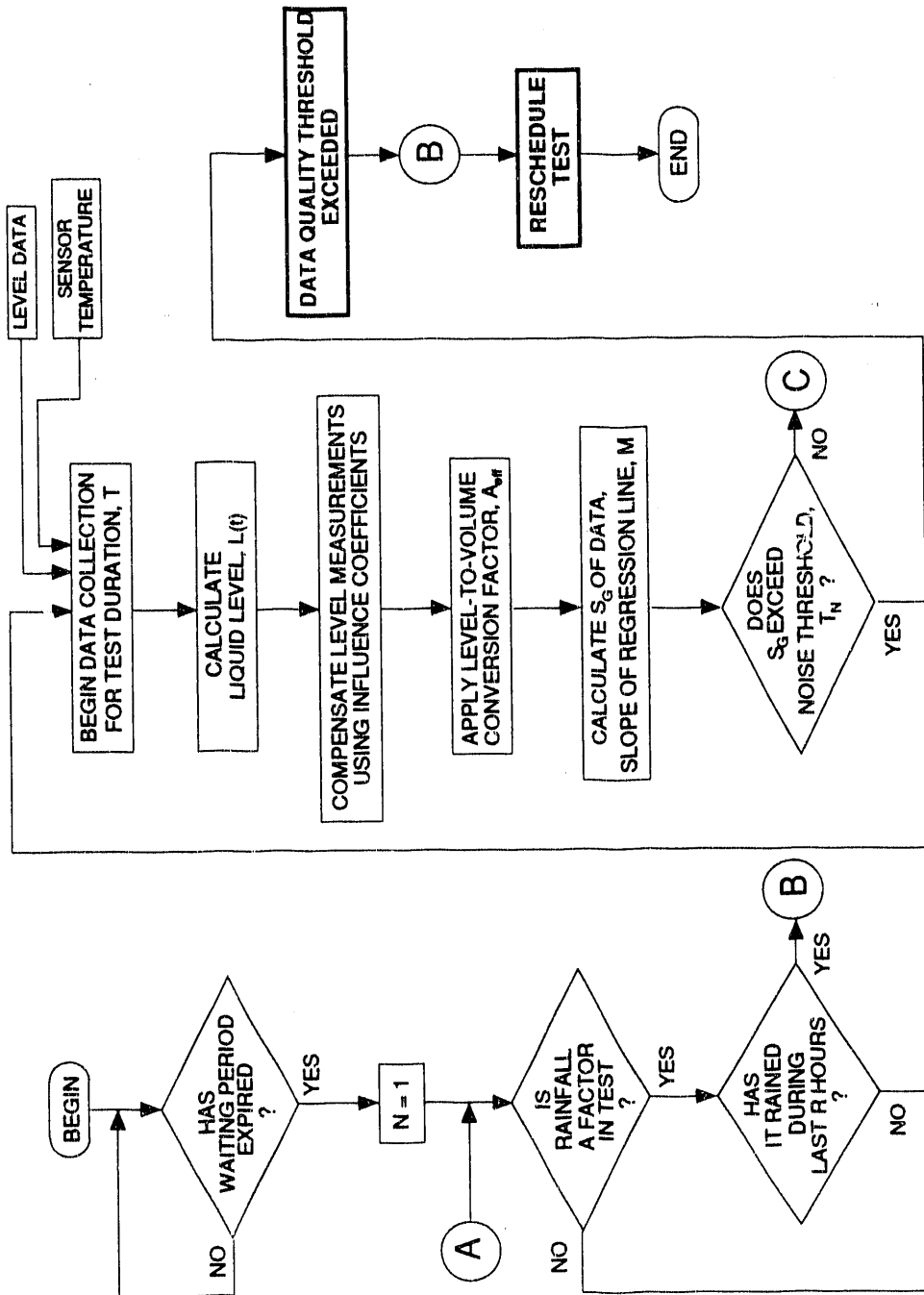


Figure 2. Leak-test algorithm and protocol for small LLLW tanks.

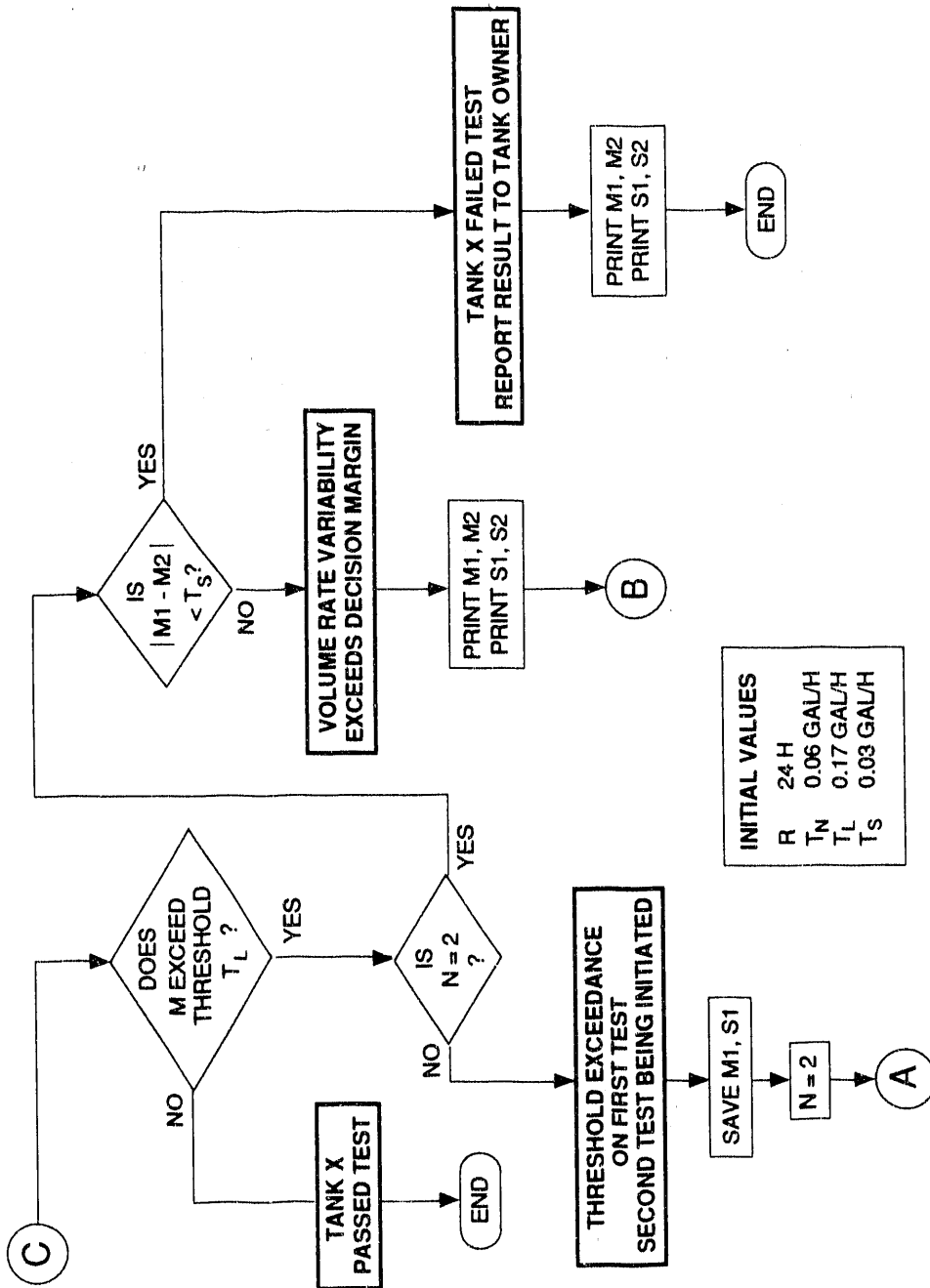


Figure 2 (concluded). Leak-test algorithm and protocol for small LLLW tanks.

The test procedure entails the collection of data, followed by compensation for temperature effects and a volume rate calculation. After the volume rate has been calculated, the data quality is determined. This is accomplished by calculating the standard deviation of the compensated data and comparing this value to a value of noise threshold. If the standard deviation exceeds the noise threshold, the test is determined to be flawed as a result of this noise, and the test is rescheduled. If the standard deviation of the data is less than the noise threshold, the volume rate is compared to a detection threshold. If the volume rate is less than the threshold, the tank is determined to have passed the leak test, and the test ends. If the volume rate exceeds the detection threshold, the exceedance is noted and another test is immediately initiated. If the result of a second test also exceeds the detection threshold, and if the absolute value of the difference between the first- and second-test volume rates is smaller than some decision-margin value, the tank is reported as having failed the leak test. The advantage of using a two-test strategy is that, to the extent the tests are independent, the probability of false alarm is greatly reduced. This is discussed in detail in the evaluation report [1].

Table 1 summarizes the method, the minimum waiting period, and the test duration for each of the LLLW tanks to be tested. This table shows, as was discussed above, that tanks with large volume-to-height ratios will be tested by means of a modified DP-cell method or the Robertshaw tape, while the smaller tanks will be tested by the differential pressure method. Appendix B provides the details of the leak testing plan for the LLLW system. This appendix provides a description of each component to be tested, the method that will be used to test it, the protocol for conducting a test on this particular component, and a brief notation of special factors that could influence the test results, together with mitigation measures.

The calculations of the strapping tables for the horizontal tanks are given in Appendix A. In the event that the manufacturer's (or an ORNL-determined) strapping table is not available to the leak test algorithms, the data in Appendix A may be used.

All test results, whether the tank has passed or failed, will be reported to a central office within Waste Management at ORNL. These records will be used to develop a database on the LLLW tanks. As test results are accumulated, the database will be used to gain a more complete picture of the integrity of the LLLW tanks, and to improve the performance of the leak detection methods.

3.3 Leak Testing Schedule

It is planned that each of the tanks within the LLLW system that are subject to leak testing will be tested monthly. If rain or other factors prevent a test from being completed as scheduled, the test will be rescheduled for the next period of opportunity.

Table 1. Summary of Tank Characteristics and Leak Detection Protocols

Tank	Orien- tation	Diameter*	Length*	Volume (Max/ Nominal Max) (Gal)	Volume/ Height** (Gal/In.)	Method	Waiting Period (h)	Test Duration (h)
2026A	V	4 ft	6 ft 11 in.	/500	7.77	DP	12	24
B-2-T	V	7 ft	8 ft 10.375 in.	1870	23.88	DP	12	24
B-3-T	V	7 ft	8 ft 10.375 in.	1870	23.88	DP	12	24
C-1	H	12 ft	61 ft	50,000	446.69***	mod DP	24	24
C-2	H	12 ft	61 ft	50,000	446.69***	mod DP	24	24
C-6-T	V	4 ft	(8 ft 10.625 in.)	710	7.77	DP	12	24
F-111	V	2 ft 3 in.	(5 ft 0.188 in.)	125	2.44	DP	4	12
F-126	V	5 ft 6 in.	(8 ft 2 in.)	1200/940	14.72	DP	12	24
F-201	V	1 ft 6 in.	(3 ft 3 in.)	/40	1.08	DP	2	4
F-501	V	4 ft	(4 ft 11.5 in.)	/200	7.77	DP	4	12
HFIR	H	(8 ft)	(35 ft)	13,000/9100	170.26***	mod DP	12	24
L-11	V	(4 ft)	(6 ft)	500	7.77	visual	N/A	N/A
LA-104	H	3 ft	6 ft 6 in.	296	11.55***	DP	4	12
N-71	V	2 ft 6 in.	7 ft	240	3.02	DP	4	12
P-3	V	3 ft	4 ft	197	4.36	DP	4	12
P-4	V	3 ft	4 ft	197	4.36	DP	4	12
S-223	H	7 ft	10 ft 6 in.	3000	42.54***	DP	12	24
S-324	H	5 ft 4 in.	6 ft	1000	18.04***	DP	12	24
S-523	H	5 ft 4 in.	6 ft	1000	18.04***	DP	12	24
T-1	H	10 ft	27 ft 5 in.	15,000/10,500	164.74***	mod DP	12	24
T-2	H	10 ft	27 ft 5 in.	15,000/10,500	164.74***	mod DP	12	24
T-13	H	7 ft	10 ft 6 in.	3000	42.54***	DP	12	24
W-12	V	5 ft 6 in.	6 ft 9.5 in.	1000/700	14.72	DP	12	24
W-16	V	5 ft 6 in.	6 ft 9.5 in.	1000/700	14.72	DP	12	24
W-21 through W-31	H	12 ft	61 ft	50,000	446.69***	mod DP	24	24
WC-2	V	5 ft 6 in.	6 ft 9.5 in.	1000/700	14.72	DP	12	24
WC-3	V	5 ft 6 in.	6 ft 9.5 in.	1000/700	14.72	DP	12	24
WC-7	V	5 ft 4 in.	7 ft 5 in.	1100/750	13.84	DP	12	24
WC-9	V	7 ft	10 ft 9 in.	2150/1500	23.88	DP	12	24
WC-10	H	6 ft 4 in.	10 ft 4 in.	2300/1650	38.11***	DP	12	24
WC-19	H	6 ft	10 ft 6.375 in.	2150/1500	36.97***	DP	12	24
WC-20	H	10 ft	19 ft 5.625 in.	10,000/7000	114.87***	mod DP	12	12

* Overall length and diameter given; entries in parentheses indicate estimates.

** V/H calculation includes 3/16-in. wall thickness for vertical tanks.

*** V/H depends on level in tank; mid-tank values given.



4 PIPELINES

There are thousands of feet of underground pipelines within the LLLW system that need to be tested for leaks. Detection of leaks in these lines is difficult. Whereas other kinds of pipelines can be pressurized for a leak detection test, many of the LLLW lines cannot be isolated from the tanks and thus cannot be pressurized. An overview of the various components of the LLLW pipeline system and a general description of the testing program proposed for this portion of the system were given in Volume I of this report.

The pipelines that will be tested in this program are the pipelines associated with the 42 tanks discussed above. Figure 3 categorizes the subdivisions of the two types of pipelines that will undergo testing: gravity-fed lines and those that transfer product under pressure. Based on the information in Figure 3, applicable methods of leak detection can be determined. Final selection of a leak detection system will be based on the characteristics of each line and will be specific to that line.

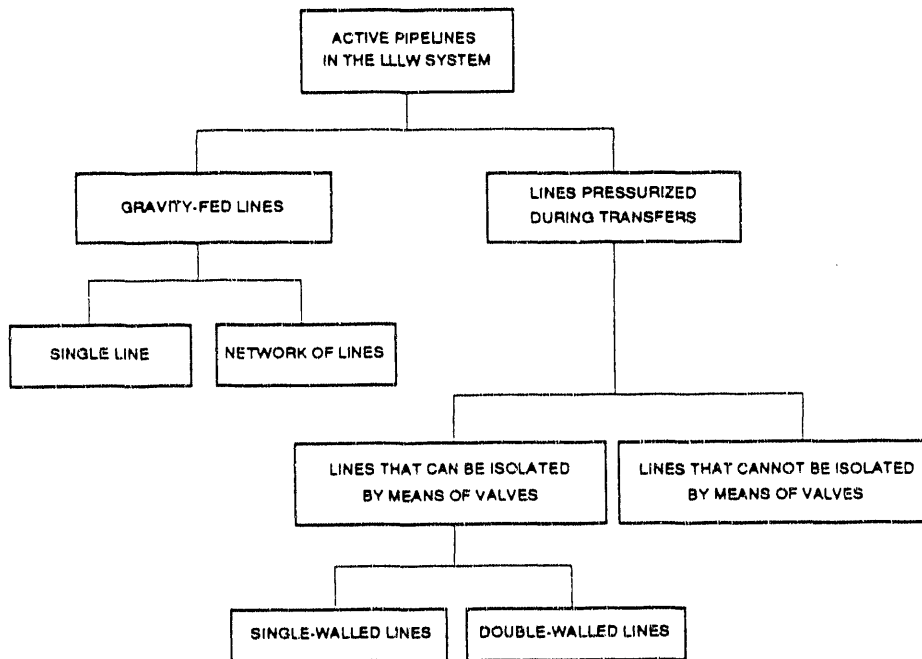


Figure 3. Category chart of pipelines that will be tested for leaks.

This section presents one or more methods for testing each type of pipeline within the LLLW system. Most of these methods have not been applied to a system like the LLLW. Those that have (pressure tests, for example) have not been evaluated for performance, and since their performance is unknown, the results of a test cannot be interpreted. The first step, therefore, is to demonstrate the operational feasibility of methods that have not been used on the LLLW system, and the second step is to evaluate the performance of leak detection systems based on these methods. Once a leak detection system has demonstrated that it meets the minimum performance standard, it can be used to test the appropriate component of the LLLW pipeline system.

As stated above, the pipelines are divided into two categories, gravity-fed lines and those that are operated under pressure during liquid transfers. Only during a deliberate transfer of waste is liquid intentionally transported through either type of line; at any other time, the lines contain no liquid other than what may accumulate in low spots at the bottom of a horizontally oriented pipe.

The gravity-fed pipelines generally transport only small volumes of waste (e.g., fractions of a gallon to a few tens of gallons) at any given time, carrying the liquid from a hot cell to a collection (or accumulation) tank. Such transfers are infrequent and none of these lines can be isolated from the tank for a leak test. One approach to testing these lines is volume balancing, in which a known volume of liquid (distilled water is planned) put into one end of the pipeline is compared to the volume that actually reaches the collection tank. (Volume balancing is also the only leak detection method specifically described in the FFA.) However, the performance of the volume-balancing method, in terms of the smallest leak that can be reliably detected in the line, in terms of its probability of detection (P_D) and probability of false alarm (P_{FA}), is unknown. Whether this method is operationally feasible depends on the volume of liquid that must be added to conduct a test capable of achieving the required performance; this method is presently being modeled in advance of validation demonstrations. The volume-balancing method has the greatest performance potential for small-diameter lines draining into small to moderate tanks (i.e., tanks with small values of V/H).

Pipelines that carry liquid waste from one tank to another are operated under pressure, and generally carry a larger volume than do gravity-fed lines, albeit infrequently and on an intermittent basis. Only a few of the pressurized lines can be isolated from their respective tanks by valves. For those lines that can be isolated, a number of conventional techniques may be applicable. Some of these techniques have been developed, evaluated, and used successfully to test pressurized pipelines at retail and industrial petroleum storage and dispensing facilities. However, their performance on long lines such as those found in the LLLW system has not been evaluated. Those lines that cannot be isolated present a technical challenge, and suitable methods of testing them must be developed and evaluated.

While it is premature to make a final selection of the leak detection systems for the various lines in the LLLW system at this time, there are preferred choices based on performance and operational issues. In most instances, further analysis, demonstrations, and evaluations of different leak detection systems are necessary to validate the choices. The program outlined here has as its goal the selection of a leak detection system appropriate for a given line, defining the system's test protocol and decision criterion, demonstrating its feasibility, evaluating its performance, and using it to test the integrity of the line. More than one leak detection system may be applicable to a given line. When two or more systems have similar performance, the selection will ultimately depend on the time required to initiate and conduct a test, operational considerations, and the overall cost of testing.

4.1 Leak Detection Systems for Gravity-Fed Pipelines

There are two types of leak detection tests that might be applicable to the gravity-fed pipelines at ORNL: (1) volume balancing and (2) tracers. A volume balancing method assumes that the difference between the volume of product put into one end the pipeline and the volume of

product measured at the other end is due to a leak. A reliable volume-balancing method requires that this difference be large enough that it can be measured by instruments at the input and output ends of the line and that any sources of ambient noise be small. Figure 4 illustrates the typical measurement setup required to test a gravity-fed pipeline. The volume of liquid added to the line must be accurately measured and released at a constant rate, the tank receiving the liquid must be tight, the level gauge in the tank must be able to measure small changes, and the volume changes that occur in the tank during the test must be small or must be compensated for.

The smallest leak rate that can be reliably detected is dependent upon (1) the smallest volume change that can be measured with the tank's level gauge and (2) the volume of fluid that must be added to the line in order for an orifice or leak in that line to produce a measurable loss of liquid (and the rate of addition of this fluid to the line). Rate is important because, in a non-pressurized line, the amount of liquid lost as the result of a leak may be largest when the liquid is added slowly. A test employing the volume-balancing method must account for the ambient volume changes that occur both in the tank and in the line during a test. The minimum detectable leak rate can be estimated theoretically but must be confirmed experimentally. Before a test is conducted, the line should be flushed with a known volume of liquid. This serves both to wet the walls of the line and to fill in any low spots in the bottom part of the line. This is particularly important for the pipelines with very infrequent transfers and whose residual wastes may have evaporated.

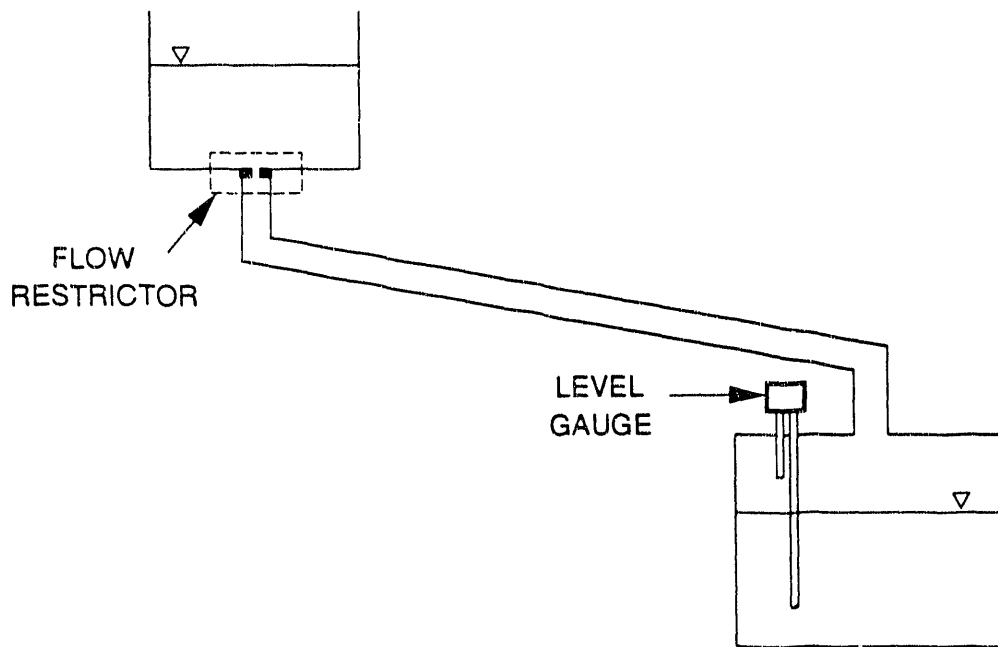


Figure 4. Schematic diagram of volume-balancing method.

An estimate was made of the volume of liquid that must be added to a 2-in.-diameter line that empties into a 64-in.-diameter, 1,000-gal vertically oriented tank equipped with a differential pressure sensor. Experimental estimates have shown that the differential-pressure level sensor used to test the LLLW tanks for leaks, which the manufacturer states has a precision of 0.01 in.

(0.139 gal), can detect the level changes that result from the instantaneous addition of 1,000 ml (0.264 gal) of liquid to the tank (equivalent to a height change of 0.019 in.). However, because there are other sources of noise in the tank, a volume change of this size is not very detectable if it is measured over a longer period of time. A theoretical estimate was made of the volume of liquid that must be added to the line to permit detection with a differential-pressure sensor having a precision of 0.01 in. in a 1000-gal, vertically oriented tank. The flow rate due to a leak was estimated using an equation that describes free flow through an orifice, and the volume of liquid that must be added was estimated using Manning's equation.

Table 2 presents the results of calculations for a 2-in.-diameter pipeline with a 1% (1:100) slope to determine how much liquid must be added and how long a test must continue before the difference between the quantity of liquid input to the line and that output from the line into a 64-in. vertically oriented tank exceeds the precision of the level sensor. When the difference between input and output exceeds 1.645 times the precision of the tank's level sensor (the value at which a level change of 0.0165 in. occurs in the tank), the test has reached its minimum length. The calculations were done as a function of hole diameter and the depth of the liquid flowing in the pipe. The estimates assumed that the slope of the line was 1% and that there was no uncertainty in the volume of liquid added to the line and no ambient changes in the level of fluid in the tank during the test. Also shown in Table 2 is the leak rate for these conditions. Several observations can be made. First, the smallest detectable leak rates are much larger than 0.2 gal/h for all but the smallest holes. Second, only tests in the lines with larger holes can be done in less than 15 min. Third, the duration of a test in a line with a small hole (1/32-in. diameter) is many hours, and a large volume of liquid must be added. Fourth, for tests longer than 15 min, volume changes that occur in the tank must be considered. This means that the threshold must be higher, and a higher threshold requires both a larger volume of added liquid and a longer test duration. Fifth, when the depth of flow is very low (for example, 0.125 in.), the validity of the assumptions used in calculations to estimate the leak rate is unknown.

Table 2. Test Duration Required for the Difference between Input Volume to the Line and Output Volume to a 64-in.-diameter Tank to Exceed 1.645 Times the Precision of the Level Sensor (1.645 x 0.01 in. x 13.962 gal/in.) (All calculations assumed a slope of 1%.)

Depth	0.125 in.			0.250 in.			0.500 in.		
	Hole Diameter (in.)	Leak Rate (gal/h)	Volume Added (gal)	Duration (h)	Leak Rate (gal/h)	Volume Added (gal)	Duration (h)	Leak Rate (gal/h)	Volume Added (gal)
1/32	0.07	26.4	3.24	0.10	80.4	2.29	0.14	233	1.62
1/16	0.28	6.6	0.81	0.40	20.1	0.57	0.56	58.4	0.41
3/32	0.63	2.9	0.36	0.90	8.9	0.25	1.27	26.0	0.18
1/8	1.13	1.6	0.20	1.60	5.0	0.14	2.26	14.6	0.10

Table 3 shows a calculation of the minimum test duration and volume of liquid that must be added to detect a leak rate of 0.2 gal/h and a leak equivalent to 0.1 gal/h. The 0.1-gal/h equivalent leak rate assumes that all of the liquid transfers occur during a 1-h period during any 24-h period. The diameter of the holes required to generate these leaks is also shown. The table

indicates that leaks from holes with diameters as small as 0.037 in. can be detected in a 1-h test by the addition of 166 gal of liquid. The table also indicates that a leak equivalent to 0.1 gal/h can be detected in a short-duration test (6 min) with the addition of about 13.7 gal of liquid. Since it is expected that the pipelines will be tested annually, it is planned that the 0.1-gal/h leak rate criterion will be employed. (It is noted that the values in Table 3 are for a P_{FA} of 5%, at a P_D of 50% [i.e., the leak test criterion is the same as the threshold value]. For a P_D of 95%, larger quantities of water must be added; these calculations will be done prior to demonstrations of the method.)

An experimental program is required to verify these calculations and to demonstrate that such a test is feasible. To achieve a higher level of performance with volume balancing, it will probably be necessary to implement a method of retarding the flow so that there is more time for liquid to be released at any possible hole in the line.

Table 3. Estimate of Hole Size, Volume of Liquid to Be Added for Test, and Test Duration

Leak Rate (gal/h)	Hole Diameter (in.)	Δh Depth of Flow (in.)	Volume Added (gal)	Duration (h)
0.2	0.053	0.125	9.2	1.13
0.2	0.044	0.25	40.5	1.16
0.2	0.037	0.50	166	1.16
0.1*	0.183	0.125	0.8	0.09
0.1*	0.153	0.25	3.4	0.10
0.1*	0.129	0.50	13.7	0.10

* assumes that all liquid transfers occur during a 1-h period during every 24-h period

4.2 Leak Detection Systems for Pipelines that Transfer Liquid under Pressure

There are four types of leak detection tests applicable to pipelines that transfer liquid under pressure. Because these lines have widely diverse characteristics, a single type of test may not suffice for all the lines in the LLLW system. None of the types of test discussed here has been evaluated on pipelines such as those found at ORNL, nor have any been evaluated in the operational environment found there.

4.2.1 Volumetric Tests

There are many kinds of volumetric tests for pipelines. Such tests require that for the duration of a test the line be isolated from the tanks by means of valves. The line is filled with liquid and then pressurized. Measurements are made of the volume changes required to maintain a constant pressure in the line; these indicate the volume changes in the line itself. Previous tests with volumetric systems have shown that they have a very high level of performance, exceeding the leak detection criteria established for these tests.

Volumetric testing can be done on lines containing gas as well as those containing liquid. The test procedure is identical as regards pressurization and the addition or removal of gas or liquid to or from a container outside the line. Performance is better, however, with a liquid than with a gas, because the noise that controls performance is much greater in the case of gas-filled lines. Thermally induced volume changes are one example of such noise. In a gas-filled pipe, a 1°C change in temperature would result in a volume change of 0.057 gal per 100 ft of 2-in.-diameter pipe, while in a water-filled pipe, the same temperature change would cause a volume change of only 0.0034 gal per 100 ft of pipe. Nevertheless, the use of either gas or liquid is acceptable provided that it is operationally feasible and that the performance standards are met.

4.2.2 Pressure Tests

There are two types of pressure tests used on pipelines. As with a volumetric test, the line must be isolated from the tanks by means of valves for the duration of a test. In a pressure test, the line is filled with a gas such as nitrogen or carbon dioxide, or a liquid. After the line has been pressurized, the pressure is monitored for a specified time and then compared to a threshold pressure drop. It can be shown that the performance achieved by pressure tests is not as good as that achieved by volumetric tests because (1) the relationship by which pressure measurements are converted to volume measurements cannot be determined if the line is leaking and (2) pressure tests require a longer waiting period for temperature changes in the product to become negligible. However, an important advantage of a pressure test is that no liquid needs to be added to or removed from the line during a test.

It is common practice at ORNL to use a pressure test on some of the lines before a transfer of product. The line is pressurized, and drops in pressure are monitored as part of the test. If the various sources of ambient noise produce volume changes small enough to be negligible, or if the effects can be compensated for, the performance of the pressure testing system should be evaluated and the system considered for use on ORNL lines to which it is applicable.

4.2.3 Acoustic Tests

Acoustic tests can be used for both detection and location. Experiments on pressurized pipelines containing petroleum (the type normally found at retail service stations) suggest that leaks can be located with an accuracy that is within 1% of the line length [4]. The lines in these experiments were 125 ft in length, and leaks of approximately 1 gal/h were accurately located. Although only a few tests have been done on gas-filled lines, similar performance should be achievable. In the experiments on petroleum-filled lines, the line was isolated from the tank by means of valves, and the fluid in the line remained static during the test. The ability to detect/locate leaks in a line when product is being transferred through the line is unknown. In principle, detection/location should be possible if the noise produced by product moving through the line is not exceedingly high.

In an acoustic leak detection/location test, the pressure inside the line must be different from that outside the line; tests can be done if the pipeline is under negative pressure. Figure 5 shows the setup for an acoustic test. The sensors can be attached directly to the outside of the pipeline. Since the transducer is flat, a simple metal collar can be used to ensure good contact between it and the pipe. Location/detection is accomplished by means of a coherence analysis.

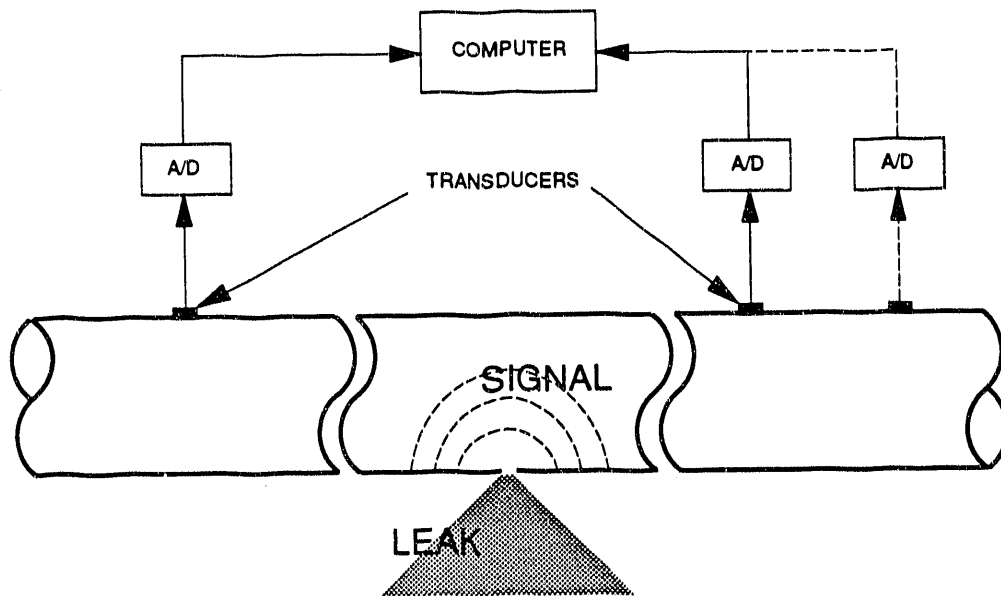


Figure 5. Acoustic leak detection/location.

The performance of an acoustic detection/location system depends on the size of the leak signal that is generated. The magnitude of the signal depends on the way the line is pressurized and on the backfill and groundwater conditions outside the line. A strong acoustic signal should be present during a transfer of product under pressure; whether the signal is detectable depends on the level of noise created by the turbulent flow through the pipeline. Since the magnitude of the acoustic signal depends on the pressure of the line, it is possible to enhance the signal by conducting acoustic tests at different pressures. Detection can also be enhanced by changing the pressure in a known pattern. It must be demonstrated, however, that such signals, if they exist at all, are large enough to be detected in lines as long as those commonly found at ORNL.

4.2.4 Tracers

There are two general types of tracer techniques that might be used to detect leaks in the LLLW pipeline system: halocarbons and helium. Each of the tracer methods requires that samples be taken over the ground surface, along the line, or around the area of interest.

Halocarbons, members of the CFC (chlorinated fluorocarbon) family, have been used to detect and locate leaks in underground pipelines carrying motor and aircraft fuels. A tracer liquid is usually added to an underground or aboveground storage tank and mixed with the contents. If a leak is present, the tracer will leave the pipeline during transfer operations. The gas is then free to escape from the solution and migrate upward through the soil. Sampling containers are positioned along the pipeline at closely spaced intervals, typically 15 to 25 ft, and samples are collected for analysis with a gas chromatograph. If halocarbons are present in the samples, the existence of a leak is confirmed. It may take several days to several weeks to complete a test, depending on the permeability characteristics of the subsurface soil and the level of the groundwater. To differentiate leaks in lines that are in close proximity, different types of halocarbon compounds can be used that are separately identified during analysis.

There are a number of advantages to the use of halocarbons. First, they have been successfully used for a number of years, and their performance has been evaluated and found to meet the EPA performance standard for a tank and line tightness test. Second, the probability of a false alarm is very remote because the specific halocarbons used as tracers are not normally found in nature. Third, different lines in close proximity can be independently tested by means of different halocarbons. Repeated application of this tracer technique depends on the residence time of the tracer in the ground.

One of the disadvantages of the halocarbon tracer method is that, because the technique works best in a highly permeable soil, the high groundwater levels and clay soil found around the LLLW system will degrade its performance. This particularly true when the pipeline is located below the water table (although it is not impossible for halocarbon tracers to find leaks in such lines). In addition to this disadvantage, there are four operational issues to contend with. First, halocarbon tracers do not work well unless all portions of the system to be tested are sealed tight. It has been observed that surface runoff and/or groundwater infiltrates certain ORNL vaults and tanks through loose connections; because of this leakage into the system, halocarbon tracers would not work well on either these tanks or nearby pipelines. Second, halocarbon tracers require the installation of many sampling containers along the line and the collection of samples over a long period of time. For the long pipelines at ORNL, it could take several weeks to complete a test. Third, in order for this test to be effective, the precise location of the line must be known; this is not the case for many of the ORNL lines. Fourth, because the network of tanks and piping within the LLLW system is complex, and many of the lines are in close proximity, interpretation of the test results could be difficult if the same tracer is used in more than one line. Thus, while halocarbons have certain advantages, there are many reasons why an alternative tracer method should be assessed and validated.

Helium tracers have been used to both detect and locate leaks in underground pipelines carrying motor and aircraft fuels. Their primary use, however, has been in their application to locating a leak once one has been detected. It is important to note that the sensitivity of helium-tracer measurement systems varies widely, and not all systems would work well at ORNL. The methodology is straightforward. Helium is added to a pipeline and a sniffer probe is walked along the surface of the ground. If leaks are to be found in the vicinity of tanks or pipes covered by concrete, small holes must be drilled so that the helium gas can escape. The performance of helium tracers is not well known, although false alarms have been reported. Helium is such a small molecule that it escapes through portions of the tank or pipeline system that are liquid tight. This is one reason that it is usually used after a leak has been detected by another technique.

The main advantage of helium tracers is that they are easy to use and tests can be completed fairly quickly. Helium tracers have the same disadvantages as halocarbons, except that no *in situ* sampling points are required. However, unlike the halocarbon technique, the same tracer, helium gas, is used in all lines to be tested. To the extent that the soil residence time for the helium in the ground is long, interpretation of the measurements is made more difficult because discrimination cannot be achieved and because residual amounts from previous tests may be present. However, like the halocarbons, the preferred migration of the gas is vertical, and the helium will eventually escape into the atmosphere. The success of these tests will depend on

whether or not the helium gas that escapes in the proximity of the tank migrates horizontally along the ground and contaminates the data being collected by the sniffer. As with halocarbon tracers, repeated application depends on the residence time of helium in the ground.

Based on the information at hand, a helium tracer is the recommended choice for testing a pressurized line (when it is not possible to use a pressure test). The principal reasons for selecting helium are that tests are easy to conduct. Before this technique is attempted, however, some preliminary demonstrations will be conducted to determine (1) the vertical migration of helium in the soil found at ORNL, (2) the extent of the helium plume released, (3) the residence time of helium in the soil, and (4) the sensitivity of the sensing system to concentrations of helium in "leak-like" flows.

4.3 Recommendations

All of the methods discussed above have potential application to the LLLW pipeline system, but feasibility demonstrations are required before most of them can be used. While the gravity-fed pipelines present formidable problems for leak detection, it is fairly easy to determine whether the volume-balancing method can be used on these lines. The performance and operational issues associated with volume-balancing can be experimentally investigated at the ORNL LLLW Simulator (LLLWSIM) located in Edison, New Jersey.

Currently, lines that can be isolated from the tank system undergo pressure testing before any liquid is transferred through them. These lines are pressurized with gas for such tests. An evaluation of the performance of this technique should be conducted, and, if the results are satisfactory, the technique should be implemented on the pipelines to which it is applicable.

The remaining pipelines to be tested cannot be isolated from the tank systems found on either end of the line. A series of demonstrations will be conducted to assess the applicability of the helium tracer and acoustic techniques. While helium tracer methods probably offer the simplest operational approach to leak location, a variety of tests must be done to assess the feasibility of using helium as a tracer under the varied operational conditions found at ORNL. This is also true of the acoustic methods. Because of the simplicity of the helium test, it is recommended that this approach be considered first. A demonstration is currently pending that will assess the use of a helium tracer.

Table 4 lists various testing methods that may be applicable to the LLLW pipelines. It also shows the important issues that must be resolved before the method can be considered for use.

Table 4. Demonstration Experiments Required Before a Method Can Be Considered for Leak Testing

Testing Method	Main Issues That Must Be Resolved
Volume-Balancing	<ul style="list-style-type: none">• Leak rate through a hole of given size under different conditions for pipeline slope and input flow
Volumetric Test with Gas under Pressure	<ul style="list-style-type: none">• Volume changes in the gas that are due to temperature changes
Volumetric Test with Liquid Under Pressure	<ul style="list-style-type: none">• Operational issues; no technical issues
Helium Tracer	<ul style="list-style-type: none">• Helium migration through clayey soils of varying moisture content• Residence time of the helium in the soil• High mobility of helium atom
Acoustic Test on Line That Is Isolated and Pressurized with Gas or Liquid	<ul style="list-style-type: none">• Detectability of signal based on size of hole and length of line
Acoustic Test on Line That Is Isolated and Placed Under a Negative Pressure with Gas	<ul style="list-style-type: none">• Existence of signal and conditions under which it is detectable• Detectability of signal based on size of hole and length of line
Acoustic Test while Liquid Is Being Transferred	<ul style="list-style-type: none">• Masking of signal by flow-generated noise during a hydrostatic test

5 CONCLUSIONS

This leak testing plan has examined the various components of the LLLW system that require testing, and has developed and discussed the testing approach for each of these components. The approach includes the methods to be used for each of the components and the leak detection criteria that will be employed with each method. A more detailed testing plan will be prepared as modeling and demonstration results become available. A detailed test plan will be prepared and submitted in accordance with the requirements of the FFA. This detailed leak detection test plan will include schedules for testing each of the components.

Figure 6 summarizes the details of the approaches described in the plan. Figure 6 shows that the tanks in the LLLW system can be divided into two categories—large tanks and small tanks—and that testing solutions for these two categories are straightforward. The small tanks will be tested monthly, by means of a method based upon a liquid-level sensor that is presently installed in the tanks. This method affords a cost-effective solution to testing 25 of the 42 tanks in the system and will incorporate algorithms and protocols designed to give value-added benefit to the existing sensor. As necessary, upgrades will be made to this system to provide digital data collection and automated leak-test capabilities. The 17 large tanks that comprise the second category will also be tested monthly, using a modified version of the small tank method, or by means of a level sensor and test protocol adapted for use in the LLLW environment. Since the tank system will be tested monthly, these methods will employ a leak detection criterion of 0.2 gal/h.

The performance evaluation of the small tank method was completed in November 1991 [1]. The evaluation was conducted by Vista Research at the EPA's Underground Storage Tank Test Apparatus in Edison, New Jersey. The results of the evaluation indicate that the small tank method meets the EPA's performance standards for monthly monitoring. (See Volume III.)

The pipeline portion of the LLLW system is more complex than the tank portion because it contains more component categories that require separate testing solutions. At the first level, the LLLW pipelines can be divided into two categories, gravity-fed lines and pressurized lines. Gravity-fed lines typically have many source drains and have no valves that can be used to isolate portions of the line from the tanks or from other lines that interconnect with them. In addition, most of these experience a very weak negative pressure (i.e., a vacuum) as a result of the Hot Off-Gas (HOG) system that is used to sweep off evaporant products that could otherwise escape from the tanks. The gravity-fed lines will be tested by means of an enhanced volume balancing method whose performance will be evaluated prior to its implementation. During these tests, small quantities of distilled water will be injected into the lines and allowed to drain into the accumulator tank; the volume received will be compared to the volume injected. Tests will be performed annually, employing a use-equivalent leak detection criterion of 0.1 gal/h.

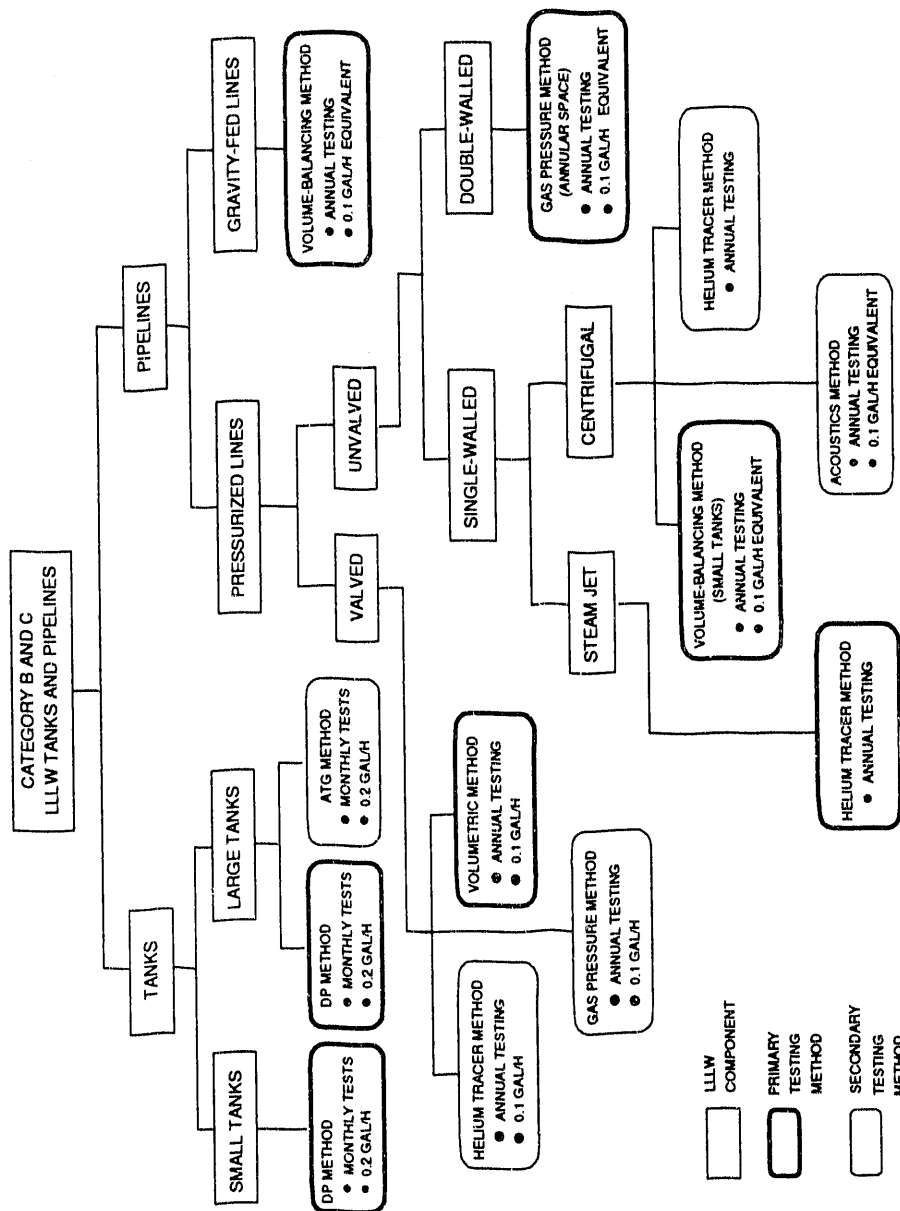


Figure 6. Summary chart showing LLLW components, primary leak testing methods, and schedules.

The pressurized pipelines are those in which liquid wastes are transferred by upstream pumping—by either steam-jetted or centrifugal pumps. Because of the complexity of testing these lines, they will be tested annually using a use-equivalent leak detection criterion of 0.1 gal/h. These lines have a number of component subdivisions that determine the specific leak test method to be employed. First, the lines may be valved or unvalved; the valved lines can be isolated from the remainder of the LLLW system, whereas the unvalved lines cannot. Those lines that can be isolated will be tested with one of three methods: a gas pressure volumetric method adapted from current practice at ORNL, a helium tracer method, or a volumetric method. The unvalved lines can be further subdivided according to whether they are single-walled or double-walled (in the latter case, with a high pressure maintained in the annular space), and whether they are pumped by means of a steam jet or a centrifugal pump. For the double-walled lines, the gas pressure volumetric method will be used to test the annular space. For the single-walled, jetted lines, the helium tracer method will be used. Those lines that are single-walled and centrifugally pumped will be tested by means of either the volume balancing method, a helium tracer, or acoustics.

Each of the leak testing approaches described above requires that the method in question undergo a demonstration of operational feasibility on the applicable component(s) and that its performance in that technical capacity be evaluated. The demonstration and evaluation portion of the present leak testing program will continue until all the ORNL components designated for testing have been matched with a suitable method of leak detection. The implementation portion of the program will follow.

REFERENCES

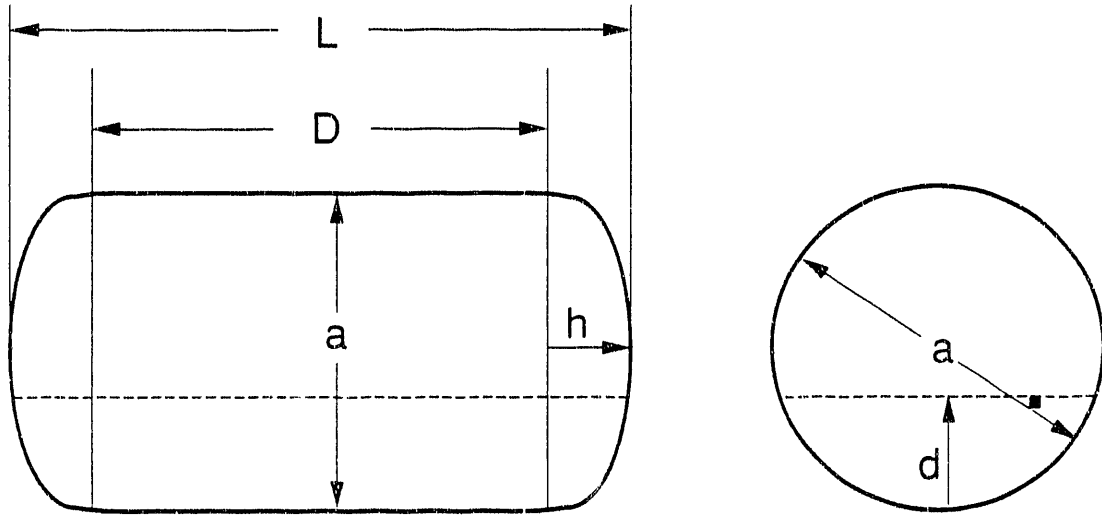
1. D. Douglas, R. F. Wise, J. W. Starr and J. W. Maresca, Jr., "Leak Testing Plan for the Oak Ridge National Laboratory Liquid Low-Level Waste System (Active Tanks), Vol. III: Evaluation of the ORNL/LT-823DP Differential Pressure Leak Detection Method," Report No. ORNL/ER/Sub/92-SK263/1, Purchase Order No. 12X-SK263C with Martin Marietta Energy Systems, Inc., Vista Research, Inc., Mountain View, California (1 June 1992).
2. S. Niaki and J. A. Broschious, "Underground Tank Leak Detection Methods: A State-of-the-Art Review," EPA/600/2-86/001, IT Corporation, Pittsburgh, Pennsylvania, prepared for the Hazardous Waste Engineering Research Laboratory, U.S. EPA, Washington, D.C. (January 1986).
3. "Federal Facilities Agreement Plans and Schedules for Liquid Low-Level Radioactive Waste Tank Systems at Oak Ridge National Laboratory, Oak Ridge, Tennessee," Report No. ES/ER-17&D1, prepared by the Waste Management and Remedial Action Division, Martin Marietta Energy Systems, Inc., Contract No. DE-AC05-84OR21400, Oak Ridge, Tennessee (March 1992).
4. E. G. Eckert and J. W. Maresca, Jr., "Location of Leaks in Pressurized Petroleum Pipelines," ASTM Symposium on Leak Detection for Underground Storage Tanks (January 1992).

Appendix A

TANK CHART CALCULATIONS FOR HORIZONTAL TANKS

TANK CHART CALCULATIONS FOR HORIZONTAL TANKS

There are 24 horizontally aligned tanks in the LLLW system that are covered by this leak testing plan. These tanks are built to American Society of Mechanical Engineering (ASME) specifications; most tank drawings call out an "F&D (flanged and dished) head" for the end caps of the tanks. This configuration can be closely modeled by a cylindrical tank section with elliptical end caps, where the height of the end cap (h) is one-quarter the diameter of the tank (a). This geometry is used to calculate the tank strapping charts and the volume-to-height charts shown below. If the actual strapping table for a particular LLLW tank is known, that table should be used in the leak testing algorithms. If the tank strapping table is not available, the material in this appendix can be used.



ASME Tank Configuration
(Elliptical End Caps)

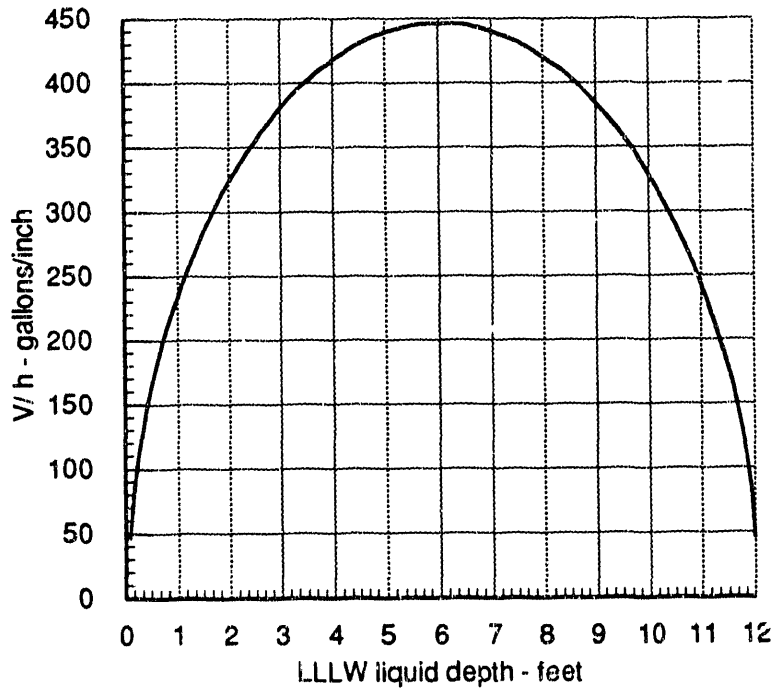
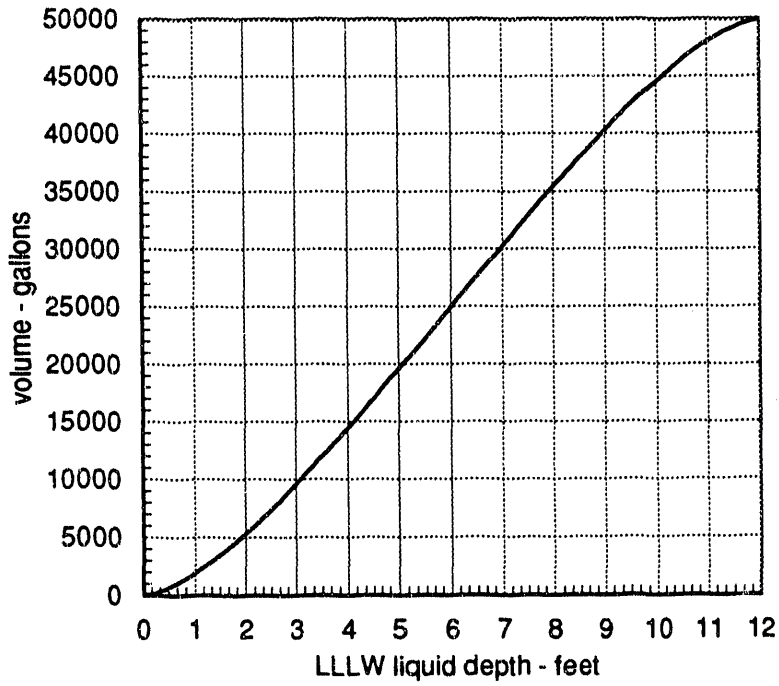
The volume of an ASME elliptical tank with diameter (a) and overall length (L), filled to a depth (d), is given by

$$V(d) = D \left[\left(\frac{\pi a^2}{8} \right) - \left(\frac{a}{2} - d \right) \sqrt{ad - d^2} - \left(\frac{a^2}{4} \right) \sin^{-1} \left(1 - \frac{2d}{a} \right) \right] + \pi h d^2 \left(1 - \frac{2d}{3a} \right),$$

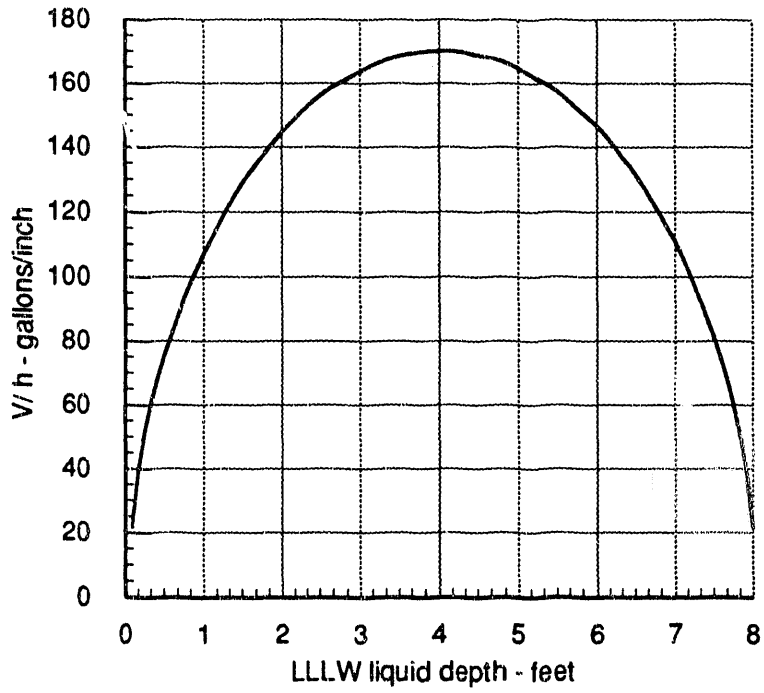
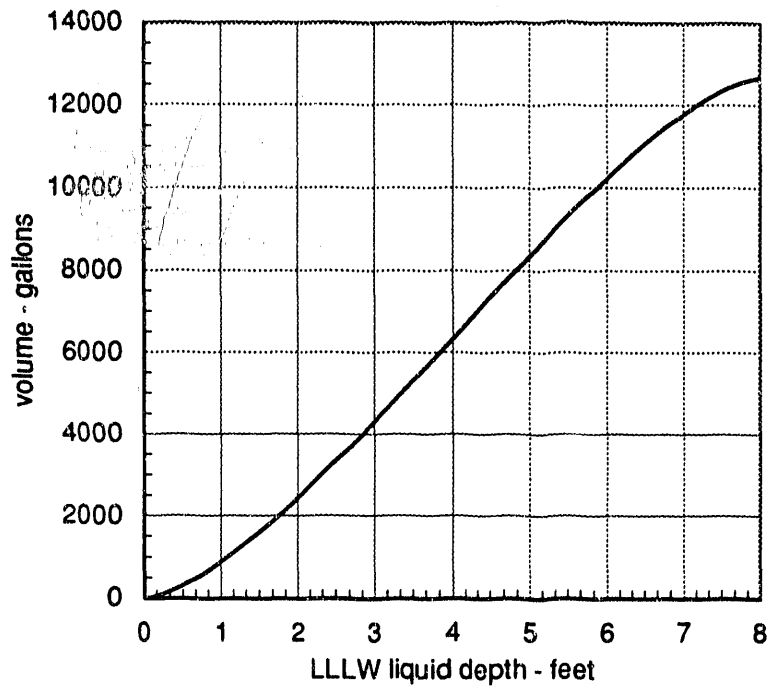
where

$$D = L - \frac{2a}{4}.$$

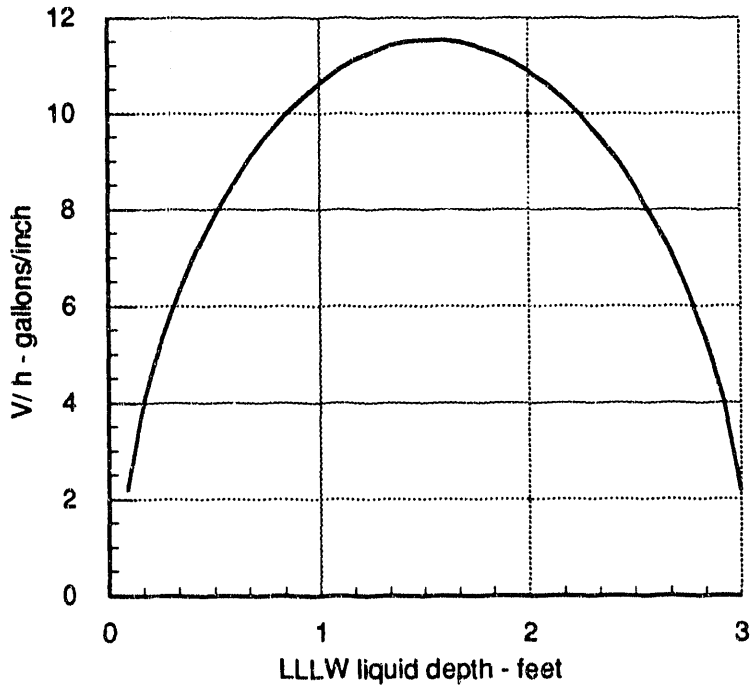
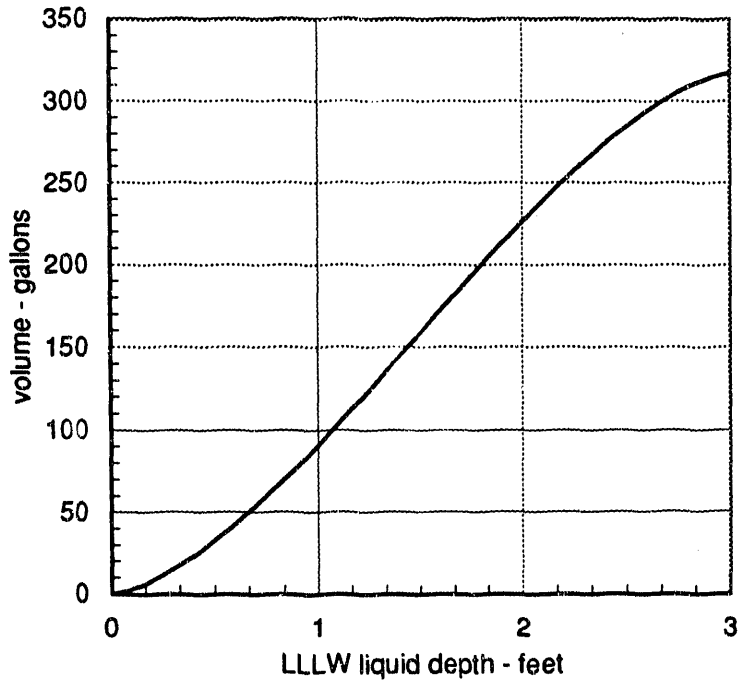
C-1 / C-2 Tank Chart Calculation



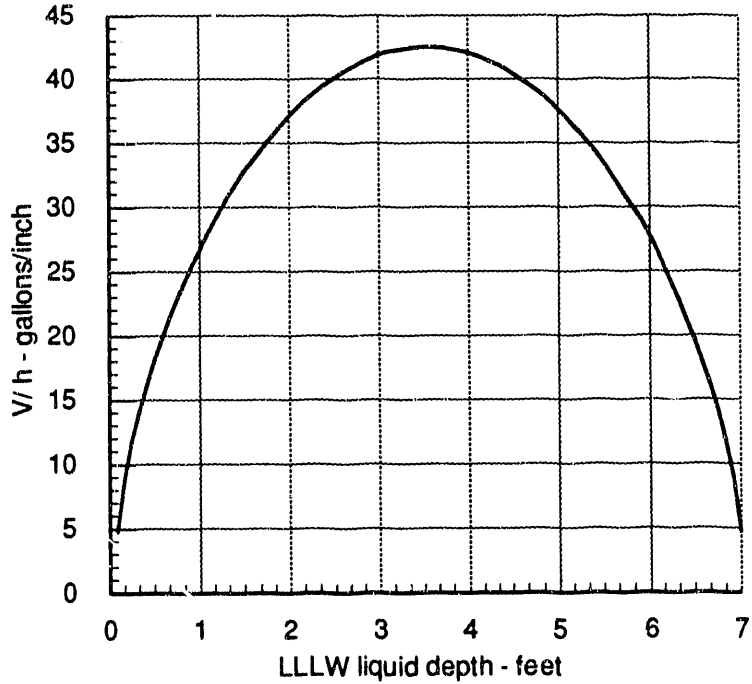
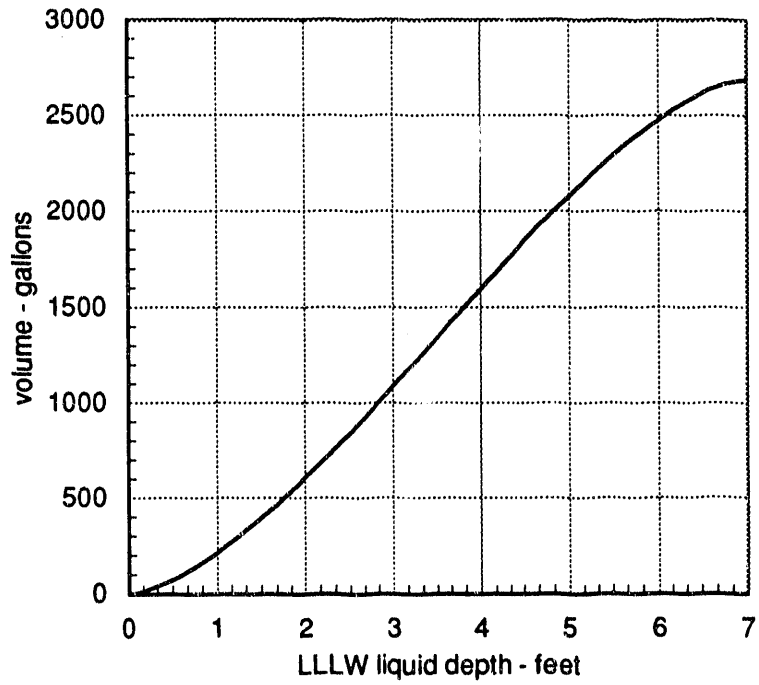
HFIR Tank Chart Calculation



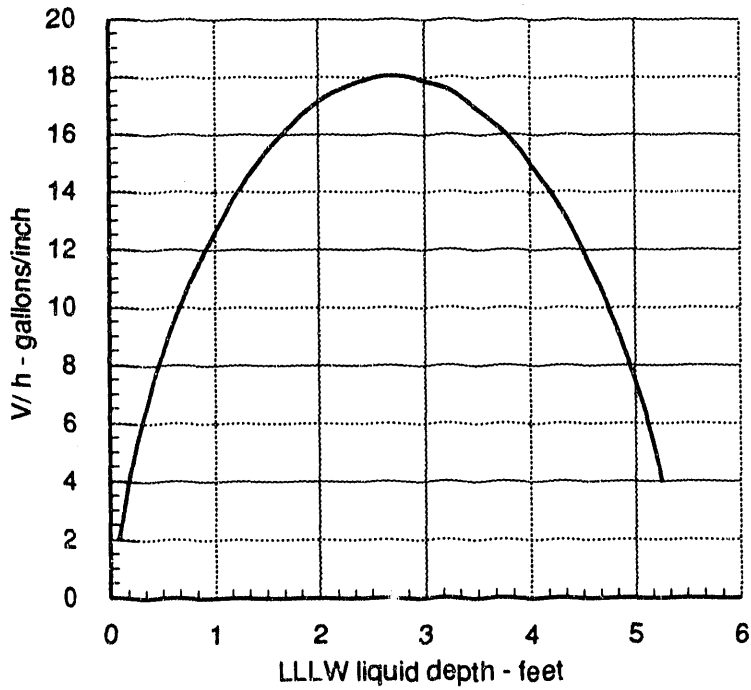
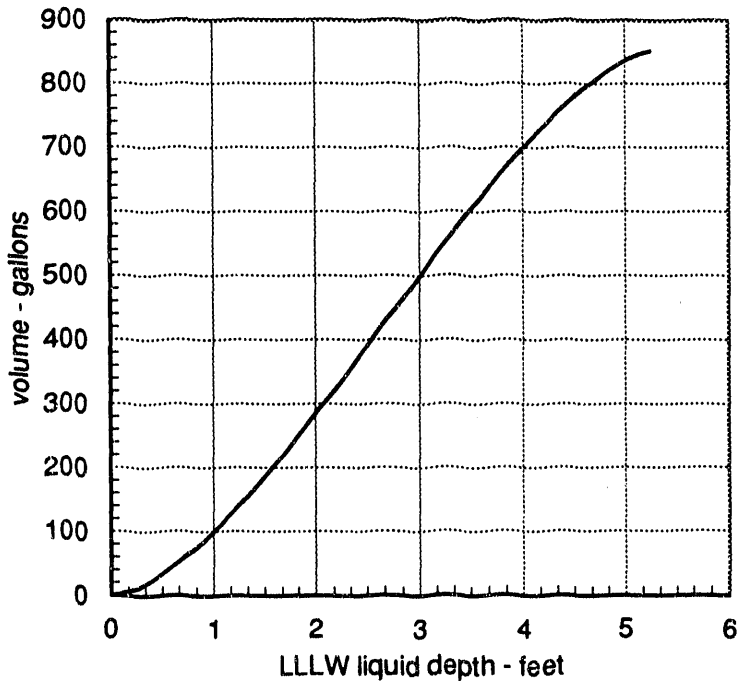
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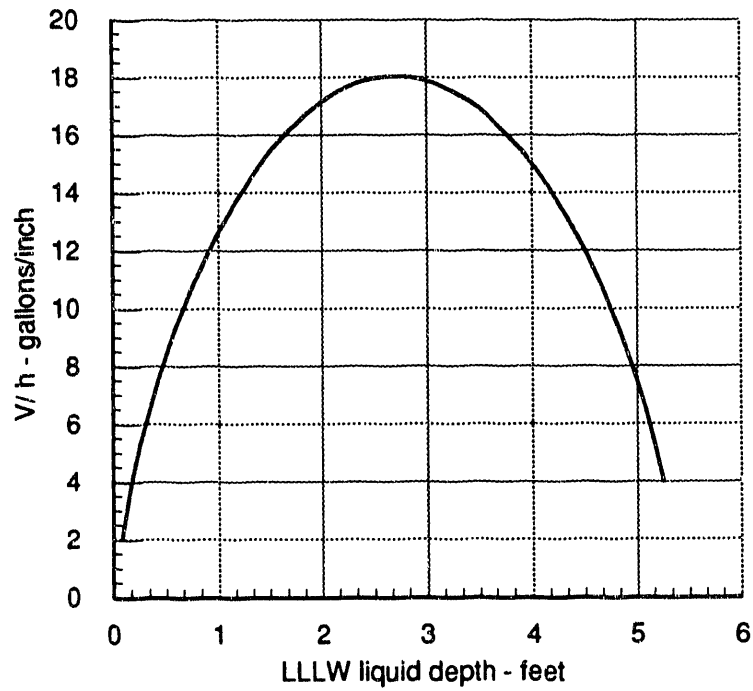
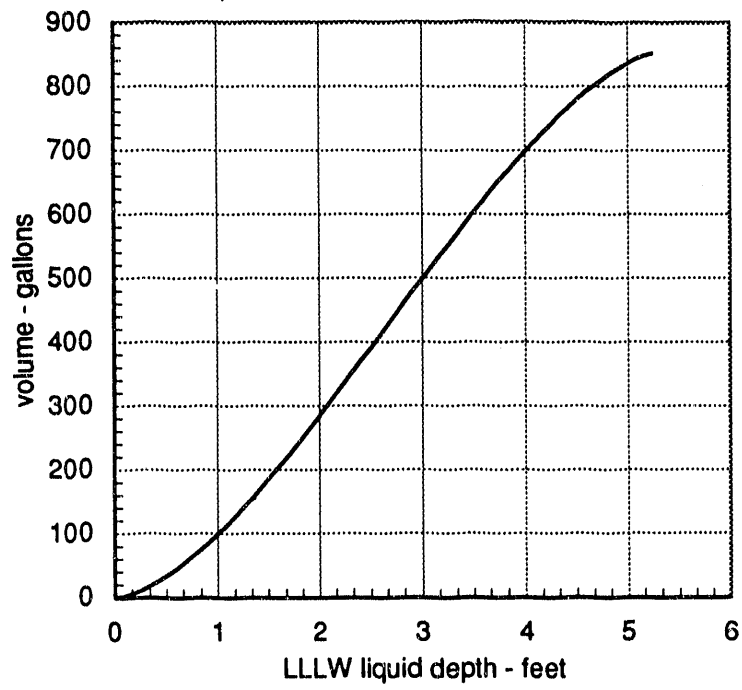
S-223 Tank Chart Calculation



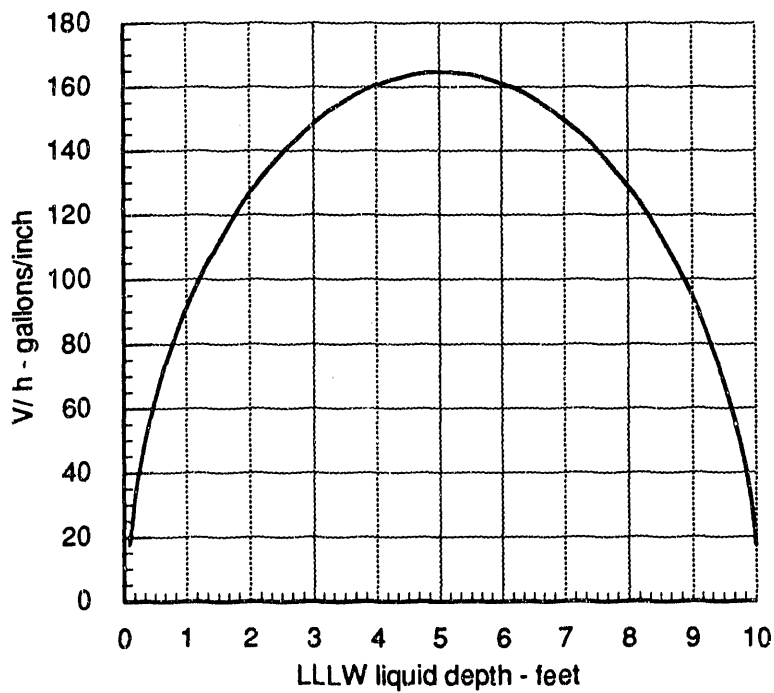
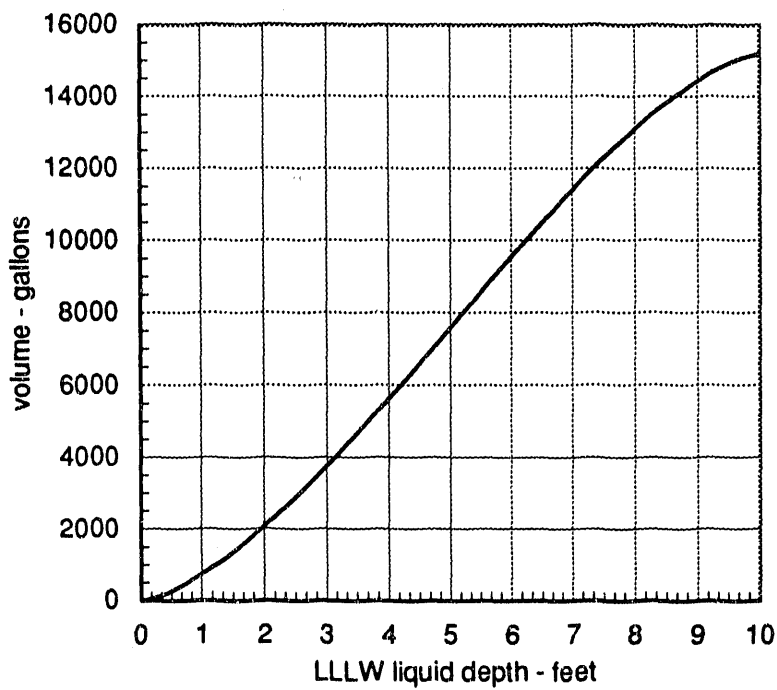
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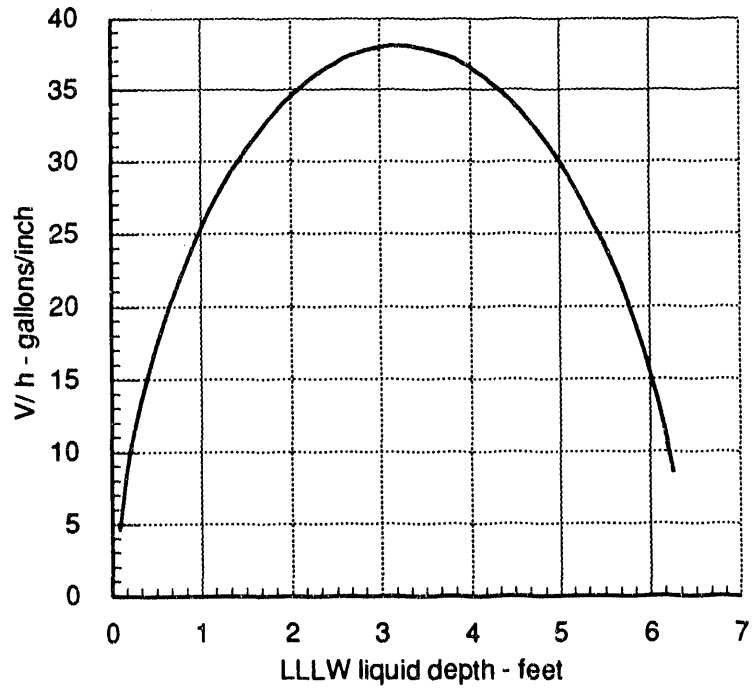
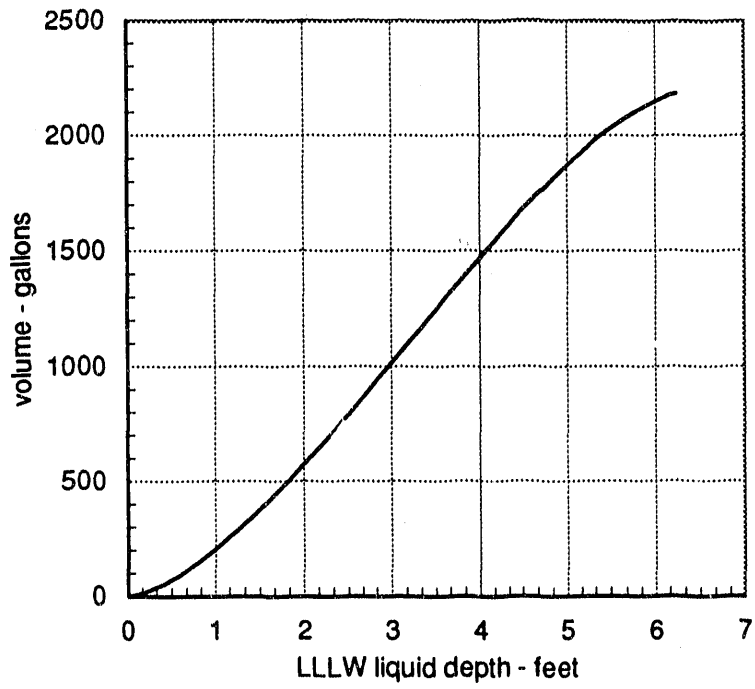
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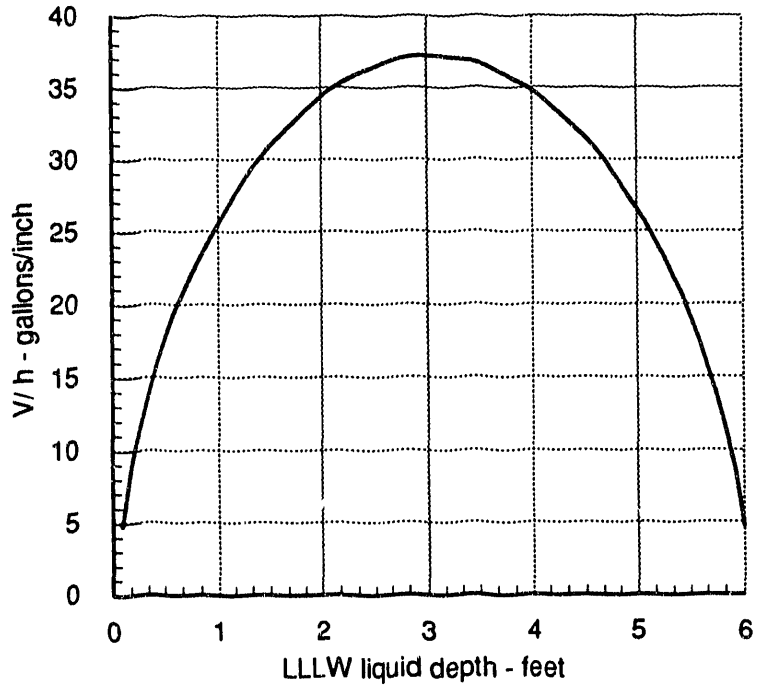
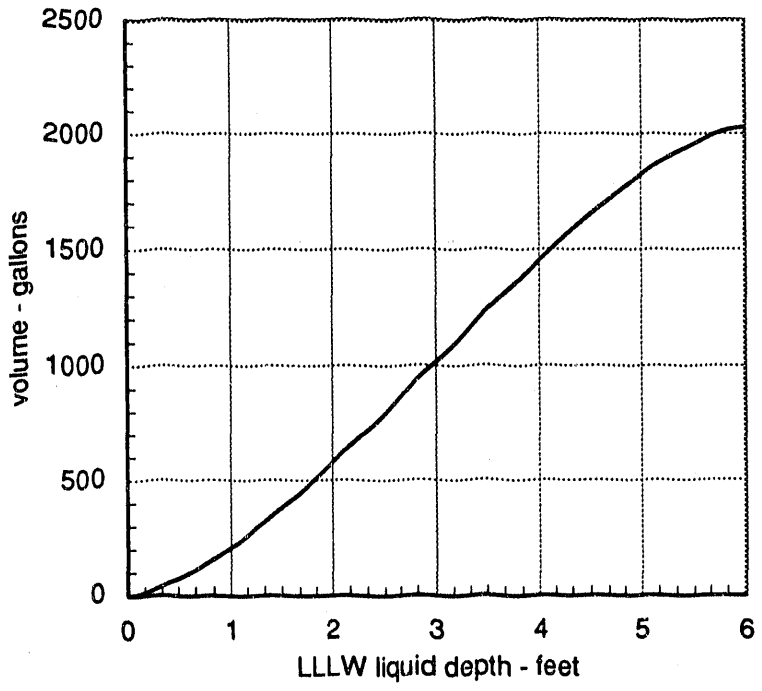
T-1 / T-2 Tank Chart Calculation



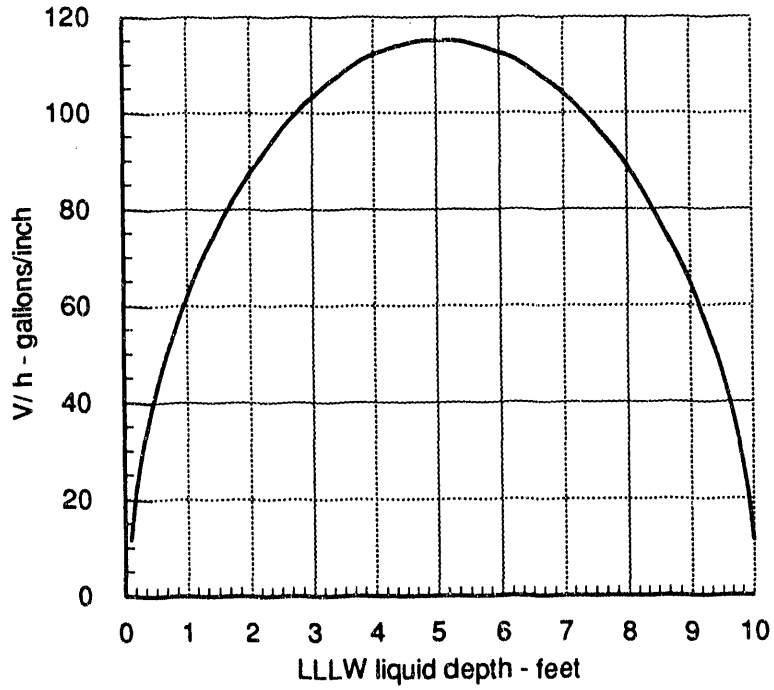
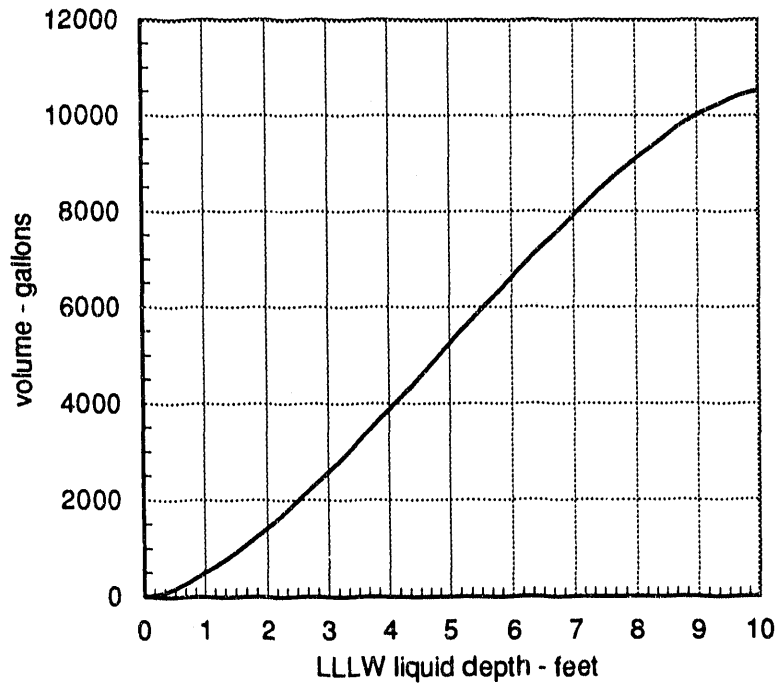
WC-10 Tank Chart Calculation



WC-19 Tank Chart Calculation



WC-20 Tank Chart Calculation



Appendix B

LEAK TESTING PLANS

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: 2026A (F-401)

LOCATION: Bethel Valley, SE corner of Bldg. 2026, outside

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1962

Orientation: vertical

Dimensions: diameter 4 ft, length 6 ft 11 in.

Volume capacity (nominal maximum): 500 gal

Volume-to-height coefficient: 7.77 gal/in.

Material: hastelloy "C" tank, 304L SS heads

Containment: single

LLLW transfer method: gravity (inlet), steam jet #J-401 (outlet)

LEAK TESTING METHOD:

Description: volumetric; ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 hours

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- If rain runoff is known (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN **(Methods, Protocols, Schedules)**

TANK: B-2-T

LOCATION: Melton Valley, NE corner of Bldg. 7930, inside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1965

Orientation: vertical

Dimensions: diameter 7 ft, length 8 ft 10 7/8 in.

Volume capacity (nominal maximum): 1870 gal

Volume-to-height coefficient: 23.88 gal/in.

Material: 304L SS

Containment: vault (exterior-lined)

LLLW transfer method: gravity from 7930G (inlet), steam jet (outlet)

LEAK TESTING METHOD:

Description: volumetric; ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- It is known that there is a 40 SCFM HOG air sweep; it is surmised that this may cause evaporation losses of about 0.1 to 0.2 gal/h.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: B-3-T

LOCATION: Melton Valley, NNE portion of Bldg. 7930, inside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1965

Orientation: vertical

Dimensions: diameter 7 ft, length 8 ft 10 7/8 in.

Volume capacity (nominal maximum): 1870 gal

Volume-to-height coefficient: 23.88 gal/in.

Material: 304L SS

Containment: vault (exterior-lined)

LLLW transfer method: steam jet (inlet and outlet)

LEAK TESTING METHOD:

Description: volumetric; ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period.
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: C-6-T

LOCATION: Melton Valley, N portion of Bldg. 7930, inside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1965
Orientation: vertical
Dimensions: diameter 4 ft, length 8 ft 10 7/8 in.
Volume capacity (nominal maximum): 710 gal
Volume-to-height coefficient: 7.77 gal/in.
Material: 304L SS
Containment: vault (exterior-lined)
LLLW transfer method: steam jet (inlet and outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler
Sensor: Foxboro 823DP pressure transmitter
Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h
Minimum waiting period following small-volume transfers: 4 h
Minimum waiting period following tank sparge: 12 h
Test duration: 24 h (single test), 48 h (double test)
Total time required for leak test: 24 h minimum, 60 h maximum
Data sampling frequency: 0.017 Hz (one sample per minute)
Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: C-1, C-2

LOCATION: Bethel Valley, N of Bldg. 2531, outside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1964

Orientation: horizontal

Dimensions: diameter 12 ft, length 61 ft

Volume capacity (nominal maximum): 50,000 gal

Volume-to-height coefficient: varies with level (446.69 gal/in. at mid-tank [see tank plots for C-1, C-2])

Material: 304L SS

Containment: concrete vault

LLLW transfer method: steam jet (inlet and outlet)

LEAK TESTING METHOD:

Description: volumetric; modified 823DP

Sensor: Foxboro DP cell

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following transfers: 12 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 to 48 h (single test), 48 to 96 h (double test)

Total time required for leak test: 36 h minimum, 108 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: F-111

LOCATION: Melton Valley, Bldg. 7920, inside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1966

Orientation: vertical

Dimensions: diameter 27 in., length 60 3/16 in.

Volume capacity (nominal maximum): 125 gal

Volume-to-height coefficient: 2.44 gal/in.

Material: 304L SS

Containment: vault

LLLW transfer method: gravity (inlet), steam jet (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 4 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 12 h (single test), 24 h (double test)

Total time required for leak test: 12 h minimum, 36 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Rainfall is known to enter tank pit through pit top; if rain runoff is found (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: F-126

LOCATION: Melton Valley, Bldg. 7920, inside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1966

Orientation: vertical

Dimensions: diameter 66 in., length 8 ft 1 in.

Volume capacity (maximum/nominal maximum): 1200/940 gal

Volume-to-height coefficient: 14.72 gal/in.

Material: 304L SS

Containment: vault

LLLW transfer method: steam jet (inlet and outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Rainfall is known to enter tank pit through pit top; if rain runoff is found (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN (Methods, Protocols, Schedules)

TANK: F-201

LOCATION: Bethel Valley, Bldg. 3525, basement

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1962

Orientation: vertical

Dimensions: diameter 18 in., length 39 in.

Volume capacity (nominal maximum): 40 gal

Volume-to-height coefficient: 1.08 gal/in.

Material: 304L SS

Containment: above ground in basement of building

LLLW transfer method: gravity (inlet), steam jet to F-501 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 2 h

Minimum waiting period following small-volume transfers: 0 h

Minimum waiting period following tank sparge: 2 h

Test duration: 4 h (single test), 8 h (double test)

Total time required for leak test: 2 h minimum, 10 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: F-501

LOCATION: Melton Valley, S of Bldg. 3525

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1964

Orientation: vertical

Dimensions: diameter 48 in., length 4 ft 11 1/2 in.

Volume capacity (nominal working maximum): 200 gal

Volume-to-height coefficient: 7.77 gal/in.

Material: 304L SS

Containment: in concrete pit

LLLW transfer method: gravity and steam jet from F-201 (inlet), steam jet J-501-1 and J-501-2 to W-12 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 4 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 4 h

Test duration: 12 h (single test), 24 h (double test)

Total time required for leak test: 12 h minimum, 28 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: HFIR

LOCATION: Melton Valley, S of Bldg. 7910

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1961

Orientation: horizontal

Dimensions: diameter 8 ft, length 35 ft

Volume capacity (maximum/nominal maximum): 13,000/9,100 gal

Volume-to-height coefficient: varies with level (170.26 gal/in. at mid-tank [see tank plot for HFIR])

Material: SS

Containment: none; concrete poured around tank

LLLW transfer method: centrifugal pump from 7900, 7913, 7911 (inlet), centrifugal pump to MV diversion box (outlet)

LEAK TESTING METHOD:

Description: volumetric; modified DP cell method

Sensor: Foxboro 823DP

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following transfers: 12 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 to 48 h (single test), 48 to 96 h (double test)

Total time required for leak test: 36 h minimum, 108 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

Cannot suspend inflows without shutting down HFIR

HOG condensate known to enter system

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: L-11

LOCATION: Bethel Valley, Bldg. 3544, south wall

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1974

Orientation: vertical

Dimensions: diameter 48 in., length 72 in.

Volume capacity (nominal maximum): 500 gal

Volume-to-height coefficient: 7.77 gal/in.

Material: SS

Containment: in-building vault

LLLW transfer method: centrifugal pump L-10 (inlet), centrifugal pump L-10 to VB-1 (outlet)

LEAK TESTING METHOD:

Description: external, visual inspection

Sensor: N/A

Evaluated performance: N/A

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: N/A

Minimum waiting period following small-volume transfers: N/A

Minimum waiting period following tank sparge: N/A

Test duration: 0.5 h (estimated)

Total time required for leak test: 0.5 h

Data sampling frequency: N/A

Measured quantities: liquid or accumulating dried waste

FACTORS INFLUENCING TEST PROCEDURE:

QA and documentation procedures to be developed

DATA INTERPRETATION:

qualitative; changes

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: LA-104 (F-104)

LOCATION: Bethel Valley, SE corner of Bldg. 3047

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1960

Orientation: horizontal

Dimensions: diameter 36 in., length 6 ft 6 in.

Volume capacity (nominal maximum): 296 gal

Volume-to-height coefficient: varies with level (11.55 gal/in. at mid-tank [see tank plot for LA-104])

Material: 304L SS

Containment: concrete vault

LLLW transfer method: gravity from RHD (inlet), steam jet to 3047 HD header (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 4 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 12 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: N-71

LOCATION: Bethel Valley, Bldg. 3019 (Cell 7), inside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1954
Orientation: vertical
Dimensions: diameter 30 in., length 84 in.
Volume capacity (nominal maximum): 240 gal
Volume-to-height coefficient: 3.02 gal/in.
Material: 304L SS
Containment: above-ground vault
LLLW transfer method: gravity (inlet), (outlet N/A)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler
Sensor: Foxboro 823DP pressure transmitter
Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 4 h
Minimum waiting period following small-volume transfers: 4 h
Minimum waiting period following tank sparge: 12 h
Test duration: 12 h (single test), 24 h (double test)
Total time required for leak test: 12 h minimum, 36 h maximum
Data sampling frequency: 0.017 Hz (one sample per minute)
Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: P-3

LOCATION: Bethel Valley, inside Bldg. 3019 (Cell 6, lower level)

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1954
Orientation: vertical
Dimensions: diameter 36 in., length 48 in.
Volume capacity (nominal maximum): 197 gal
Volume-to-height coefficient: 4.36 gal/in.
Material: 347 SS
Containment: above-ground vault
LLLW transfer method: gravity (inlet), (outlet N/A)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler
Sensor: Foxboro 823DP pressure transmitter
Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 4 h
Minimum waiting period following small-volume transfers: 4 h
Minimum waiting period following tank sparge: 12 h
Test duration: 12 h (single test), 24 h (double test)
Total time required for leak test: 12 h minimum, 36 h maximum
Data sampling frequency: 0.017 Hz (one sample per minute)
Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: P-4

LOCATION: Bethel Valley, inside Bldg. 3019 (Cell 6, lower level)

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1954

Orientation: vertical

Dimensions: diameter 36 in., length 48 in.

Volume capacity (nominal maximum): 197 gal

Volume-to-height coefficient: 4.36 gal/in.

Material: 347 SS

Containment: above-ground vault

LLLW transfer method: gravity (inlet), (outlet N/A)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 4 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 12 h (single test), 24 h (double test)

Total time required for leak test: 12 h minimum, 36 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: S-223

LOCATION: Bethel Valley, N side of Bldg. 3517 (Cell 23)

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1955

Orientation: horizontal

Dimensions: diameter 84 in., length 126 in.

Volume capacity (nominal maximum): 3000 gal

Volume-to-height coefficient: varies with level (42.54 gal/in. at mid-tank [see tank plot for S-223])

Material: 304L SS

Containment: below-ground vault

LLLW transfer method: steam jet from S-523 (inlet), jet pump J52-23 to VB-2 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Rainwater enters vault; pumping vault sump during leak test will invalidate result. If cell sump pumped during test, reschedule test.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: S-324

LOCATION: Bethel Valley, N side of Bldg. 3517 (Cell 24)

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1955

Orientation: horizontal

Dimensions: diameter 64 in., length 72 in.

Volume capacity (nominal maximum): 1000 gal

Volume-to-height coefficient: varies with level (18.04 gal/in. at mid-tank [see tank plot for S-324])

Material: 304L SS

Containment: below-ground vault

LLLW transfer method: gravity from EPOG (inlet), steam jet J54-24 to VB-2 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Rainwater enters vault; pumping vault sump during leak test will invalidate result. If cell sump pumped during test, reschedule test.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: S-523

LOCATION: Bethel Valley, N side of Bldg. 3517 (Cell 23)

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1955
Orientation: horizontal
Dimensions: diameter 64 in., length 72 in.
Volume capacity (nominal maximum): 1000 gal
Volume-to-height coefficient: varies with level (18.04 gal/in. at mid-tank [see tank plot for S-324])
Material: 304L SS
Containment: below-ground vault
LLLW transfer method: gravity from FD (inlet), steam jet J53-23 to S-223 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler
Sensor: Foxboro 823DP pressure transmitter
Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h
Minimum waiting period following small-volume transfers: 4 h
Minimum waiting period following tank sparge: 12 h
Test duration: 24 h (single test), 48 h (double test)
Total time required for leak test: 24 h minimum, 60 h maximum
Data sampling frequency: 0.017 Hz (one sample per minute)
Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Rainwater enters vault; pumping vault sump during leak test will invalidate result. If cell sump pumped during test, reschedule test.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: T-1

LOCATION: Melton Valley, Old Hydrofracture Facility, near Bldg. 7567

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1963

Orientation: horizontal

Dimensions: diameter 120 in., length 27 ft 5 in.

Volume capacity (maximum/nominal maximum): 15,000/10,500 gal

Volume-to-height coefficient: varies with level (164.74 gal/in. at mid-tank [see tank plot for T-1/T-2])

Material: 304L SS

Containment: none; in gravel pit with dry pipe sump

LLLW transfer method: centrifugal pump HFIR/other via MV diversion box (inlet), centrifugal pump P-1 and P-2 to VB at South Parking Lot (outlet)

LEAK TESTING METHOD:

Description: volumetric; modified DP cell method

Sensor: Foxboro 823DP

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following transfers: 12 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 to 48 h (single test), 48 to 96 h (double test)

Total time required for leak test: 36 h minimum, 108 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: T-2

LOCATION: Melton Valley, Old Hydrofracture Facility, near Bldg. 7567

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1963

Orientation: horizontal

Dimensions: diameter 120 in., length 27 ft 5 in.

Volume capacity (maximum/nominal maximum): 15,000/10,500 gal

Volume-to-height coefficient: varies with level (164.74 gal/in. at mid-tank [see tank plot for T-1/T-2])

Material: 304L SS

Containment: none; in gravel pit with dry pipe sump

LLLW transfer method: centrifugal pump HFIR/other via MV diversion box (inlet), centrifugal pump P-1 and P-2 to VB at South Parking Lot (outlet)

LEAK TESTING METHOD:

Description: volumetric; modified DP cell method

Sensor: Foxboro 823DP

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following transfers: 12 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 to 48 h (single test), 48 to 96 h (double test)

Total time required for leak test: 36 h minimum, 108 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: T-13

LOCATION: Melton Valley, Bldg. 7860, NHF

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1979

Orientation: vertical

Dimensions: TBD

Volume capacity (maximum/nominal maximum): 3,000 gal

Volume-to-height coefficient: TBD

Material: SS

Containment: concrete lined vault

LLLW transfer method: sump pump from tank pit, steam jet from 7860 equipment & tank T-14, gravity from 4, 6" floor drains (inlet), centrifugal pump P-8 to 7860 equipment & MVSTs (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: W-12

LOCATION: Bethel Valley, S Tank Farm

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1947
Orientation: vertical
Dimensions: diameter 4 ft, (approx) length 9 ft
Volume capacity (nominal maximum): 700 gal
Volume-to-height coefficient: 7.7 gal/in.
Material: SS
Containment: buried tank
LLLW transfer method: steam jet (inlet and outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler
Sensor: Foxboro 823DP pressure transmitter
Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h
Minimum waiting period following small-volume transfers: 4 h
Minimum waiting period following tank sparge: 12 h
Test duration: 24 h (single test), 48 h (double test)
Total time required for leak test: 24 h minimum, 60 h maximum
Data sampling frequency: 0.017 Hz (one sample per minute)
Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Rainfall may influence results.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: W-16

LOCATION: Bethel Valley, S Tank Farm

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1951

Orientation: vertical

Dimensions: diameter 66 in., length 81 5/8 in.

Volume capacity (maximum/nominal maximum): 1,000/700 gal

Volume-to-height coefficient: 14.72 gal/in.

Material: 347 SS

Containment: none; crushed stone to top of tank

LLLW transfer method: from 3026D via valve pit VP-3026 (inlet), steam jet J-W 16-1-1 to VB-1 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Tank is in saturated zone; if rain runoff (or groundwater) is found (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: W-21, W-22, W-23

LOCATION: Bethel Valley, N of Bldg. 2537, outside

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1979

Orientation: horizontal

Dimensions: diameter 12 ft, length 61 ft

Volume capacity (nominal maximum): 50,000 gal

Volume-to-height coefficient: varies with level (446.69 gal/in. at mid-tank [see tank plot for C-1])

Material: 304L SS

Containment: concrete vault

LLLW transfer method: steam jet (inlet and outlet)

LEAK TESTING METHOD:

Description: volumetric

Sensor: Robertshaw tape

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following transfers: 12 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 to 48 h (single test), 48 to 96 h (double test)

Total time required for leak test: 36 h minimum, 108 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, sensor temperature

FACTORS INFLUENCING TEST PROCEDURE:

Water may enter tanks from vault sumps pumped during rainy periods

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated volume rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: W-24, W-25, W-26, W-27, W-28, W-29, W-30, W-31

LOCATION: Melton Valley, Bldg. 7830

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1980

Orientation: horizontal

Dimensions: diameter 12 ft, length 61 ft

Volume capacity (nominal maximum): 50,000 gal

Volume-to-height coefficient: varies with level (446.69 gal/in. at mid-tank [see tank plot for C-1])

Material: 304L SS

Containment: SS lined concrete vault

LLLW transfer method: steam jet (inlet and outlet)

LEAK TESTING METHOD:

Description: volumetric

Sensor: Robertshaw tape

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following transfers: 12 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 to 48 h (single test), 48 to 96 h (double test)

Total time required for leak test: 36 h minimum, 108 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, sensor temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated volume rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: WC-2

LOCATION: Bethel Valley, NW of Bldg. 3038

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1951

Orientation: vertical

Dimensions: diameter 66 in., length 81 5/8 in.

Volume capacity (maximum/nominal maximum): 1,000/700 gal

Volume-to-height coefficient: 14.72 gal/in.

Material: 347 SS

Containment: in-ground burial

LLLW transfer method: gravity from 3028/3048 (inlet), centrifugal pump P-WC-2-101 to VB-2 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: WC-3

LOCATION: Bethel Valley, S of Bldg. 3025

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1951

Orientation: vertical

Dimensions: diameter 66 in., length 81 5/8 in.

Volume capacity (maximum/nominal maximum): 1,000/700 gal

Volume-to-height coefficient: 14.72 gal/in.

Material: 347 SS

Containment: none; crushed stone to top of tank

LLLW transfer method: gravity from 3025 (inlet), steam jet J-WC3-101 to WC-19 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- If rain runoff is found (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN (Methods, Protocols, Schedules)

TANK: WC-7

LOCATION: Bethel Valley, SW of Bldg. 3504

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1951

Orientation: vertical

Dimensions: diameter 64 in., length 89 in.

Volume capacity (maximum/nominal maximum): 1,100/750 gal

Volume-to-height coefficient: 13.84 gal/in.

Material: 347 SS

Containment: none; crushed stone and earth backfill

LLLW transfer method: gravity from 3504 (inlet), steam jet to VB-1 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- If rain runoff is found (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: WC-9

LOCATION: Bethel Valley, S of Bldg. 3503

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1952

Orientation: vertical

Dimensions: diameter 84 in., length 129 in.

Volume capacity (maximum/nominal maximum): 2,150/1,500 gal

Volume-to-height coefficient: 23.88 gal/in.

Material: 347 SS

Containment: none

LLLW transfer method: gravity from 3503, sump pump from pump pit, WC-8 (inlet), centrifugal pump to VB-2 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- If rain runoff is found (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: WC-10

LOCATION: Bethel Valley, S of Bldg. 3587

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1951

Orientation: horizontal

Dimensions: diameter 6 ft 4 in., length 10 ft 4 in.

Volume capacity (maximum/nominal maximum): 2,300/1,650 gal

Volume-to-height coefficient: varies with level (38.11 gal/in. at mid-tank [see tank plot for WC-10])

Material: SS

Containment: none; on concrete foundation with crushed stone and earth backfill

LLLW transfer method: gravity from 3039, 3093, jet pump from W-11 (inlet), steam jet to VB-1 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Downstream piping suspected of leaking

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: WC-19

LOCATION: Bethel Valley, N of Bldg. 3047

FFA DESIGNATION: Active, Category "C" (existing tank without secondary containment)

CHARACTERISTICS:

Installation date: 1955

Orientation: horizontal

Dimensions: diameter 72 in., length 10 ft 6 3/8 in.

Volume capacity (maximum/nominal maximum): 2,100/1,500 gal

Volume-to-height coefficient: varies with level (36.97 gal/in. at mid-tank [see tank plot for WC-19])

Material: 347 SS

Containment: none; crushed stone and earth backfill

LLLW transfer method: gravity from 3042, 3119, 3019, pump from Tank 3001-B (inlet), steam jet to valve pit VP-3026 to VB-2 (outlet)

LEAK TESTING METHOD:

Description: ORNL/LT-823DP bubbler

Sensor: Foxboro 823DP pressure transmitter

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 24 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

- Known inleakage; tank in saturated zone; if rain runoff is found (or suspected) to contribute to tank volume, reschedule leak test for non-rainy period.

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

LEAK TESTING PLAN
(Methods, Protocols, Schedules)

TANK: WC-20

LOCATION: Melton Valley, N of Bldg. 7567

FFA DESIGNATION: Active, Category "B" (existing tank with secondary containment)

CHARACTERISTICS:

Installation date: 1976

Orientation: horizontal

Dimensions: diameter 120 in., length 19 ft 5 5/8 in.

Volume capacity (maximum/nominal maximum): 10,000/7,000 gal

Volume-to-height coefficient: varies with level (114.87 gal/in. at mid-tank [see tank plot for WC-20])

Material: 304L SS

Containment: below-ground vault

LLLW transfer method: centrifugal pump via MVST (inlet), centrifugal pump P1/P2 to VB at south parking lot (outlet)

LEAK TESTING METHOD:

Description: volumetric; modified DP cell method

Sensor: Foxboro 823DP

Evaluated performance: $P_D \geq 0.95$, $P_{FA} \leq 0.05$ for single-test leak rate of 0.2 gal/h

LEAK TESTING PROTOCOL:

Minimum waiting period following large-volume transfers: 12 h

Minimum waiting period following small-volume transfers: 4 h

Minimum waiting period following tank sparge: 12 h

Test duration: 12 h (single test), 48 h (double test)

Total time required for leak test: 24 h minimum, 60 h maximum

Data sampling frequency: 0.017 Hz (one sample per minute)

Measured quantities: tank level, DP cell temperature

FACTORS INFLUENCING TEST PROCEDURE:

None known

DATA INTERPRETATION:

- Level-to-volume conversion: theoretical ratio calculated from tank geometry
- Leak rate calculation: linear regression of temperature-compensated volume changes during test period
- If standard deviation of calculated leak rate data exceeds noise threshold during test period, test is invalid due to excessive noise and should be rescheduled.
- If initial test result is positive, second test is initiated. Absolute value of calculated leak rate differences between two successive tests must be less than 0.03 gal/h for valid result.

SCHEDULE: Monthly testing

**Leak Testing Plan for the Oak Ridge National Laboratory
Liquid Low-Level Waste System
(Active Tanks)**

**Vol. III. Evaluation of the ORNL/LT-823DP
Differential Pressure Leak Detection Method**

**Dennis G. Douglas
Richard F. Wise
James W. Starr
Joseph W. Maresca, Jr.**

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	v
LIST OF FIGURES.....	vii
LIST OF TABLES	ix
LIST OF ABBREVIATIONS AND ACRONYMS.....	x
1 INTRODUCTION	1
2 DESCRIPTION OF THE ORNL/LT-823DP METHOD	3
2.1 Mechanical Description	3
2.2 Principle of Operation	4
2.3 Protocol for Using the DP Method	5
2.4 Product-Level Monitoring Test	5
3 TEST AND EVALUATION APPROACH	9
3.1 Requirements	9
3.2 Test Method	9
3.2.1 Test Items	9
3.2.1.1 LLLW Tanks and (Simulated) Waste Liquid	9
3.2.1.2 In-Tank Instrumentation	9
3.2.1.3 ORNL/LT-823DP	10
3.2.1.4 Data Collection	11
3.2.1.5 Housekeeping and Data Quality	11
3.2.2 Temperature Conditioning, Structural Deformation, and Leak Control	11
4 SENSOR CHARACTERIZATION	14
4.1 Linearity and Signal Characterization	15
4.2 Noise Characterization	17
4.2.1 Thermal Expansion/Contraction of LLLW Liquid	18
4.2.2 Thermal Inhomogeneities	19
4.2.3 Deformation	22
4.2.4 Temperature Sensitivity	24
4.3 Sensor Precision	27

5	ANALYSIS OF EVALUATION DATA	29
5.1	Data Summary and Test Chronology	29
5.2	Test Conduct	31
5.3	Performance Analysis	32
5.4	Performance of ORNL/LT-823DP Extrapolated to Larger LLLW Tanks	38
6	CONCLUSIONS AND RECOMMENDATIONS	41
	REFERENCES	42
	Appendix A: SAMPLE EVALUATION DOCUMENTS (EPA FORMS)	43
	Appendix B: STUDENT'S t-DISTRIBUTION	55

EXECUTIVE SUMMARY

A leak detection method has been developed for the Liquid Low-Level Waste (LLLW) tanks at the Oak Ridge National Laboratory (ORNL). This method is based upon an existing differential pressure level sensor that is installed in most of the LLLW tanks. The method, called the ORNL/LT-823DP, will be used to leak test the active LLLW tanks that have a volume capacity less than 3,000 gal.

Vista Research, Inc., has performed a technical evaluation of the ORNL/LT-823DP leak testing method in accordance with evaluation test procedures recommended by the U. S. Environmental Protection Agency (EPA) for monthly monitoring methods. The EPA's minimum standard for such devices requires a P_D of not less than 95% and a P_{FA} of no more than 5%, with a leak detection criterion of 0.2 gal/h. Analysis of the data collected during the evaluation showed that the method will detect a 0.2-gal/h leak with a single-test probability of detection (P_D) that is greater than 99.5% and a single-test probability of false alarm (P_{FA}) that is less than 0.5%; thus, the performance of the ORNL/LT-823DP meets the federal standards.

LIST OF FIGURES

	Page
Figure 1. Configuration of the level sensor in the LLLW tanks at ORNL.	4
Figure 2. Flow chart summarizing the ORNL/LT-823DP protocol.	6, 7
Figure 3. Raw volume measured by DP cell over weekend period.	14
Figure 4. A plot of voltage-versus-time during a calibration run.	16
Figure 5. A voltage-versus-level calibration plot.	17
Figure 6. Height-to-volume data for 4 calibrated bars (DP #0).	18
Figure 7. Variability of the height-to-volume data, expressed in gal/volt (DP #0).	19
Figure 8. Comparison of volumes of uniformly thick slabs in vertical and horizontal tanks.	20
Figure 9. Volumetric effects of temperature change in the liquid are compensated by the DP cell sensor: (a) shows an example of the thermistor data during one of the evaluations runs at LLLWSIM; (b) shows the level data recorded from the DP cell that was in the vertical tank as the warm water was added.	21
Figure 10. Effect of a temperature condition on the readings made by the ORNL level sensor: (a) shows the data from four thermistors; (b) shows only the level data from the DP cell that was in the vertical tank as the cold water was added.	23
Figure 11. Effects of deformation when 200 gal of water is removed from an LLLWSIM tank.	24
Figure 12. Effects of deformation when 200 gal of water is added to an LLLWSIM tank.	25
Figure 13. A plot of the temperature of the DP cell during a weekend period.	26
Figure 14. A scatterplot of cell-body temperature versus measured level (DP #0).	26
Figure 15. Cell-body compensated level (DP #0).	27
Figure 16. Cell-body compensated level; same data as Figure 15, but on expanded scale (DP #0).	28

Figure 17. Distribution of measurement error on a tight tank and on a leaking tank. 35

Figure 18. Histogram of leak rate (i.e., noise) produced by ORNL/LT-823DP (29 test runs). 36

Figure 19. Cumulative probability distribution of noise produced by ORNL/LT-823DP. 37

LIST OF TABLES

	Page
Table 1. Matrix of test Parameters Used in the Evaluation	13
Table 2. Summary of Noise Measurements Indicating Precision of DP Cell Sensors	28
Table 3. Chronology of Tests in the Evaluation of the ORNL/LT-823DP Leak Detection Method	30
Table 4(a). Reporting Form for Leak Rate Data, ORNL Volumetric Tank Gauge Method	33
Table 4(b). Reporting Form for Leak Rate Data, ORNL Volumetric Tank Gauge Method	34
Table 5. Bias and Standard Deviation Data from Evaluation of ORNL/LT-823DP	37
Table 6. P_D and P_{FA} in the Evaluation of the ORNL/LT-823DP	38
Table 7. Precision Error in Tanks with Capacities of 1,000 and 3,000 Gal Installed Vertically and Horizontally	40
Table 8. Estimate of the Maximum Influence Coefficient Error in Tanks with Capacities of 1,000 and 3,000 Gal Installed Vertically and Horizontally	40

LIST OF ABBREVIATIONS AND ACRONYMS

- A_{eff} = effective cross-sectional area (of the surface of a liquid in a container)
- A/D = analog/digital
- API = American Petroleum Institute
- ASME = American Society of Mechanical Engineers
- ATG = automatic tank gauge
- $^{\circ}\text{C}$ = degrees Celsius
- CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
- CFR = Code of Federal Regulations
- df = degrees of freedom
- ΔP (or DP) = differential pressure
- DOE = Department of Energy
- EPA = Environmental Protection Agency
- ft = feet
- F & D head = flanged and dished head (for end caps of tanks)
- FFA = Federal Facilities Agreement
- $^{\circ}\text{F}$ = degrees Fahrenheit
- gal = gallon(s)
- gal/in. = gallons per inch
- gal/h = gallons per hour
- gal/volt = gallons per volt
- h = hour
- HOG = hot off-gas
- H/V = height to volume

Hz = Hertz
in. = inch(es)
in./°C = inches per degree Celsius
in./volt = inches per volt
LLLW = low-level liquid waste
LLLWSIM = liquid low-level waste simulator
LVDT = linear voltage displacement transducer
MMES = Martin Marietta Energy Systems
ORNL = Oak Ridge National Laboratory
ORR = Oak Ridge Reservation
PC = personal computer
 P_D = probability of detection
 P_{FA} = probability of false alarm
RTD = resistance temperature detector
SARA = Superfund Amendment and Reauthorization Act
SS = stainless steel
TDEC = Tennessee Department of Energy and Conservation
UST = underground storage tank
USTTA = (EPA) Underground Storage Tank Test Apparatus
V/H = volume to height

1 INTRODUCTION

This report presents the results of an evaluation of the performance of a differential pressure volumetric leak detection method that will be employed at the Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, to test the integrity of the underground storage tanks that are part of the Liquid Low-Level Waste (LLLW) system. The evaluation reported here describes the performance of the volumetric method, designated as ORNL/LT-823DP. The tests and analysis leading to the performance estimates were accomplished in accordance with the testing protocols, quality assurance procedures, and test and evaluation methods established by the Environmental Protection Agency (EPA) in its research program to evaluate volumetric tank tightness test methods [1-3]. The evaluation of the ORNL leak detection method is also consistent with the EPA protocols for evaluating automatic tank gauges and volumetric tank methods [4,5]. To facilitate review, the results are reported in the EPA's format for reporting the results of evaluation tests.

Vista Research performed the evaluation described here under contract to Martin Marietta Energy Systems, Inc., Oak Ridge, Tennessee, and is solely responsible for the material presented in this report. The work was conducted at the Liquid Low-Level Waste Simulator (LLLWSIM) facility, located at the EPA's UST Test Apparatus in Edison, New Jersey. Vista Research performed the evaluation as an independent third-party testing laboratory.

The ORNL/LT-823DP leak detection method was developed from an existing differential-pressure level sensor that is installed in most of the LLLW tanks at ORNL and is used for monitoring the LLLW inventories in the tanks. As it is presently used for inventory control, the sensor measures level to the nearest 0.25 to 0.50 in.; as modified for leak detection, the sensor can measure changes to less than 0.01 in. The sensor measures the pressure difference at a point near the bottom of the tank and at another point in the vapor space of the tank. For a constant specific gravity of the tank contents, the pressure differential is proportional to the liquid level. The leak detection method compensates the raw liquid level readings for known temperature drifts of the sensor, and directly compensates for the thermally induced volume changes in the liquid. It converts level to tank volume, and employs a protocol specifically developed for this volumetric method. Although the ORNL/LT-823DP method was designed to test a portion of the active tanks that comprise the LLLW system at ORNL, it could, with some adaptation, be used to test other tanks for leaks.

For monthly monitoring, the EPA requires that a method be capable of detecting a 0.2-gal/h leak with a probability of detection (P_D) of no less than 95% and a probability of false alarm (P_{FA}) of no more than 5%. It will be shown below that the performance of the ORNL/LT-823DP method meets the EPA's requirements for monthly monitoring methods. Since the sensor that is the key to the method's performance is already installed in many LLLW tanks at ORNL, the method can be implemented more quickly than if a new system were to be installed. Furthermore, installing a new system might pose environmental risks, but, since the sensor is already in place, implementation of the leak testing method poses little or no such risk.

Section 2 of this report provides a description of the ORNL/LT-823DP method, and Section 3 describes the approach Vista has taken in the evaluation. Section 4 describes the characteristics of the sensor, and Section 5 discusses the evaluation data and the analysis results. Appendix A of this report summarizes the results of the evaluation on the forms provided by the EPA. Appendix B is a table of values for the Student's t-distribution; this is used in Section 5.

2 DESCRIPTION OF THE ORNL/LT-823DP METHOD

2.1 Mechanical Description

The ORNL/LT-823DP leak detection method is based on an existing liquid-level measurement sensor that is installed as part of the permanent instrumentation in the LLLW tanks at ORNL. The level sensor measures the pressure differential that exists between the bottom of the tank and the vapor space of the tank and that is caused by the head of liquid. As the liquid level increases or decreases, the sensor transmits an electrical current that is proportional to the increases or decreases in pressure.

At ORNL, the level sensors in the LLLW tanks are configured as illustrated in Figure 1. Liquid level-sensing is accomplished by using a differential pressure transmitter (a "DP cell"), two rotameters, and a regulated supply of air. The rotameters control the flow rate of a supply of pressure-regulated air into two tubing circuits. One side of one of the tubing circuits is connected to the "high" (measurement) side of the differential pressure sensor, while the other side of that circuit is connected to a *bubble pipe* that is immersed in the process liquid and that terminates near the bottom of the tank. A similar tubing circuit configuration connects a controlled flow of air to the "low" (reference) side of the differential pressure cell and to a line that terminates open-ended in the vapor space of the LLLW tank. Liquid level is determined on the "high" side of the sensor, by measuring the pressure required to force the air into the liquid; changes in level cause the pressure in the high side of the bubble tubing to increase or decrease. This measurement scheme produces a thin stream of bubbles that exit from the end of the pipe, which is thus called a *purge bubbler*, or simply a *bubbler*. The bubbles serve to ensure a free-flowing system in corrosive or solids-bearing liquids, and they prevent backflow of radioactive gases into the sensor body or tubing circuits. The bubbles also eliminate the capillary action and surface tension effects that could degrade the precision of a static dip-leg system.

The LLLW system incorporates a "hot off-gas" (HOG) system that sweeps air from the vapor space of the tank to reduce potential contamination from evaporated particulates. The differential pressure measurement is referenced to the vapor space of the tank (e.g., the "low" side of the process fitting on the sensor), and thus the effects of fluctuations in HOG pressure (in addition to fluctuations in atmospheric pressure) that would otherwise affect the pressure in the bubble pipe are mitigated. Because an air flow is generated through the reference piping, radioactive gases are prevented from flowing to the sensor, and changes in pressure within the piping system that could affect the differential pressure measurement are mitigated.

A temperature sensor is used in conjunction with the ORNL/LT-823DP to measure level. As will be shown later, the differential pressure sensor is sensitive to its own temperature. Thus, the leak detection method compensates the raw level data for the temperature drift of the DP cell, thereby greatly improving the precision of the device.

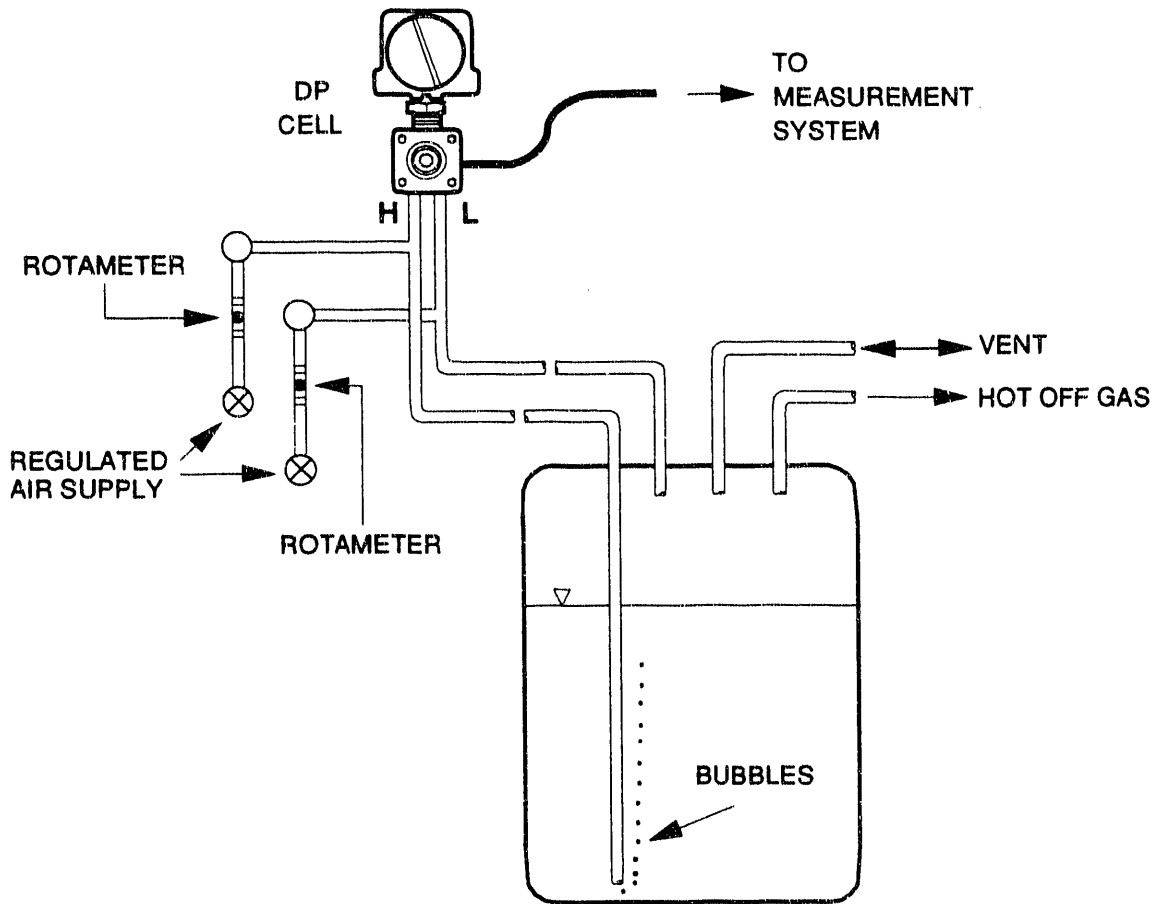


Figure 1. Configuration of the level sensor in the LLLW tanks at ORNL.

2.2 Principle of Operation

The ORNL/LT-823DP leak detection method uses the *bubbler* for level measurement together with a sensor to measure the temperature of the body of the DP cell. Air is passed through a rotameter to a bubble tube (or dip leg) immersed in the liquid. The lower end of the tube is at a fixed distance from the bottom of the tank. The pressure of the air supply is high enough to overcome the hydrostatic head on the tube, and the excess pressure appears as small bubbles coming out of the bottom of the tube.

In this configuration, the back pressure in the dip leg is a measure of the pressure on the bottom of the tube due to the level of the liquid. Since the position of the tube is fixed, any change in the back pressure is due to a change in the level of the liquid. (It will be shown later that the ORNL/LT-823DP method is a mass-measurement device; thus, *changes in temperature* in the liquid that cause the liquid volume to expand or contract do not produce corresponding changes in the measured level.) The back pressure in the bubbler tube is connected to the high-pressure side of the transmitter, and the low side of the transmitter is vented to the top of the tank. As the liquid head increases, the voltage across a resistor in series with the DP cell also increases; thus, the liquid level is proportional to the voltage drop.

Prior work has shown that the output of the differential pressure sensor used at ORNL is directly correlated with the temperature of the sensor itself [6,7]. Thus, the ORNL/LT-823DP incorporates a temperature sensor to measure the temperature of the body of the device so that the temperature-induced drift of the DP cell can be compensated for. During a leak detection test, data from both the temperature sensor and the differential pressure transmitter are sampled at 1-min intervals and recorded. The temperature data are used to compensate the level data for thermally induced changes in *measured* level, to obtain the compensated changes in liquid level.

2.3 Protocol for Using the DP Method

The ORNL leak testing plan [6,7] indicates that each of the tanks addressed by that plan will be tested at least once per month. Figure 2 provides a flow diagram of the test protocol for using the ORNL/LT-823DP method at ORNL. Upon initiation of a leak detection test on a particular tank, waste generation and waste transfer operations into and out of that tank are suspended until the test has been concluded. Certain manual checks are made to ensure that rainfall and other environmental factors do not preclude the start of the data collection period, if those factors are known to affect the test results. If the test cannot be executed at the scheduled time, or if a test in progress is interrupted for any reason, it is rescheduled.

During the data collection period, liquid level and body temperature data are recorded once per minute, as noted above. Following the data collection period, the level data are compensated for changes in sensor body temperature, and a net volume rate over the test interval is determined. Following a data quality test, the calculated volume rate is compared to a threshold value. If the volume rate does not exceed the threshold, the tank is determined to have successfully passed the leak detection test. If the volume rate does exceed the threshold, a second test is initiated. If the volume rates from both the first and second tests exceed the threshold, and if the difference between the volume rates is within a specified value, the tank is declared to be leaking. Reporting procedures will be implemented as part of the leak testing plan.

A two-test strategy is invoked to reduce the false alarm rate. The false alarm rate for a two-test sequence is a complicated function of the single-test false alarm rate and the correlation coefficient between two tests. If the two tests are independent, significant improvements in the false alarm rate can be achieved. Since the consequences of a false alarm at ORNL are more significant than a false alarm at a petroleum retail station, reducing the false alarm rate is an important goal for the method. The correlation coefficient between multiple tests by the ORNL/LT-823DP method will be determined during the first year's use of the method at ORNL, and an estimate of the performance of the two-test approach will be made.

2.4 Product-Level Monitoring Test

The ORNL/LT-823DP method employs a product-level monitoring test that consists of two separate, consecutive tests of tank integrity, as outlined above. The test protocol is designed so that both tests can be accomplished within a weekend period. The data collection for a single test requires approximately 24 h. The volume rate is calculated as the slope of the least-squares line that is fit to a 24-h block of temperature-compensated volume data.

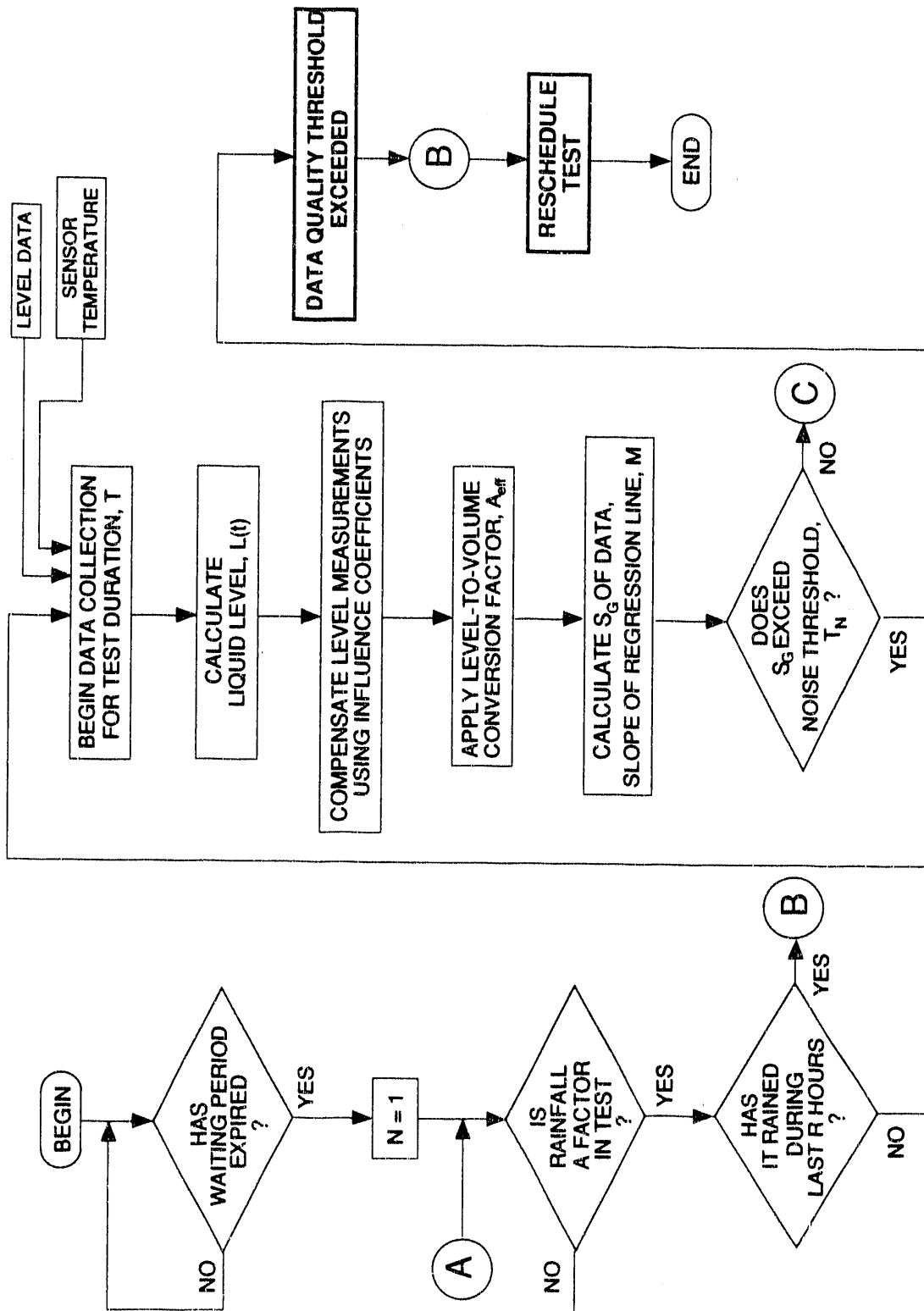


Figure 2. Flow chart summarizing the ORNL/LT-823DP protocol.

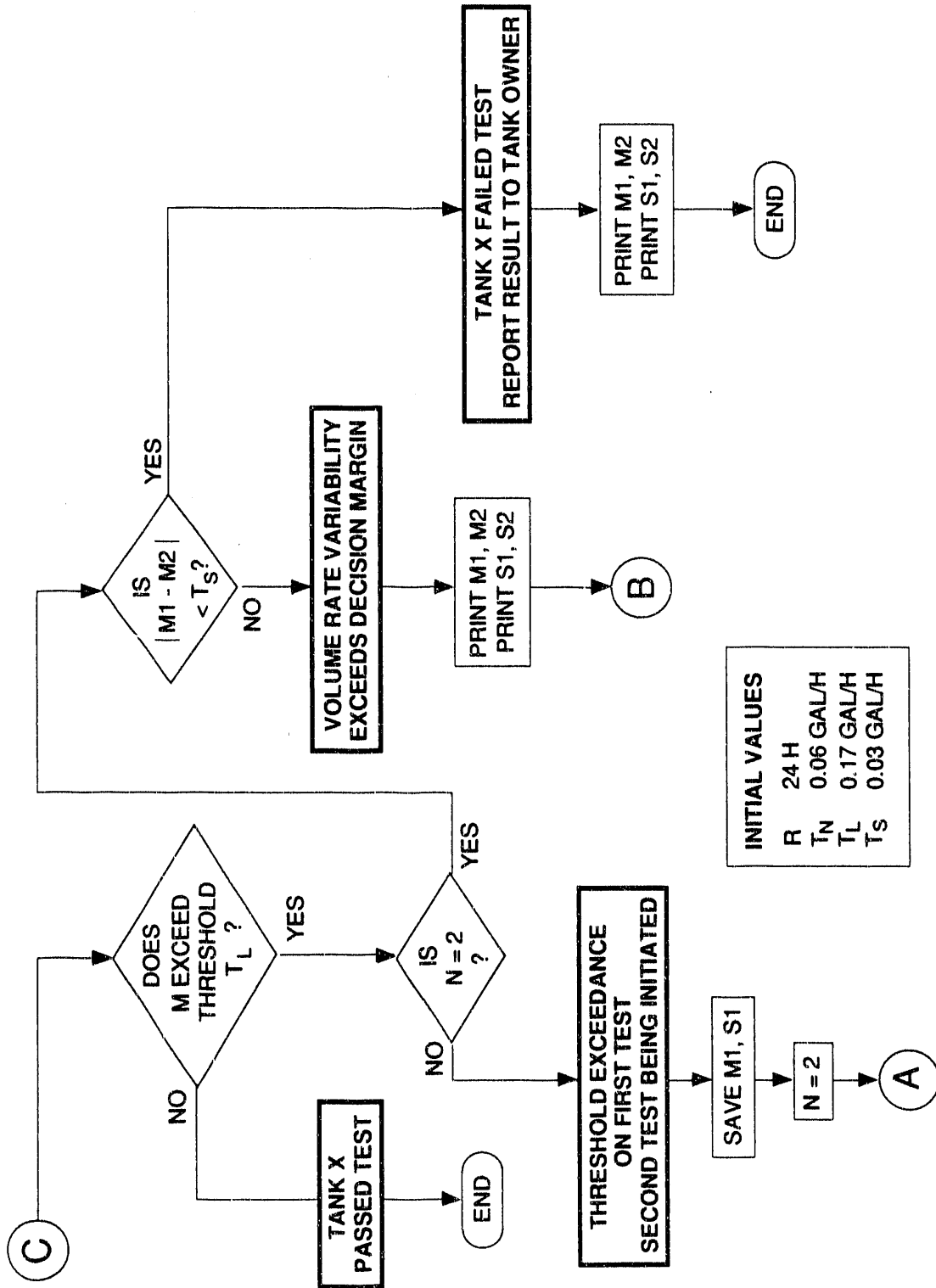


Figure 2 (concluded). Flow chart summarizing the ORNL/LT-823DP protocol.

Accurate release detection testing of underground storage tanks takes time because the magnitude of many of the environmental noise sources is time-dependent. While the system noise may be relatively constant, the environmental noise field is largest immediately after the tank has been disturbed as a result of additions or transfers. For a volumetric leak detection system such as the ORNL/LT-823DP, the largest disturbances will be associated with large-volume additions to the tanks or large-volume transfers from the tanks. Large changes in level will cause the tank to mechanically deform, and as a result large inhomogeneities in the temperature field will develop. An accurate test cannot be conducted until these changes become small enough to be negligible. Thus the product-level monitoring test includes a waiting period to allow the magnitude of the changes to subside. During this waiting period, all tank activity is suspended.

The required waiting period depends upon tank size and is described in the leak testing plan. In the LLLW tanks on which the ORNL/LT-823DP method will be used, the waiting period necessary for the contents of the tank to reach thermal equilibrium ranges from a few minutes for a 40-gal tank to a few hours for a 2,500-gal tank. The amount of time necessary for deformation effects in a tank to subside depends on the tank's installation configuration and, to a lesser extent, its size. For a typical 1,000-gal LLLW tank buried in backfill, mechanical equilibrium should be re-established within a few hours after a large-scale volume change has been completed. For a similar-sized tank installed in a vault, deformation recovery should occur almost immediately since there is no "resistance" from the surrounding backfill to impede the mechanical distortion; thus, the waiting period for these tanks would be very short. For the ORNL/LT-823DP product-level monitoring tests to be conducted on the ORNL LLLW tanks, conservative waiting periods of 4 to 12 h have been established. The specific waiting time for each tank is given in Volume II of the leak testing plan [7].

The ORNL/LT-823DP product-level monitoring test incorporates a set of *data quality indices* that are used to determine that the tank has stabilized sufficiently for an accurate leak test to be accomplished. Either of two conclusions is drawn from the data quality indices: (1) the test is inconclusive or (2) the data are of sufficient quality that the detection criterion can be applied to determine whether the tank should be declared leaking or not. There are two types of inconclusive test results: (a) the ambient noise fluctuations are too large, or (b) the results of a second test are sufficiently different from the first test that a firm conclusion cannot be drawn. A third type of inconclusive result can be obtained if it is determined that instrumentation problems or some aspect of the test procedure has interfered with the test.

A single-threshold detection criterion is used to determine whether the tank "passes" or "fails" the leak test. The threshold is selected so as to give a P_{FA} of less than 0.05 for a single test. A tank can only be declared leaking if the threshold is exceeded in two consecutive tests. The tank can be declared tight on the basis of a single test. Any time the threshold is exceeded during a first test, it is assumed that this is a false alarm. A multiple test strategy is used to minimize the false alarms resulting from large, time-dependent noise sources. The two-test sequence also reduces the number of false alarms due to random noise fluctuations.

3 TEST AND EVALUATION APPROACH

This section of the report describes the particular approach taken by Vista Research to conduct the required tests and perform the evaluation of the ORNL/LT-823DP method.

3.1 Requirements

The ORNL/LT-823DP method was developed to meet the pertinent requirements for an automatic tank gauging (ATG) system for underground storage tanks as specified by the EPA. While there are no regulatory requirements requiring that the leak detection methods used at ORNL meet the EPA's standards, there were sound technical reasons for doing so. These reasons were given in ORNL's leak testing plan [6,7].

The regulations describing the performance requirements for ATG systems can be found in 40 CFR 280 [8]. The test and analysis procedures used to estimate the performance of the ORNL/LT-823DP method are consistent with those recommended by the EPA for the evaluation of automatic tank gauging equipment [4]. Some minor changes to these procedures were made, however; these changes, which are noted below, reflect the specific operational environment of the LLLW system found at ORNL. These changes result in estimates of the performance of the system as it will be used at ORNL.

According to the EPA regulation, an automatic tank gauge must test monthly for the loss of product from any portion of the tank that routinely contains product. The specific release detection requirements for ATG systems are covered in Sections 280.40(a) and 280.43(h) of the Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks [8]. These regulations require that tests using automatic tank gauging equipment must be conducted at least once a month and must have sufficient performance to detect leaks as small as 0.2 gal/h, with a P_D of no less than 0.95 and a P_{FA} of not greater than 0.05.

3.2 Test Methods

As noted above, all of the tests reported here were conducted by Vista Research at the LLLWSIM facility located at EPA's UST Test Apparatus in Edison, New Jersey. This test and evaluation facility was built by Vista Research and Martin Marietta Energy Systems especially to perform the evaluation described here. Before the LLLWSIM was built, EPA approval for its construction was requested and obtained. The material below describes the particular procedures and other features employed during the test and evaluation of the ORNL/LT-823DP method.

3.2.1 Test Items

3.2.1.1 LLLW Tanks and (Simulated) Waste Liquid

As indicated in the leak testing plan, the ORNL LLLW system is comprised of both vertically and horizontally oriented tanks. The ORNL/LT-823DP leak detection method will be used for both orientations. The evaluation of the ORNL/LT-823DP was performed in tanks

installed at the EPA's Underground Storage Tank Test Apparatus, in Edison, New Jersey, that simulate the LLLW system (LLLWSIM). One of the LLLWSIM tanks was installed vertically and the other was installed horizontally. Since the liquid low-level wastes are aqueous, with a specific gravity near unity, tap water was used to simulate the wastes. Both LLLWSIM tanks have a capacity of 1,000 gal; the diameter of these tanks is 64 in. and their length 72 in.

3.2.1.2 In-Tank Instrumentation

Each of the LLLWSIM tanks is instrumented with sensors that provide a measure of "truth" in the tanks. One of these is a measure of the temperature at various vertical strata in the tank. This measurement is made with a vertically oriented array of calibrated thermistors. Each thermistor array is comprised of five thermistors. The thermistors provide data about the temperature of the liquid at various distances above the bottom of the tank and allow the thermal history of the tank's contents to be recorded within several layers or "slabs." In the vertical tank, the thermistors are located at 5, 15.1, 25.2, 35.3, and 45.4 in. above the tank bottom. In the horizontal tank, the thermistors are located at 4.5, 13.4, 22.3, 31.1, and 40.0 in. above the tank bottom. The selection of array locations was based upon a division of the tank into equal-volume slabs. Since the LLLW tanks at ORNL are never filled to more than 70% of capacity (in terms of volume), and the evaluation would be performed with this maximum volume, the tank was divided into slabs of equal volume spaced between 0% and 70% of the tank's height. Each thermistor was placed so that it was effectively in the center of the slab. The height of the vertical tank is 72 in.; 70% capacity is at 50.4 in. Thus, the thermistor at 15.1 in. in the vertical tank is midway between a slab extending from about 10.1 in. to about 20.2 in.

The thermistors were calibrated before the evaluation began and checked again in late October. The thermistors had an estimated precision of about 0.001°C.

Another in-tank "truth" instrument at LLLWSIM is a linear-voltage displacement transducer, or LVDT. As configured at LLLWSIM, the LVDT is a level sensor that measures the displacement of a small float with respect to a fixed reference. The LVDT has a measurement precision of about 0.0001 in., with a total displacement range of the float of about 0.5 in. So that the LVDT can be used at a variety of LLLWSIM liquid levels, it is installed on a sliding mount attached to a pole, and is re-positioned when the tank level is changed.

3.2.1.3 ORNL/LT-823DP

Two ORNL/LT-823DP leak detection systems were operated concurrently during the evaluation, one in the vertical tank and one in the horizontal tank. Each leak detection system employed a single Foxboro model 823DP differential pressure transmitter (DP cell). Each of the DP cells was connected to its respective LLLWSIM tank by means of polyethylene tubing 0.25 in. in diameter, with a stainless steel dip leg in each tank. While the reference pressure of the DP cell was measured in the vapor space of the tanks, it was impractical to attempt to simulate the HOG system at LLLWSIM. It is estimated that the effect of the HOG on the field performance of the ORNL/LT-823DP will be minor. The quantitative assessment of such effects will be determined during the demonstrations, following the implementation of the method.

The DP cells were powered by a Hewlett-Packard Model 6212C DC power supply operated at 40 volts. The current output of the 823DP (10 to 50 milliamps over the calibrated span of the cell) was measured as the voltage dropped across a 1/3-watt, 160-ohm precision resistor in series with the power supply and the DP cell. Calibration runs were made several times during the evaluation to ensure that the proper voltage-to-height conversion coefficients were being used.

The temperature of the stainless steel body of the 823DP was measured at LLLWSIM using a calibrated thermistor with a precision of approximately 0.001°C. At Oak Ridge, the body temperature of the 823DP will be measured with a *resistance temperature detector* (RTD) with a precision of approximately 0.1°C. It is expected that the consequences of using a less-precise temperature sensor will be minor, but this will be assessed during the demonstrations, following implementation of the method.

3.2.1.4 Data Collection

During the evaluation, the sensor outputs were measured by means of an HP-3497a data acquisition system, incorporating a 16-bit analog-to-digital converter with 14-bit precision. Data from the output of the ORNL/LT-823DP method (DP cell and temperature sensor) were sampled at a rate of once per minute. At Oak Ridge, the data from the 823DP and the temperature sensor will be measured with a digital data acquisition system that affords similar measurement precision; one-minute sampling will also be employed.

3.2.1.5 Housekeeping and Data Quality

In addition to the parameters described above, the LLLWSIM evaluation data recording system also recorded several voltage and current references. These data served as a quality assurance tool during the evaluation. In the event anomalous data are observed or suspected, the voltage and current records can be checked to determine if power supply fluctuations were observed that could affect the data quality.

3.2.2 Temperature Conditioning, Structural Deformation, and Leak Control

The EPA's standard test procedures for evaluating volumetric methods [5] require that a minimum of 24 tests be conducted to form a reliable estimate of performance in terms of the P_D and the P_{FA} . Three factors are included in the test sequences. One factor is *temperature conditioning*. Here, liquid at a temperature different from that of the tank's contents is added. The objective of temperature conditioning is to verify that the test method properly compensates for a changing thermal environment in the particular tank being tested. For most volumetric methods, compensation is accomplished by waiting until the thermal changes are small, and by measuring the temperature change and actively compensating by calculation of the thermally induced volume changes.

Another factor is *structural deformation*. In this case, large quantities of liquid are withdrawn from or added to the tank prior to initiation of the leak test. The purpose of this

process is to determine that the leak testing method adequately recognizes and deals with the phenomenon of structural deformation. In most cases, since deformation is not easily predicted, it is usually addressed in the leak test protocol by including a *waiting period*.

A third factor is *leak rate*. Here, several different leak rates that span the range of the method are used during the evaluation. The purpose of varying the leak rate is to determine that the method accurately measures small leaks.

In the case of conditioning, the EPA's test procedures state that a 5°F condition should be used. This conditioning is appropriate for the evaluation of the ORNL/LT-823DP method because when liquid wastes are added to the LLLW tanks, there can be a temperature difference between the new and extant liquids.

When liquids of different temperatures are mixed, a thermal separation occurs, usually with the warmer product rising to the top as the cooler product settles to the bottom, and with an infinite variety of thermal gradients between the top and bottom layers. In general, the performance of a volumetric leak detection system will be affected by the thermal instabilities in the tank because of the volumetric expansion and contraction that occurs in various layers and because, in the case of a horizontal tank, the volume-to-height geometry of the tank changes with height. Thus, for a volumetric device based upon sensing the air/liquid interface, the level will increase and decrease with the expansion and contraction of the liquid, and thus the inferred volume will increase and decrease. Unless the level measurement is *temperature compensated* through measurement of the temperature of the liquid in a number of "slabs" within the liquid volume, there can be errors in the calculated volume rate. It will be shown later in this report that the ORNL/LT-823DP is *mass measurement* device; as such, this method will not be affected by temperature changes in the contents of the vertical tanks, and will be only slightly affected by temperature changes in the contents of horizontal tanks.

The addition (or withdrawal) of large quantities of liquid to (from) the tank causes a physical distortion of the tank to occur as the hydrostatic pressure is suddenly changed. When deformation occurs, the liquid level in the tank is changed. Deformation will cause the level to change rapidly immediately after the volume change, then more slowly until equilibrium is re-established. Since deformation is not easily measured, a product-level monitoring test should not be conducted in the presence of marked deformation. The the changes in level associated with deformation can degrade the performance of the method — most likely leading to a false alarm.

The evaluation procedures require that large quantities of liquid be removed from and added to the tank before a leak test is performed; this produces the type of mechanical deformation that can occur during actual field operations, and in this way it can be determined that the leak testing protocol adequately recognizes and deals with deformation. The EPA's test procedures recommend changes from 50% of the tank's capacity to 90%, to reflect the way typical gasoline storage tanks are utilized. To reflect the actual LLLW operating environment at ORNL, two types of volume changes were made. In the first case, small volume additions (at $\pm 5^\circ\text{F}$) were made prior to most of the test runs to simulate the way product is normally added to

the LLLW tanks — infrequently, and in small quantities. In the second case, larger volume transfers were made (with corresponding temperature conditions) to simulate the tank-to-tank transfers that are made.

Levels in the tanks were maintained between 50% and 70%. This was done because the volume in the LLLW tanks is very carefully monitored and is never allowed to exceed 70% of the tank's rated capacity.

The LLLWSIM is a well-instrumented facility. To simulate a leaking tank, a positive displacement pump is used to generate controllable, small-volume losses at a low rate from either of the tanks. For the purpose of evaluating the ORNL/LT-823DP method, the pump was used to generate "leaks" ranging from 0.0 gal/h to about 0.3 gal/h. To quantify the loss, the simulated waste liquid (tap water) removed from the tank was pumped into a collection carboy. At the end of the run, the volume in the carboy was measured with a graduated cylinder. The effective leak rate was determined as the volume measurement divided by the collection period.

Table 1 shows the matrix of conditions, volumes, and leak rates that were planned for the evaluation of the ORNL/LT-823DP method. The table identifies 12 runs, with the collection of runs comprising the combination of temperature conditions, volumes added, and leak rates recommended by the EPA for an evaluation of this type of method [5]. In the case of the evaluation of the ORNL/LT-823DP, it was planned that both ORNL/LT-823DP devices (one in each tank) would be tested according to the parameters in Table 1. Since there are 12 runs in the matrix and two methods undergoing evaluation, a total of 24 evaluation runs would be achieved to reach the EPA's suggested minimum number of test runs.

Table 1. Matrix of Test Parameters Used in the Evaluation

Test Name	Temperature Condition (°F)	Added Volume (gal)	Waiting Period (h)	Leak Rate (gal/h)	Length of Test (h)
T1	+5	200	12	0	24
T2	+5	10	4	0.1	24
T3	+5	10	4	0	24
T4	+5	10	4	0.2	24
T5	+5	10	4	0	24
T6	0	10	4	0.2	24
T7	-5	200	12	0	24
T8	0	10	4	0.1	24
T9	-5	10	4	0	24
T10	-5	10	4	0.2	24
T11	-5	10	4	0	24
T12	-5	10	4	0.3	24

4 SENSOR CHARACTERIZATION

The Foxboro 823DP differential pressure transmitter is the principal sensor in the ORNL/LT-823DP leak testing method. When this sensor is connected and operated as shown in Figure 1, a time series output is produced that can be related to the *raw measured level* or raw volume in a tank as a function of time; Figure 3 illustrates a typical time series. These data, collected in the 1,000-gal vertical tank at the LLLWSIM facility, shows the change in volume in the tank over the course of a weekend during the pre-evaluation characterization testing. These data were obtained by recording (digitizing) the voltage across the 160-ohm precision resistor, converting the voltage to liquid level using a previously measured conversion factor, then converting level to volume by applying the tank strapping table (volume-to-height) particular to that tank. (See Appendix A of the Leak Testing Plan for the Oak Ridge National Laboratory Liquid Low-Level Waste System (Active Tanks) [7] for a discussion of the tank strapping table values for the horizontal LLLW tanks; Appendix B of that document gives the volume-to-height coefficients for the vertical tanks.)

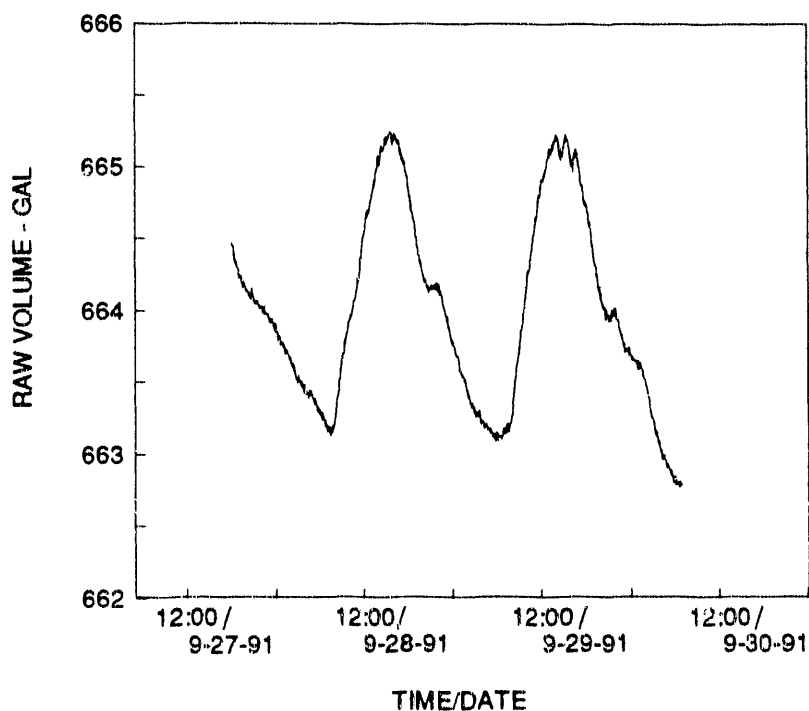


Figure 3. Raw volume measured by DP cell over weekend period.

The evaluation testing of the ORNL/LT-823DP was preceded by a series of measurements designed to provide an understanding of the sensor and its response to a variety of parameters. These data were used to ensure that the leak testing protocol addressed and adequately dealt with the pertinent issues. The results of these characterization measurements are discussed below.

4.1 Linearity and Signal Characterization

The output of the 823DP sensor is a 10- to 50-milliamp current over the calibrated span of the sensor. As implemented for the evaluation tests, the current is indirectly determined by measuring the voltage drop across a precisely known resistance. The liquid depth is calculated from the voltage by multiplying by a conversion factor. To determine the voltage-to-level conversion factor so as to record the data as liquid depth, calibration measurements were made. For these measurements, the level sensor normally in the horizontal LLLWSIM tank was moved to the vertical tank so that both of the level sensors could be calibrated at once. Then, while the voltage was being recorded by the data acquisition computer, water was added to or pumped out of the vertical tank, in stages. The actual water depth was measured with a calibrated "stick" manually inserted into the tank and read. The voltage-to-level conversion factor was determined as the slope of the least-squares fit to the voltage and level data.

An example of one such calibration series for one of the DP cells is shown in Figure 4. These data show that at about 0900 a measurement began with the water in the tank giving about 3.35 volts across the resistor. The sample rate was once per minute. At about 0930, some quantity of water was added that increased the voltage output to about 4.1 volts. About every 20 min after that the water level was raised in stages until the tank was about three-quarters full, and then lowered in stages. At each level, several "stick" readings were made and averaged; voltage data were digitized and collected for about 20 min at each stage to allow a good average voltage to be determined. Following a number of these up-and-down cycles, the recorded data were plotted with the measured voltage on the abscissa and the measured level (the stick readings) on the ordinate. These data points are shown in Figure 5 as squares for 17 independent measurements at different levels.

A regression line through the data in Figure 5 shows a least squares fit to the data. This line represents a "best fit" to the data; the slope of the line is the voltage-to-level conversion factor. For these data, the conversion factor is 13.84 in./volt. It can be seen from the figure that all of the data lie very close to the line over the entire range of the sensor, indicating that the sensor is quite linear over that portion of the calibrated span that was examined during this test.

The manufacturer of the DP cell whose data are shown in Figure 5 provided a pre-ship calibration of the particular sensor of 10-milliamp output at 0 in. of water depth and 50-milliamp output at 88 in. For the 160-ohm resistor used for the voltage measurements, the manufacturer's calibration is equivalent to 1.6 volts at 0 in. and 8 volts at 88 in. It can be shown that the voltage-to-level conversion factor derived directly from the manufacturer is 13.75 in./volt, or within about 0.5% of the measured value for voltage to level for this sensor.

The standard deviation of the ordinate of the data shown in Figure 5 is 0.29 in., and represents the spread of the data about the least-squares line. While the standard deviation of the ordinate is a measure of the precision of the DP sensor, the errors in reading the stick are also included in this value. The accuracy of using a stick to measure product height was investigated in a study for the American Petroleum Institute (API) [9]. In this study, it was found that the

standard deviation of making repeated measurements using a wooden stick was about 0.31 in. Since the standard deviation of the calibration data was about 0.29 in., the API result suggests that the fluctuations in the data of Figure 5 are as likely to be reading errors as instrument errors.

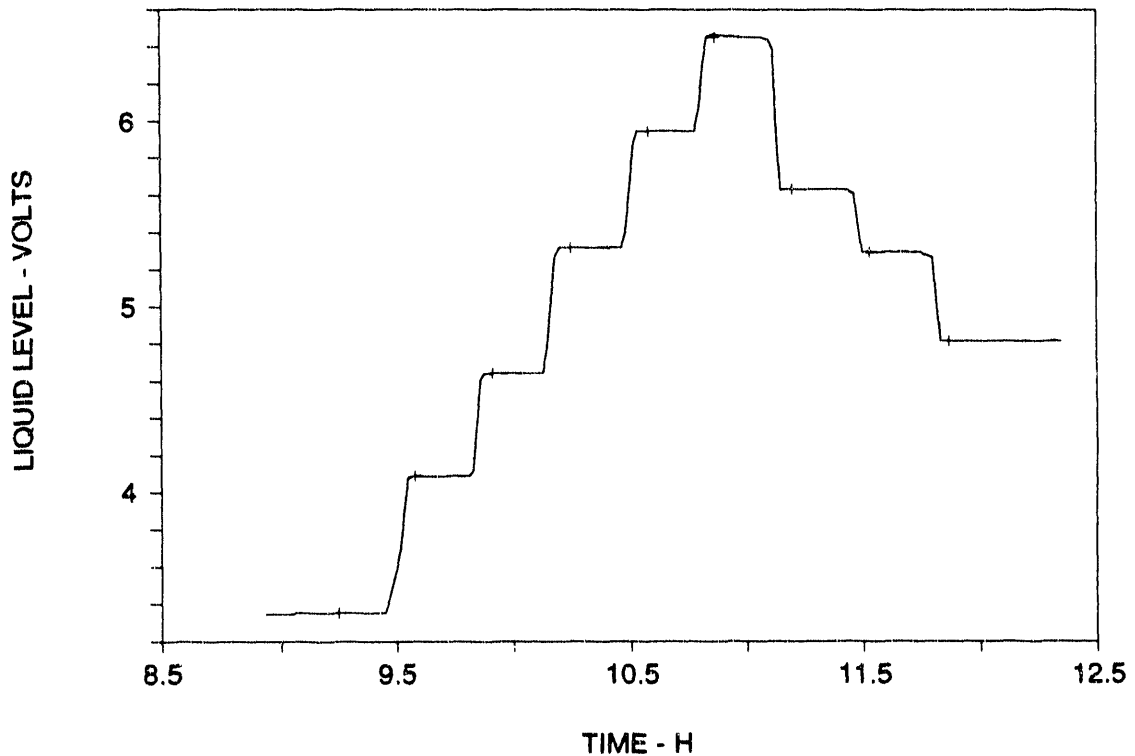


Figure 4. A plot of voltage-versus-time during a calibration run.

While the data shown in Figures 4 and 5 indicate that the voltage-to-level coefficient for the DP cell is a constant, and that it is consistent with the manufacturer's calibration data, they do not address the variability of the coefficient for small-scale changes in level. Such information is important for a leak testing method since, over short periods of time, a small leak will cause only small changes in level. To examine the response of the DP sensor to small changes in level, a number of "volume-to-height" (V/H) measurements were made. In these measurements, solid cylinders with precisely known volume displacements (i.e., calibration bars) are inserted into the tank. By examining the recorded level data after a test, the minimum detectable instantaneous level (or volume) change can be estimated. By using the tank strapping table (which is provided by the tank manufacturer and lists the tank's volume as a function of depth in the tank), the linearity of the DP sensor can be validated for small-scale volume displacements.

Figure 6 shows the measured *change* in liquid level in the 1,000-gal vertical tank at LLLWSIM during one of the V/H measurements made during the evaluation of the ORNL/LT-823DP method. The data in this figure were obtained by inserting and withdrawing four different sizes of calibration bars, 0.946, 1.544, 2.470, and 5.045 L. Each bar was used to

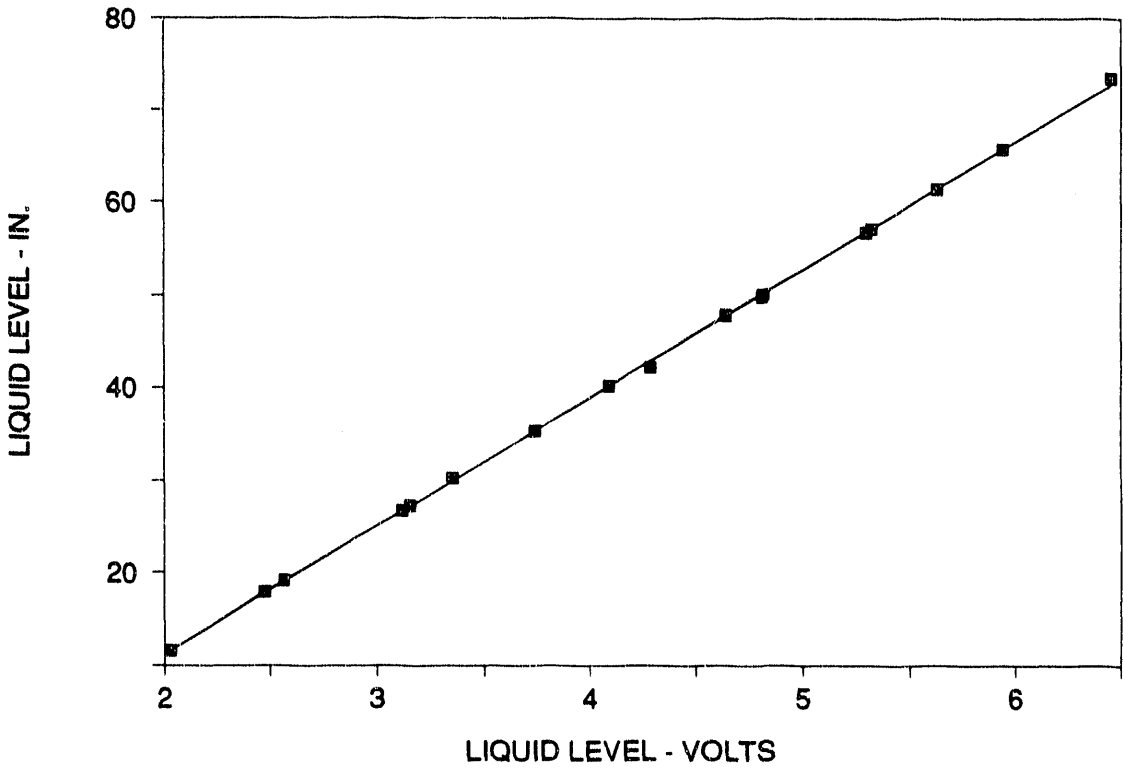


Figure 5. A voltage-versus-level calibration plot.

make two measurements, beginning with the smallest bar and ending with the largest. The 0.02-in. level change produced by the 0.946-L (0.25-gal) bar can be clearly seen in the data in Figure 6. A scale shows that the ratios between the various level changes are linear with the volumes of the bars. An analysis of the data was performed by averaging the inner portions of each of the plateaus, and then calculating each of the 16 possible level ratios. These data are plotted in Figure 7, which combines the V/H data with the voltage-to-level coefficient described above, to show the average level ratios expressed in terms of gallons per volt. The mean of these data is 190.8 gal/volt. This result is within 1% of the 192.8 gal/volt that would be inferred from the tank strapping table and the voltage-to-level data, and suggests that the DP sensor provides a very linear response for both large and small level changes.

4.2 Noise Characterization

There are several sources of noise that can interfere with volumetric leak testing methods. These noise sources include: thermal expansion (or contraction) of the product in the tank, deformation, thermal inhomogeneities, evaporation and condensation, and instrument sensitivity to environmental factors such as temperature and barometric pressure. These noise sources are discussed below, in terms of their effect on the ORNL/LT-823DP method.

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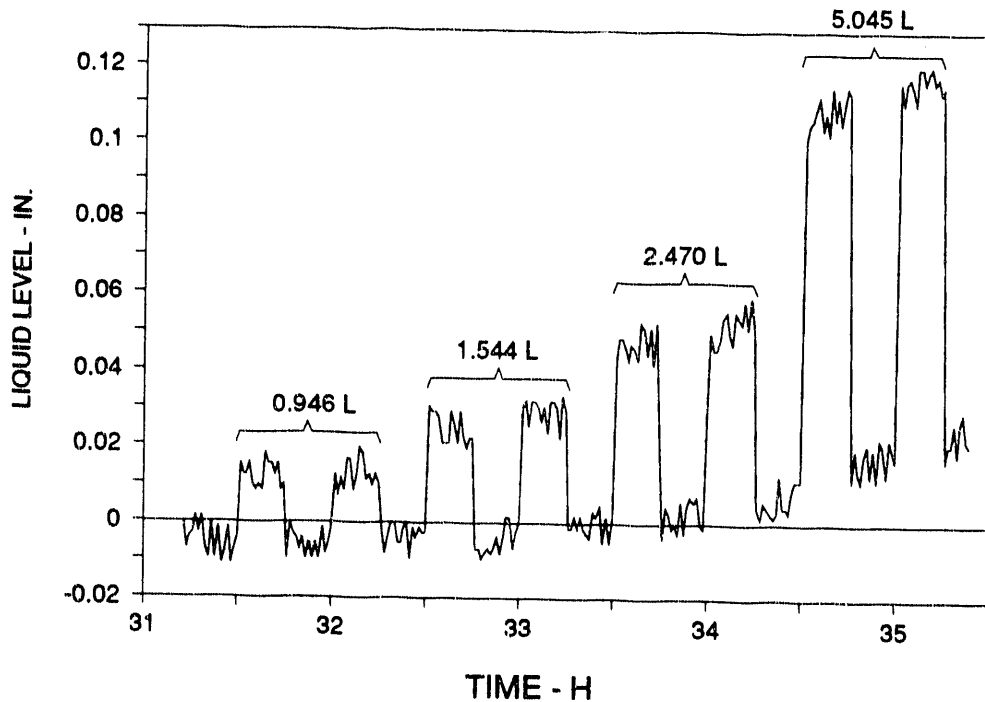


Figure 6. Volume-to-height data for 4 calibrated bars (DP #0).

4.2.1 Thermal Expansion/Contraction of LLLW Liquid

The differential pressure sensor is a mass-measurement instrument. That is, it measures the hydrostatic head with respect to the reference pressure. The head pressure, p , sensed by the DP cell is given by

$$p = F/A = mg/A = \rho Vg/A = pg (V/A) = S_g (V/A) ,$$

where S_g is the specific gravity of the liquid being measured and h is the height of the liquid surface above the bubbler piping, F is force, A is the area the force is acting upon, m equals the mass of the liquid column being measured, g is the acceleration of gravity, ρ equals the density of the LLLW liquid, and V equals the volume of the liquid. When the temperature of the liquid changes, the liquid expands or contracts by an amount determined by the coefficient of volume expansion of the liquid. Since the mass remains constant while the volume changes, it is the density of the liquid that changes. In a vertical tank, $V/A = h$, and $p = S_g h$. Thus, while the volume of the liquid contents in a vertical tank may change with temperature, the mass remains constant. In a horizontal tank, however, $V/A \neq h$, and errors can be introduced.

A DP cell with a bubble pipe located near the bottom of a vertical tank will automatically compensate for the thermal expansion and contraction of the liquids in that tank, as noted above. In a horizontal tank whose surface area changes with liquid depth, however, automatic compensation is not assured. For temperature changes occurring in uniformly thick horizontal "slabs" of liquid in a vertical tank, the DP cell effectively performs an *algebraic average* of the

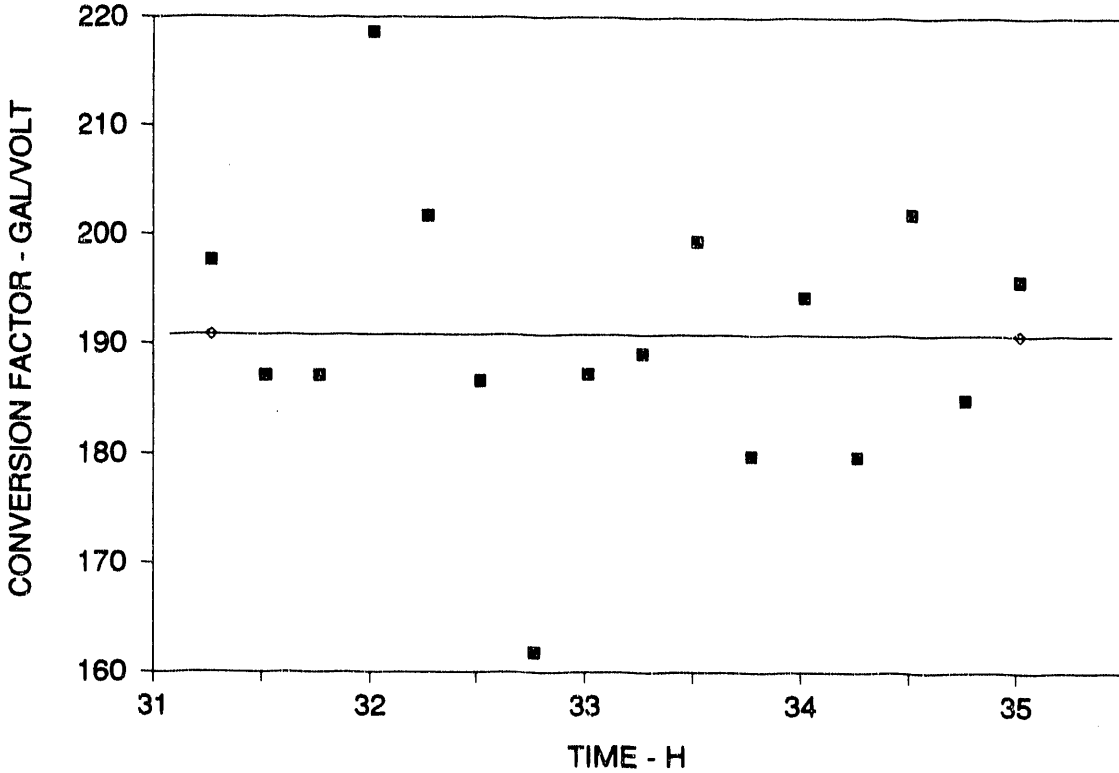


Figure 7. Variability of the volume-to-height data, expressed in gal/volt (DP #0).

temperature change. In the horizontal tank, slabs of uniform thickness have volumes that depend upon the liquid depth, and thus a *volume-weighted* average is necessary for proper temperature compensation. Figure 8 illustrates why a volume-weighted average is necessary for compensating for temperature changes in a horizontal tank.

4.2.2 Thermal Inhomogeneities

The effects of tank geometry on temperature compensation can be illustrated by the following equation, which expresses the average temperature-compensated change in volume of a tank, $\langle \Delta V \rangle$, as a function of the temperature and volume changes within layers of the liquid,

$$\langle \Delta V \rangle = C_e \sum_{i=1}^n \Delta T_i \Delta V_i$$

where C_e is the volume expansion coefficient of the liquid, ΔT_i is the change in temperature in the i^{th} slab, and ΔV_i is the change of volume for the i^{th} slab per unit change in depth. In the case of a vertical tank, ΔV_i is a constant, so the expression for $\langle \Delta V \rangle$ reduces to

$$\langle \Delta V \rangle = C_e V \sum_{i=1}^n \Delta T_i$$

Thus, in a vertical tank, the algebraic average is the same as the volume-weighted average. (It is noted that, since the bubble tube does not extend all the way to the bottom of the tank, there will be some volume that is not measured by the DP cell; temperature-induced volume changes occurring in this unsampled volume will result in small, but uncompensated, level changes even in a vertical tank.)

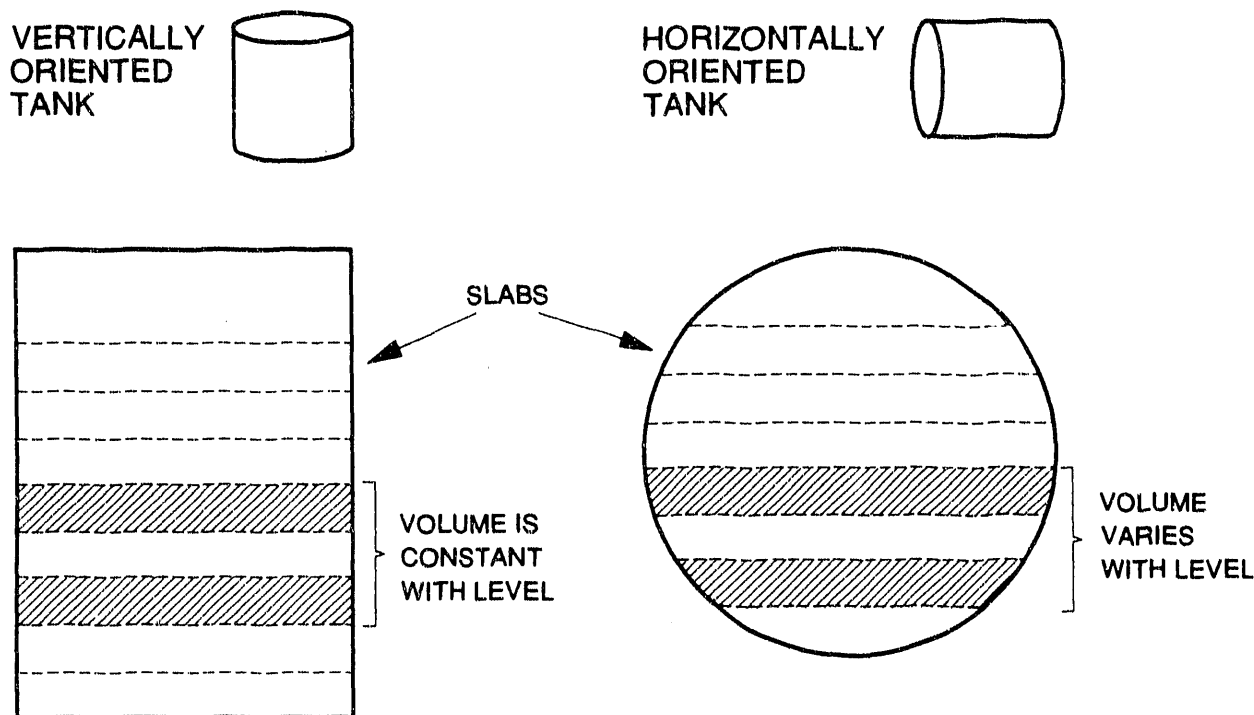


Figure 8. Comparison of volumes of uniformly thick slabs in vertical and horizontal tanks.

That the volumetric effects of temperature change in the liquid are compensated by the DP cell sensor is illustrated in Figures 9(a) and 9(b). Figure 9(a) shows an example of the thermistor data during one of the evaluations runs at LLLWSIM. In these data, 10 gal of water was added to the approximately 500 gal extant in the vertical tank at LLLWSIM. The added water was about $+10^{\circ}\text{F}$ warmer than the extant volume. Data from three thermistors are shown in Figure 9—the two closest to the bottom of the tank and the one nearest the surface of the water. The data show that when the warm water was added to the tank at about 0700 in the morning, the bottom thermistors recorded a sharp increase in temperature as the warm water cascaded into the bottom, followed by a slower decay as the warmer water rose. By about 0715, the bottom thermistors had reached an equilibrium that was about 0.6°C warmer than the starting temperature. The upper thermistor also recorded the warm water as it was added, starting from a warmer temperature since the undisturbed volume had stratified with the warmer layer on top. The newly added water produced some temperature fluctuations in the upper thermistor that, by about 0715, had reached near-equilibrium.

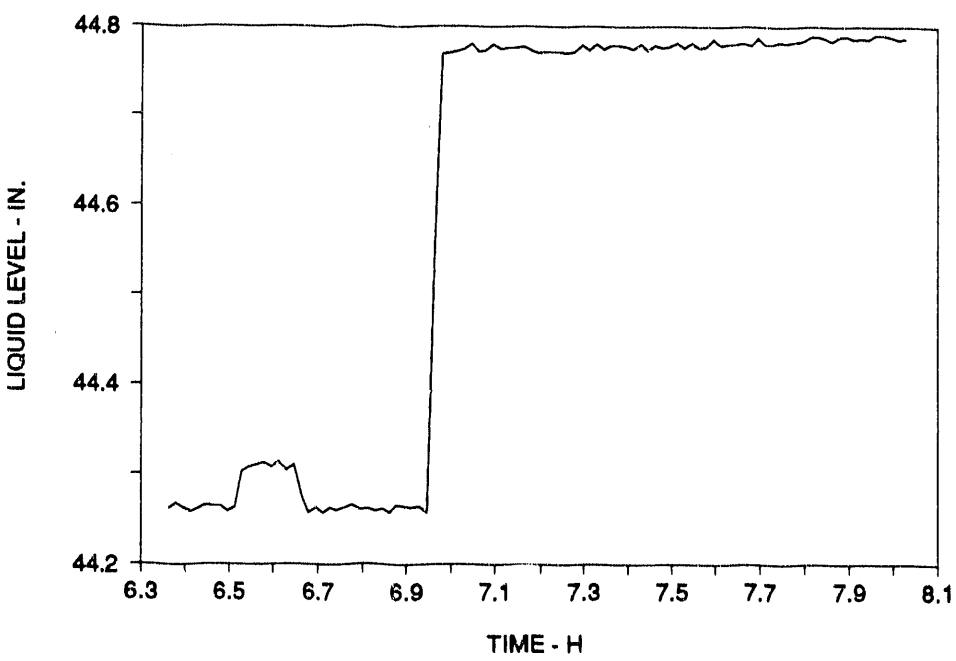
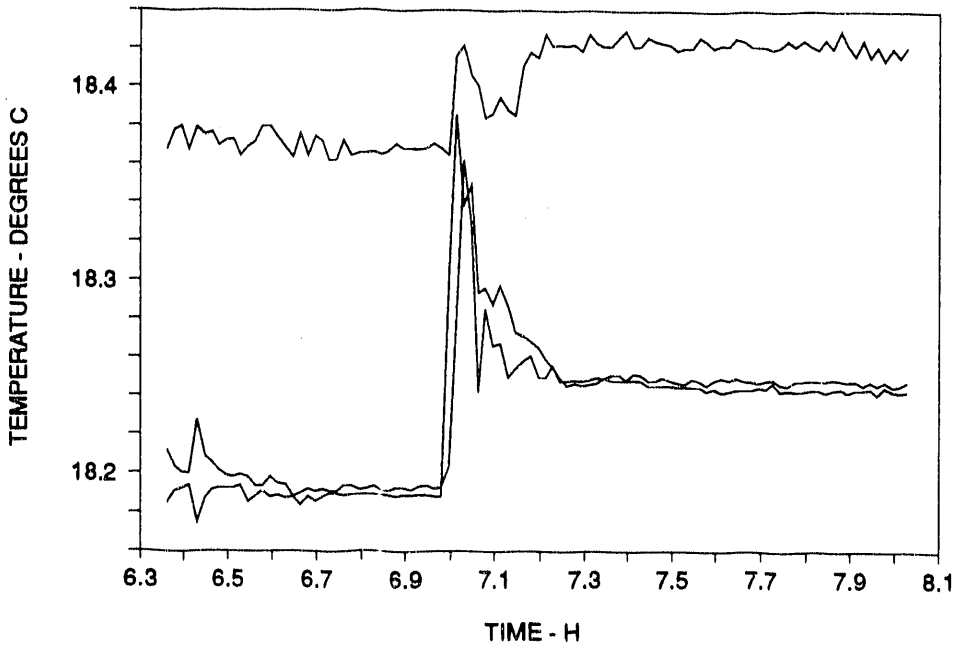


Figure 9. Volumetric effects of temperature change in the liquid are compensated by the DP cell sensor: (a) shows an example of the thermistor data during one of the evaluations runs at LLLWSIM; (b) shows the level data recorded from the DP cell that was in the vertical tank as the warm water was added.

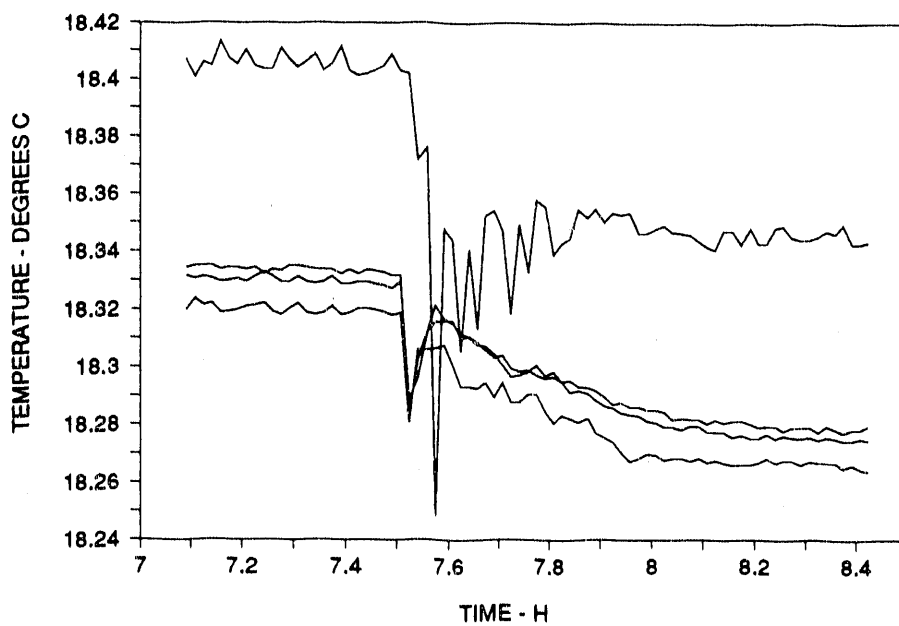
Compare these data to those of Figure 9(b). This figure shows the level data recorded by the DP cell that was in the vertical tank as the warm water was added. It can be seen that, when the warm water is added, there is an immediate increase in level with little or no undulation that might be associated with thermal effects. (In the plot, the "step" that appears to the left of the sharp level increase represents a level change caused by inserting the stick into the tank to take a level reading; also note that the gradual level increase that can be perceived to the right of the level "step" is due to the response of the DP cell to its own temperature, not the temperature of the liquid. This will be discussed below.)

Figures 10(a) and 10(b) show another example of the effect of a temperature condition on the readings made by the ORNL level sensor. In this figure, 10 gal of water that was -10°F colder than the extant volume was added to the tank. The data show that the addition of the cold water was recorded by all of the thermistors (four are shown in this figure), with equilibrium re-established about 30 min after the cold water was added. The output of the DP cell in this tank, Figure 10(b), shows only the level change; no temperature-volume effects are observed with the differential pressure level sensor.

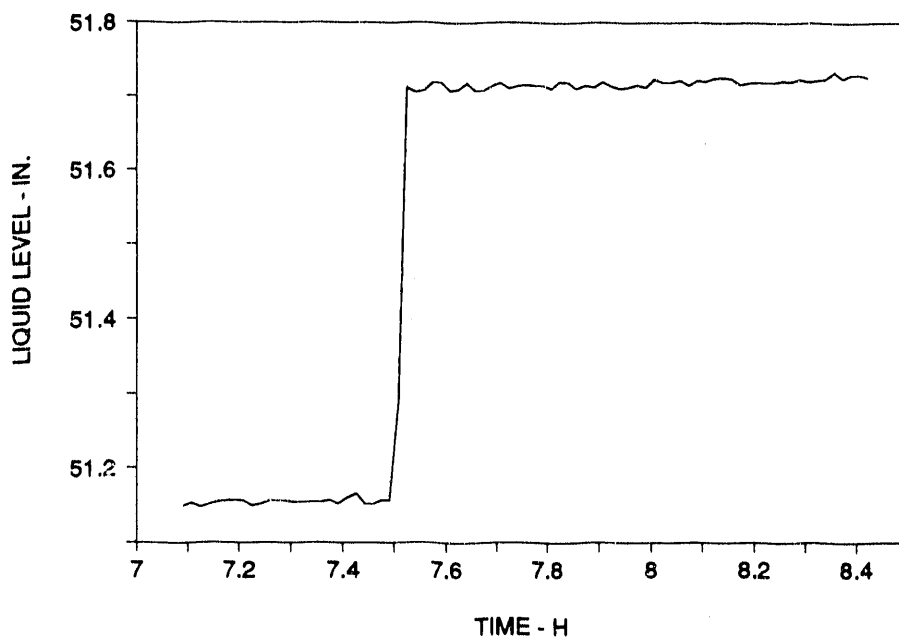
4.2.3 Deformation

Deformation is a physical distortion of the tank that occurs when liquid is rapidly added to or removed from the tank. In the case of an addition, the pressure produced by the newly added liquid causes the tank to expand against its backfill. As the tank and backfill move to accommodate the stretching caused by the newly added liquid, the level drops correspondingly to the now-greater diameter of the tank. When large amounts of product are suddenly removed from the tank, a similar distortion is experienced, but here the tank squeezes inward, increasing the level of liquid. The effects of deformation can be seen in the data collected during the evaluation of the ORNL/LT-823DP. The LLLWSIM tanks are buried in native backfill — largely sand. Figure 11 shows a plot of the level in one of the LLLWSIM tanks immediately after (i.e., within a minute of) the removal of 200 gal of water from the tank. It can be seen in the data that the tank is responding to the sudden release of pressure by increasing the level — this change is due to the backfill pressing inward on the tank. A change of about 0.020 in. (about 0.27 gal) is recorded in the first hour. After this time, the level remains more or less constant.

Figure 12 shows the effects of deformation when 200 gal of water are added to an LLLWSIM tank. Here, the plot shows that immediately after the water has been added, there is a change of about 0.005 in. (0.06 gal) as the tank expands in response to the internal pressure.



(a)



(b)

Figure 10. Effect of a temperature condition on the readings made by the ORNL level sensor: (a) shows the data from four thermistors; (b) shows only the level data from the DP cell that was in the vertical tank as the cold water was added.

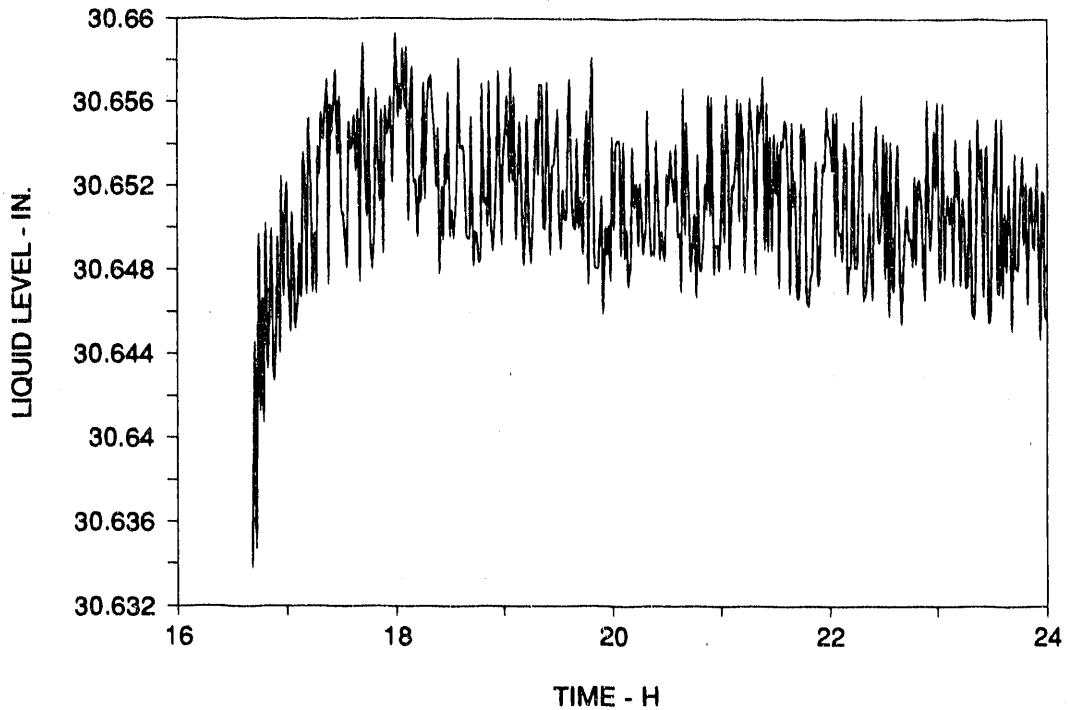


Figure 11. Effects of deformation when 200 gal of water are removed from an LLLWSIM tank.

The deformation effect at LLLWSIM appears to last no more than 1 to 2 h. Since the ORNL/LT-823DP leak test protocol requires a 12-h wait between a large volume addition or removal and the beginning of a test, deformation was not an influencing factor during the evaluation. At Oak Ridge, some of the tanks that will be tested are buried in a pea gravel backfill, while others are installed in a vaulted containment. In the case of a vault, the effects of deformation should be immediate since there is no backfill to resist the stretching of the tank when the level is changed. Thus, these tanks should rapidly adjust to any changes occurring as a result of large LLLW additions or transfers. For the tanks in gravel backfill, it is expected that deformation will take place over a period of time similar to that at LLLWSIM. Thus, the 12-h waiting period before beginning a test should be sufficient.

4.2.4 Temperature Sensitivity

One of the most marked sensitivities of the differential pressure level sensor is its sensitivity to temperature. As such, it represents a major source of noise that must be compensated for if the level sensor is to be used as a leak detection method. This sensitivity is illustrated in the data shown in Figure 3, and it will be shown that this sensitivity accounts for almost all of the fluctuation seen in that figure.

Figure 13 shows a plot of the temperature of the DP cell whose data appear in Figure 3. These data show the temperature that is being measured by a thermistor attached to the stainless

steel body of the DP cell. Since the DP cell was installed in a covered enclosure, but outside, the data of Figure 13 show a typical diurnal cycle with a maximum temperature recorded just after 1200 (noon) and a minimum temperature recorded just before dawn.

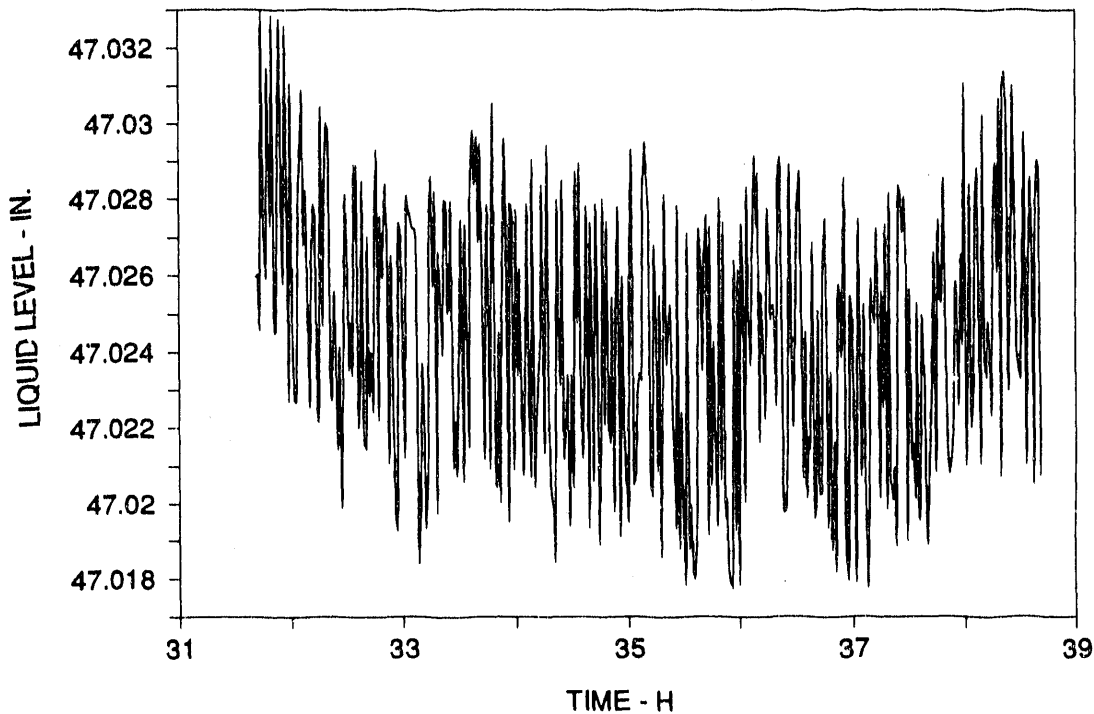


Figure 12. Effects of deformation when 200 gal of water are added to an LLLWSIM tank.

To measure the correlation between the recorded tank level (Figure 3) and the temperature of the DP cell (Figure 13), a scatter plot was made of data from a tank in a non-leaking condition. The scatter plot was comprised of all of the recorded temperature data from a weekend run (plotted on the X-axis) compared to the measured tank level (plotted on the y-axis). This scatter plot, shown in Figure 14, indicates that the data fell tightly about a line whose slope was determined to be 0.011 in./°C. (The line can be seen in Figure 14.) The slope is the *influence coefficient*, and the ORNL/LT-823DP method uses this coefficient to compensate the measured level for the temperature sensitivity of the DP cell.

The results obtained by compensating the raw level data (shown in Figure 3) for cell body temperature are illustrated in Figure 15. It can be seen in this figure, plotted to the same scale as Figure 3, that most of the fluctuations have been removed. Figure 16 provides a plot of the same data as Figure 15, but on an expanded scale.

As noted above, two DP cells were used in the course of the evaluation. During the characterization period, it was determined that the two DP cells had different influence coefficients. The level sensor used in the vertical tank had an influence coefficient of 0.011 in./°C, as noted above. The level sensor used in the horizontal tank at LLLWSIM

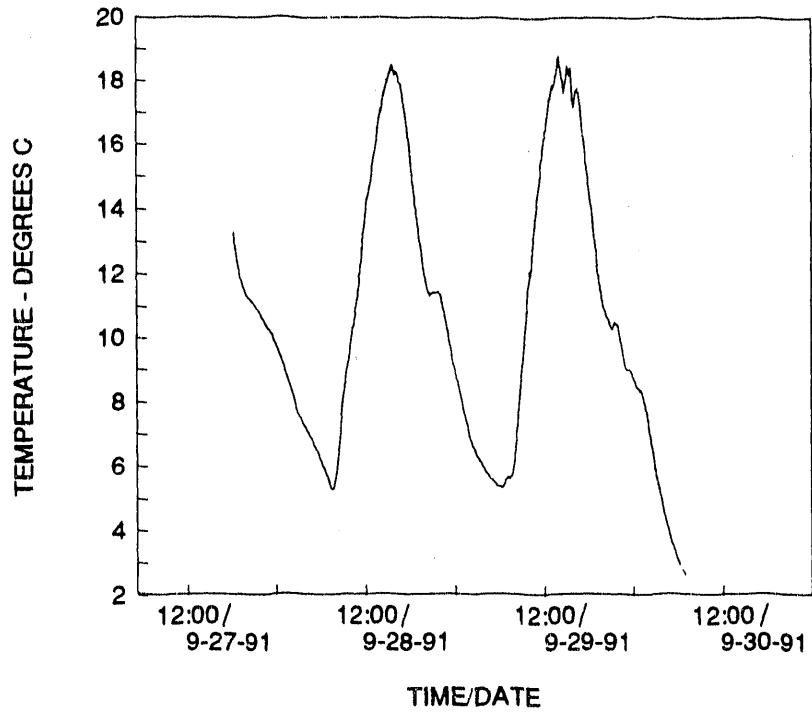


Figure 13. A plot of the temperature of the DP cell during a weekend period.

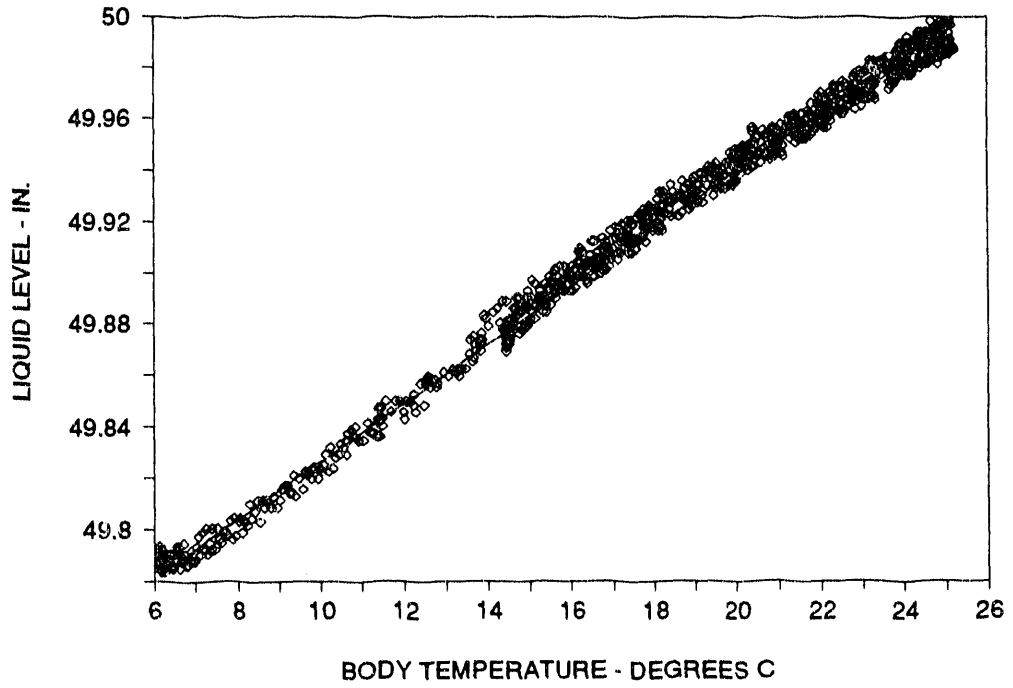


Figure 14. A scatter plot of cell-body temperature versus measured level (DP #0).

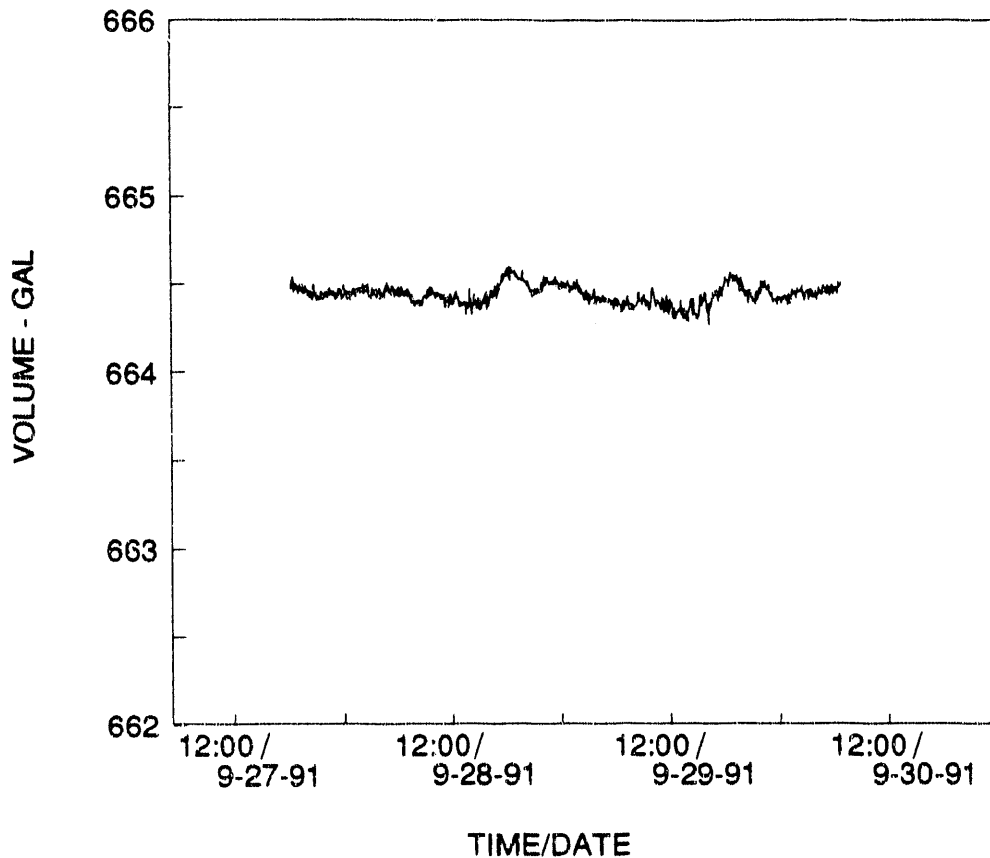


Figure 15. Cell-body compensated level (DP #0).

had an influence coefficient of 0.017 in./°C. Several attempts were made to normalize the influence coefficient to the known differences between the two DP cells, so as to develop either a single value for the influence coefficient, or to be able to calculate the value of the coefficient from some other parameter, such as the calibrated span of the cell. In the end, it was determined that the influence coefficient could vary from one DP cell to the next. Accordingly, it will be necessary to determine the influence coefficient for each of the DP cells to be used as a leak detection system prior to the use of that cell. Although the characterization and evaluation periods were short, the data obtained from the DP cells suggest that the influence coefficient has little or no drift with time or instrument age. To verify that the influence coefficient is constant, or nearly constant, analysis will be performed using data obtained during the demonstration of the ORNL/LT-823DP method at ORNL.

4.3 Sensor Precision

Using the data described above, an estimate of the precision of the DP cell was made. This estimate was made by examining the short-term fluctuations for 4-h blocks of the data. In one measurement, the "high" and "low" pressure ports on the DP cell were connected directly together with a short section of tubing. Data collected in this configuration show only the

"noise" of the sensor and the data collection system. The analysis of these data showed that the standard deviation of the sensor data is about 0.0007 in. To examine the noise of the system, as installed in a vertical tank, data collected in a non-leaking tank were analyzed. These data showed that the standard deviation of the bubbler system is approximately 0.0038 in. When these data are corrected for the temperature sensitivity of the DP cell, the noise improves slightly, to approximately 0.0032 in. These data, summarized in Table 2, indicate that the overall precision of the DP cell is about 0.003 in.

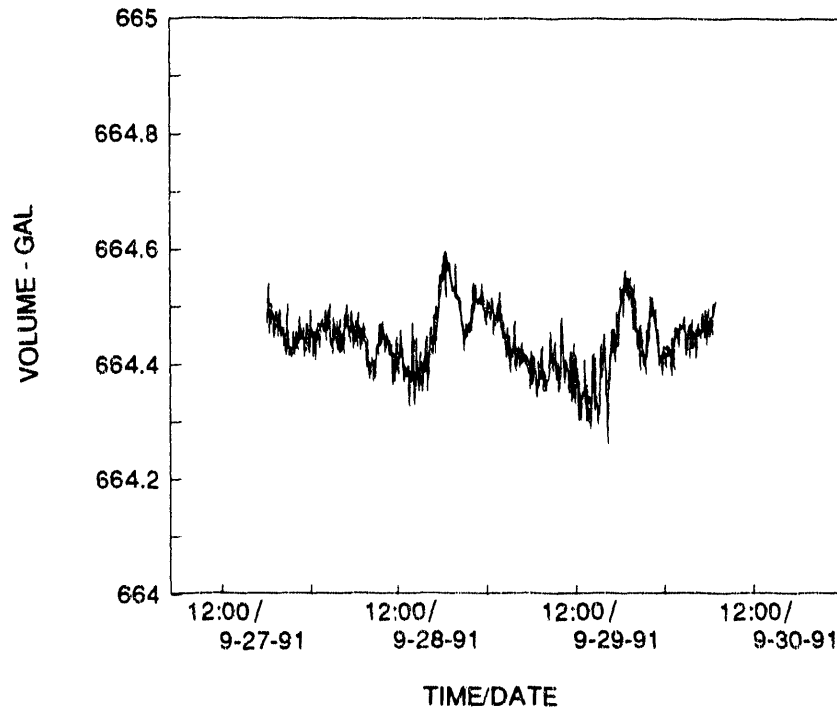


Figure 16. Cell-body compensated level; the data are the same as Figure 15, but on expanded scale (DP #0).

Table 2. Summary of Noise Measurements Indicating Precision of DP Cell Sensor

Sensor Configuration	Description	σ from 4-h Time Series
High-Low Connected	Sensor Noise	0.0007 in.
Raw DP level	System Noise	0.0038 in.
Compensated DP Level	System Noise	0.0032 in.

5 ANALYSIS OF EVALUATION DATA

This section of the evaluation report describes the tests, analysis, and results of the performance assessment made for the ORNL/LT-823DP leak detection method.

5.1 Data Summary and Test Chronology

Table 3 provides a summary of the testing performed during the evaluation period, 30 September to 5 November 1991. This table shows the date of each of the data collection runs during the evaluation and the file name under which the data have been recorded. Each data file shown in Table 3 contains one-minute samples from the various instruments comprising the LLLWSIM sensor suite along with the output from the DP cells and thermistors that comprise the ORNL/LT-823DP method. As noted above, the output from each method was comprised of a voltage proportional to the differential pressure measured by the DP cell and the temperature of the DP cell as measured by a thermistor on the cell body. Each tank had five thermistors distributed over the depth of the liquid in the tank, and a precision level sensor (an LVDT). Environmental data included air temperature and barometric pressure. System housekeeping included time of day and a constant current monitor for each current source used during the measurements.

Table 3 also shows the volume added to the vertical and horizontal tanks on the run date, the temperature condition created in the tanks, and the setting on the leak pump for those tanks. The column labeled "test numbers" indicates the designations of the data that formed the evaluation set. For example, on 2 October, a test number "V1" is indicated. This is the first data set from the vertical tank that went into the evaluation data; this data set is identified as "Test No. 1" on the "Reporting Form for Leak Rate Data" (for the vertical tank) that is part of the EPA's evaluation reporting format (see Appendix A). No data were obtained from the horizontal tank on 2 October because, as noted in the "Remarks" column, the flow of nitrogen through the rotameter connected to the ORNL/LT-823DP in the horizontal tank was erratic. This problem was traced to a defective needle valve in the rotameter.

While the rotameter was replaced on 9 October, the erratic flow through the rotameter caused large pressure fluctuations observed in the data from the horizontal tank. Since the problem was traced to the rotameter, which is not a part of the ORNL/LT-823DP, the data recorded during these tests were not included in the evaluation set.

The rotameter problem caused some delays in recording useful data from the ORNL/LT-823DP in the horizontal tank. As shown in Table 3, it was not until 10 October that the first usable data set was obtained from the horizontal tank. During the evaluation, there were a number of other incidents that interrupted the daily data collection program. On 9 October, the leak-making pump stopped pumping during a test that was underway; since the leak rate would not have been constant over the course of the evaluation run, these data were not used in the evaluation. On 23 October, the DP cells were recalibrated to verify the factory calibration of the DP cell being used on the horizontal tank.

Table 3. Chronology of Tests in the Evaluation of the ORNL/LT-823DP Leak Detection Method

Date	Filename	Horizontal Tank				Vertical Tank				Test #s V, H	Remarks
		Vol. Add (gal)	Temp. Cond. (°F)	Leak Rate (gal/h)	Vol. Add (gal)	Temp. Cond. (°F)	Leak Rate (gal/h)	Vol. Add (gal)			
9/30	930.SIM	-200	0	0	-10	0	0	0	0	--	leak pump quit; test ended early
10/2	A02.SIM	+200	-9	0	+10	+5	0	0	0	V1, --	H-tank rotameter erratic
10/3	A03.SIM	--	--	--	--	--	--	--	--	--	rotameter checkout
10/4	A04.SIM	0	0	0	+10	-10	0	0	0	V2, --	new H-tank rotameter ordered
10/5	A05.SIM	0	0	0	0	0	-0.1	-0.1	-0.1	V3, --	Δ level 6 in., vertical tank pretest
10/7	A07.SIM	0	0	0	+10	+10	0	-0.1	-0.1	V4, --	
10/8	A08.SIM	0	0	0	+10	-5	0	-0.1	-0.1	V5, --	
10/9	A09.SIM	0	0	0	+10	+5	0	-0.1	-0.1	--	rotameter on H-tank X-conm leak pump on V-tank quit
10/10	A10.SIM	+10	+5	0	+10	+5	0	-0.3	-0.3	V6, H1	leak pump erratic
10/11	A11.SIM	0	0	0	0	0	0	0	0	V7, H2	
10/14	A14.SIM	+10	+5	-0.3	+10	+5	0	0	0	V8, H3	
10/15	A15.SIM	+200	-5	-0.2	+200	-5	0	0	0	V9, H4	
10/18	A18.SIM	+10	+10	-0.1	+10	+7	0	0	0	V10, H5	new leak pump installed
10/19	A19.SIM	+10	-15	-0.1	+10	-13	0	0	0	V11, H6	
10/21	A21.SIM	+10	+7	0	+10	+10	-0.1	-0.1	-0.1	V12, H7	
10/22	A22.SIM	0	0	0	0	0	0	0	0	V13, H8	
10/23	A23.SIM	0	0	0	0	0	0	0	0	--	re-calibrate Δp cells and thermistors
10/24	A24.SIM	0	0	0	0	0	0	0	0	--	level calibration
10/25	A25.SIM	0	0	0	0	0	0	0	0	--	no data due to tank vent problem
10/28	A28.SIM	+5	+10	-0.2	+5	+10	0	0	0	V14, H9	
10/29	A29.SIM	0	0	0	0	0	0	0	0	--	calibration run for DP #1 influence coefficient
10/30	A30.SIM	10	-7	-0.2	+10	-6	0	0	0	V15, H10	
10/31	A31.SIM	+200	+5	-0.1	+200	+5	0	0	0	V16, H11	
11/3	B03.SIM	0	0	0	0	0	0	0	0	--	Sunday run, no leak
11/4	B04.SIM	10	-8	0	10	-8	-0.1	-0.1	-0.1	V17, H12	

Following the recalibration of the DP cells, a short series of level measurements were made to ensure that the system was still working properly. These measurements were made by placing both ORNL/LT-823DP systems in the vertical tank and recording data as the liquid level was changed in coarse increments. Following this measurement, the level sensor was re-installed in the horizontal tank, and data collection was resumed on 25 October. On 28 October, however, it was discovered that, at the time the level sensors were re-installed, the vents on the tanks had been closed and not re-opened. Thus, because of the possibility that the data might be defective as a result, the data recorded on 25 October were rejected from the evaluation set.

The evaluation of the ORNL/LT-823DP method was comprised of analysis of 29 leak tests totaling 696 h of recorded and processed data. Of these 696 h, 408 were collected in the vertical tank, for a total of 17 tests in that tank; 288 h of data were collected in the horizontal tank, for a total of 12 tests.

5.2 Test Conduct

As noted above, the evaluation was comprised of a total of 29 data runs. Each run sequence began with some specified volume addition (or removal) under some temperature condition, and with some leak rate. The combination of volume, condition, and leak rate needed during the evaluation was specified in the test plan matrix (Table 1), but the order in which these combinations were executed was determined by the field crew. Once the combination of volume, condition, and leak rate had been decided, the condition was established in the tank by adding the specified volume at the specified temperature. At this point, the run began. The beginning of a test signaled three events. First, both manual and computer logs were created for the run, and the digital recording of all data was initiated. Measurements were made of pertinent environmental factors such as barometric pressure, air temperature, wind and sky conditions, and facility factors such as the liquid depth in the tanks, its temperature, and so on; these were recorded in the log. Second, the test protocol for the ORNL/LT-823DP was initiated. Third, the leak collection container was emptied and then replaced so that it could collect the output from the leak-making pump during that run, and the leak-making pump was reset as necessary for the leak rate desired in the current run.

In cases where the condition is not trivial (e.g., when there is some volume added or removed), the protocol for the ORNL/LT-823DP requires a waiting period. This waiting period depends upon the size of the tank and the volume of liquid added to or removed from the tank. In the case of the 1,000-gal LLLWSIM tanks, the waiting period was either 4 or 12 h.

After the requisite waiting period had expired, an additional 24 h of data were recorded, as specified in the test protocol. (It is this last 24 h of data that are processed to form an estimate of the volume rate.) During this period, the operational status of both the ORNL/LT-823DP and the recording equipment was frequently checked to ensure that the run was proceeding smoothly. In some cases, as described in Table 3, problems were observed that interrupted a data collection run.

At the end of the run, the data recording for that run was terminated. One of the first steps at the end of the run was to measure and record the volume in the carboy for that run. At this point, the data records were scanned for completeness, then immediately analyzed. The analysis followed the test protocol: the raw level data from the DP cell were compensated for the temperature of the cell body, and a regression line was calculated for the resulting data. The slope of the regression line, the calculated volume rate, was then recorded in the manual log.

The most significant entries in the data logs for each run are summarized in Tables 4(a) for the vertical LLLWSIM tank and 4(b) for the horizontal LLLWSIM tank. These tables show each run completed, and provide the start and end dates and times of the run, and the actual conditions imposed on the tank during that run. The tables also show the actual leak rate obtained during the run as determined by measuring the volume of water collected in the carboy, and the measured leak rate during the last 24 h of the run, as determined from the calculated volume rate. The difference between the ORNL/LT-823DP-measured leak rate and the actual leak rates is a measure of the error of the ORNL/LT-823DP. Analysis of the ensemble of differences leads to the performance estimates for the ORNL/LT-823DP method.

5.3 Performance Analysis

When the last tests in the horizontal tank had been recorded, the log sheets showed that a total of 29 runs had been made — the required 12 runs in the horizontal tank and 17 runs in the vertical tank. For an overall estimate of performance of the ORNL/LT-823DP method, all of the measured/actual leak rate data can be used. Less precise estimates of performance can be obtained if the data from each type of tank are considered separately.

Performance estimates are made in terms the method's P_D and P_{FA} for a specified threshold value. A statistical analysis of the data is used to make these estimates. The performance analysis was done in accordance with the procedures outlined in the EPA's standard test procedures.

Figure 17 illustrates the statistical process. This figure shows two normal distributions. One is labeled "tight tank" and is the distribution of the noise that would be expected if the test method were used to make many measurements on a non-leaking tank; the second distribution, labeled "leaking tank," is the "signal-plus-noise" distribution, which would be expected if many measurements were made on a tank leaking at a rate of R gallons per hour. The consequences of using some threshold value, T , to indicate the presence of a leak can be examined in this figure. Remember that if the test method reports a calculated volume rate that exceeds the threshold, a leak is declared. For a non-leaking tank, a threshold exceedance is a false alarm. In the context of Figure 17, the probability of false alarm is the fractional area under the normal distribution for the *non-leaking tank* that is to the right of the threshold (shaded and labeled "A" in the figure). While it is desirable to minimize P_{FA} by setting the threshold value high (to the right in the figure), the reduced P_{FA} must be balanced against the P_D for a leaking tank. P_D is defined as one minus the probability of a missed detection (P_{MD}), where P_{MD} is the fractional area under the normal distribution for the *leaking tank* that is to the left of the threshold value (the area with the cross-hatched pattern in the figure).

Table 4(a). Reporting Form for Leak Rate Data, ORNL Volumetric Tank Gauge Method

Method Name and Version: ORNL/LT-823 DP Version: November 1991

Evaluation Period: from 30 Sept. 91 to 5 Nov. 91 (Dates)

Tank: 1,000-gal vertical

Test No	Date/Time of Addition/Withdrawal (mm/dd/yy hh:mm)	Quantity (gal)	Temp. Condition (°F)	Date/Time of Start of Test (mm/dd/yy hh:mm)	Date/Time of End of Test (mm/dd/yy hh:mm)	Planned Leak Rate (g/h)	Actual Leak Rate (g/h)	Measured Leak Rate (g/h)	Meas.-Actual Leak Rate (g/h)
1	9/30/91 1652	+10	0	9/30 2052	10/01 2052	0.0	0.0	-0.00025	-0.00025
2	10/02/91 0734	+10	+5	10/02 1134	10/03 1134	0.0	0.0	-0.00026	-0.00026
3	10/04/91 0730	+10	-10	10/04 1130	10/05 1130	0.0	0.0	-0.0004	-0.0004
4	10/05/91 1530	0	0	10/05 1530	10/06 1530	0.0	0.0	-0.1726	-0.0046
5	10/07/91 0657	+10	+10	10/07 1100	10/08 1100	-0.2	-0.162	-0.226	10.0040
6	10/08/91 1127	+10	-5	10/08 1530	10/09 1530	-0.2	-0.230	-0.268	10.034
7	10/10/91 1400	+10	+5	10/10 1800	10/11 1800	-0.3	-0.302	-0.0016	-0.0016
8	10/11/91 1800	0	0	10/11 1800	10/12 1800	0.0	0.0	10.0039	10.0039
9	10/14/91 0830	+10	+5	10/14 1230	10/15 1230	0.0	0.0	10.0058	10.0058
10	10/16/91 0730	-200	-5	10/16 2000	10/17 2000	0.0	0.0	-0.0058	-0.0058
11	10/18/91 1401	+10	+10	10/18 1800	10/19 1800	0.0	0.0	10.011	10.011
12	10/19/91 1817	+10	-13	10/19 2220	10/21 0654	0.0	0.0	-0.1008	-0.0098
13	10/21/91 0739	+10	+10	10/21 1140	10/22 1140	-0.1	-0.091	-0.1008	-0.00278
14	10/22/91 1154	0	0	10/22 1154	10/23 1140	-0.1	-0.073	10.0123	10.0123
15	10/28/91 1109	15	+12	10/28 1511	10/29 1508	0.0	0.0	10.014	10.014
16	10/30/91 1147	+10	-6	10/30 1550	10/31 1550	0.0	0.0	10.005	10.005
17	11/01/91 0730	+200	+7	11/01 2000	11/02 2000	0.0	0.0	-0.0022	-0.0022
18	11/04/91 0710	+10	-8	11/04 1142	11/05 1142	0.0	0.0		
19									
20									
21									
22									
23									
24									

Table 4(b). Reporting Form for Leak Rate Data, ORNL Volumetric Tank Gauge Method

Method Name and Version: ORNL/LT-823DP Version: November 1991

Evaluation Period: from 30 Sept '91 to 5 Nov '91 (Dates)

Test No.	Date/Time of Addition/Withdrawal (mm/dd/yy hh:mm)	Quantity (gal)	Temp. Condition (°F)	Date/Time of Start of Test (mm/dd/yy hh:mm)	Date/Time of End of Test (mm/dd/yy hh:mm)	Planned Leak Rate (g/h)	Actual Leak Rate (g/h)	Measured Leak Rate (g/h)	Meas.-Actual Leak Rate (g/h)
1	10/10/91 1353	+10	+5	10/10 1800	10/11 1800	0.0	0.0	-0.010	-0.010
2	10/11/91 1800	0	0	10/11 1800	10/12 1800	0.0	0.0	+0.0045	+0.0045
3	10/14/91 0835	+10	+5	10/14 1230	10/15 1230	-0.3	-0.307	-0.276	+0.031
4	10/16/91 0750	+200	-5	10/16 2000	10/17 2000	-0.3	-0.287	-0.278	+0.009
5	10/18/91 1359	+10	+7	10/18 1800	10/19 1800	-0.1	-0.060	-0.047	+0.013
6	10/19/91 1815	+10	-15	10/19 2220	10/21 0654	-0.1	-0.089	-0.061	+0.028
7	10/21/91 0740	+10	+7	10/21 1140	10/22 1140	0.0	0.0	-0.0349	-0.0349
8	10/22/91 1154	0	0	10/22 1154	10/23 1140	0.0	0.0	-0.0153	-0.0153
9	10/28/91 1114	+5	+9	10/28 1516	10/29 1508	-0.2	-0.162	-0.190	-0.028
10	10/30/91 1149	+10	-7	10/30 1550	10/31 1550	-0.2	-0.194	-0.220	-0.026
11	11/01/91 0755	+200	+5	11/01 2000	11/02 2000	-0.1	-0.060	-0.062	-0.002
12	11/04/91 0735	+10	-8	11/04 1142	11/05 1142	-0.1	-0.125	-0.131	-0.006
13									
14									
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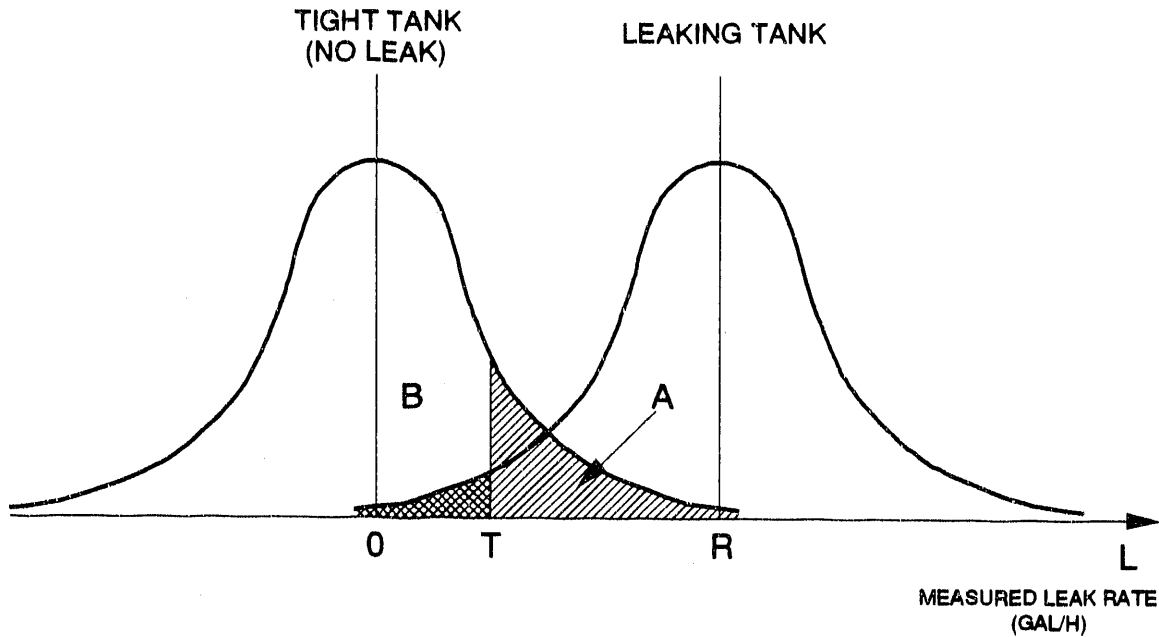


Figure 17. Distribution of measurement error on a tight tank and on a leaking tank.

Figure 18 shows a histogram of the data resulting from the 29 tests conducted during the evaluation, after the actual leak rate has been removed from the measured data. These data can be compared to the distribution shown in Figure 17. Figure 19 shows a plot of the cumulative distribution of the difference data resulting from an integration (actually, a summation) of the histogram.

Central to the performance assessment is the number of *degrees of freedom* of the measured data. Typically, the number of degrees of freedom is found by subtracting 1 from the sample size [10]. Thus, for the ensemble of the difference data reported in Table 4, there are 28 degrees of freedom. The difference data will have 16 degrees of freedom for the vertical tank and 11 degrees of freedom for the horizontal tank.

For 30 or more degrees of freedom, a normal population distribution is usually assumed. For this evaluation, with 28 and fewer degrees of freedom, the Student's *t*-distribution (Appendix B) will be used to make the probability estimates. This analysis approach follows the EPA's standard test procedures for evaluating tank gauges, as described below.

There are three parameters needed for making the performance estimates: the *bias* of the data, the *standard deviation* of the data, and the *t*-statistic for zero bias. The bias is the average difference between the method-measured and the actual leak rates, and is given by

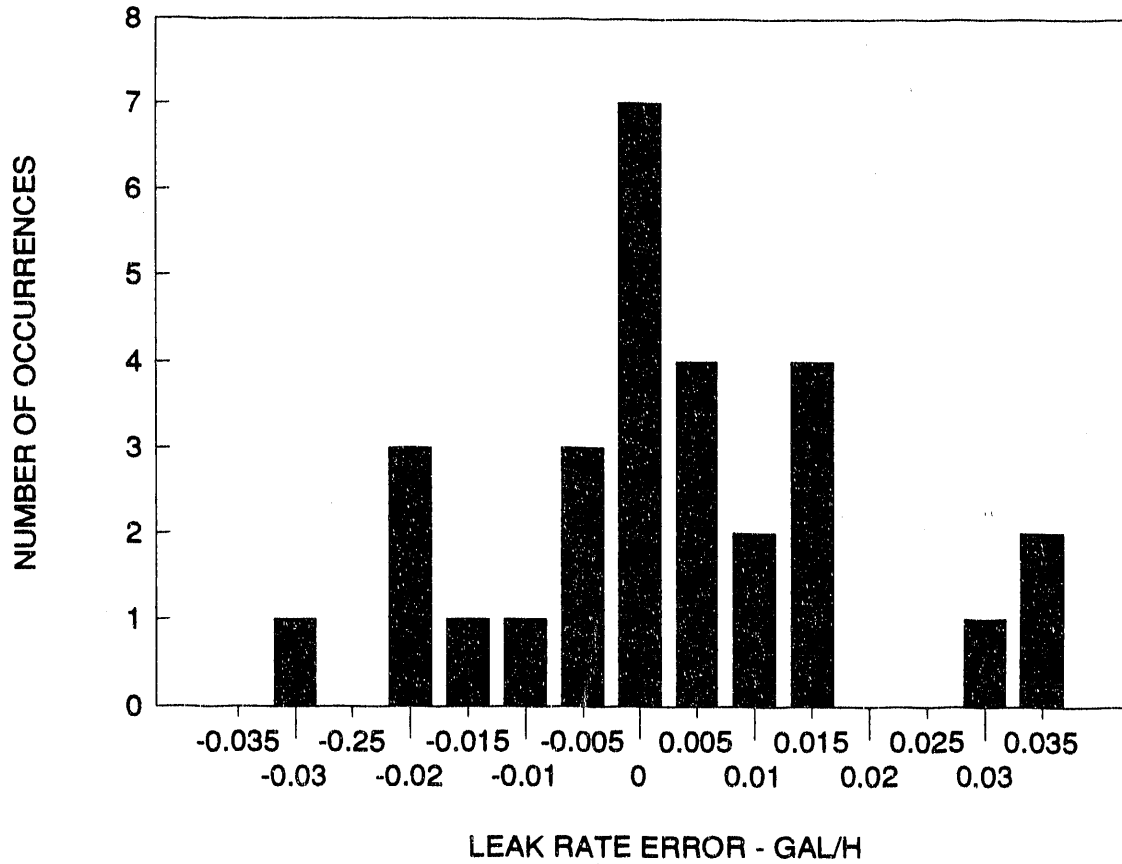


Figure 18. Histogram of leak rate (i.e., noise) produced by ORNL/LT-823DP (29 test runs).

$$B = \sum_{i=1}^N \Delta E_i / N,$$

where N is the number of tests run, and ΔE_i is the difference between the measured and actual leak rates.

The standard deviation of the data is a measure of the precision of the measurement, and is given by

$$SD = \left(\frac{1}{N-1} \sum_{i=1}^N (\Delta E_i - B)^2 \right)^{1/2}$$

The t-statistic is a measure of the accuracy of the measurement, and is given by

$$t_B = N^{1/2} \cdot B / SD.$$

Table 5 lists the bias, standard deviation, and t-statistic of the data for the ensemble of differences, and for the individual tanks. It can be shown that the bias of each of the three data sets is not statistically different from zero at a level of significance of 5%.

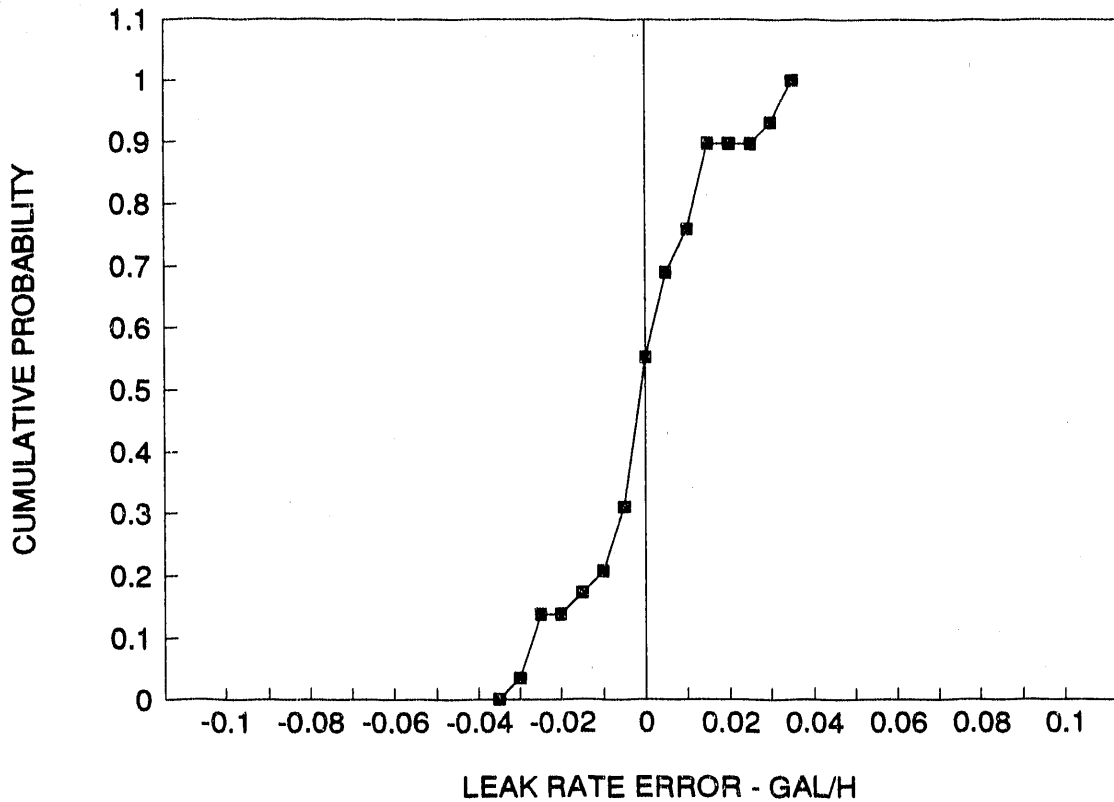


Figure 19. Cumulative probability distribution of noise produced by ORNL/LT-823DP.

Table 5. Bias and Standard Deviation Data from Evaluation of ORNL/LT-823DP

Data Set	No. Runs (h)	No. Degrees of Freedom	Bias	Standard Deviation	t_b
Ensemble	29	28	0.00002	0.01631	0.0066
Vertical tank	17	16	0.00219	0.01228	0.7353
Horizontal tank	12	11	-0.00305	0.02032	0.5199

Using the Student's t-distribution to approximate the data shown in Figure 18, together with the data in Table 5 above, the predicted false alarm rate of the ORNL/LT-823DP method can be estimated, along with the probability of detection of a 0.20-gal/h leak.

For the data reported above, the probability of false alarm can be estimated by calculating the t-statistic,

$$t_1 = T/SD,$$

for each of the configurations, where T is the detection threshold, 0.1 gal/h. This is shown in Table 6. P_{FA} can be obtained from t_1 , by entering the Student's t-distribution table with the value of t_1 at the number of degrees of freedom, and then looking up the value of the area, A.

Table 6. P_D and P_{FA} in the Evaluation of the ORNL/LT-823DP

	df	T_1	P_{FA}	P_D
Ensemble	28	6.132	<<0.005	>>0.995
Vertical tank	16	8.143	<<0.005	>>0.995
Horizontal tank	11	4.921	<0.005	>0.995

The probability of detecting a leak of 0.20 gal/h is the probability that the measured volume rate exceeds the threshold, T , when the actual leak is 0.2 gal/h. For the data above, P_D can be estimated by calculating the t-statistic,

$$t_3 = (0.20 - T)/SD,$$

and calculating the probability from the Student's t-distribution as was done above for P_{FA} . The calculated values for P_D for the ensemble and individual tank configurations are given in Table 6.

5.4 Performance of ORNL/LT-823DP Extrapolated to Larger LLLW Tanks

In general, the performance of a leak detection method will improve as the capacity of the tank decreases and will diminish as the capacity increases. When testing petroleum tanks, this difference in performance is associated mainly with the errors in measuring the average rate of temperature change in the tank. Since the evaluation testing shows that the performance of the ORNL/LT-823DP method far exceeds the minimum regulatory requirements when used in a 1,000-gal tank, it follows that the method can be used in a tank larger than 1,000-gal and still meet the minimum performance standards. The EPA's standard test procedures allow the use of a method in tanks that are up to 50% larger than the tank used during the evaluation of that method. This criterion is arbitrary because it does not take into account the performance achieved by the system during the evaluation, or the factors that degrade performance in a larger tank.

Sufficient data were collected during the evaluation of the ORNL/LT-823DP method to physically understand the sources of noise that control the testing, and to extrapolate the performance of the method to larger tanks. No attempt will be made here to determine the maximum tank size that can be tested with the ORNL/LT-823DP; rather, the data will be used to show that the method can be reliably used to test tanks up to 3,000 gal in capacity.

The total noise of a method can be expressed in terms of the sum of the squares of the standard deviation of the individual sources as

$$S_{TN}^2 = S_1^2 + S_2^2 + S_3^2 + \dots,$$

where S_i denotes the standard deviation of the noise source. Contributors to the total noise include the sensor's output current variations, power supply fluctuations, digital sampling noise, and the effect of the bubbles. Also included is the noise associated with variations in the influence coefficient (caused by fluctuations in the sensor body temperature),

temperature-induced volume fluctuations in the process liquid, evaporation and condensation, deformation effects, variations in reference pressure, and line pressure variations caused by variations in the flow rate through the rotameter.

In estimating the performance of the ORNL/LT-823DP method in tanks up to 3,000 gal in capacity, noise from many of the identified sources can be neglected because (1) it may represent only a small contribution; (2) it may have more than sufficient time to decay during the 4- to 12-h waiting period; (3) it may be averaged out over the duration of the 24-h test; or (4) it may be independent of tank size. In this case, the performance of the ORNL/LT-823DP system is mainly controlled by the precision of the sensor and the uncertainty in estimating the mean influence coefficient. A potential source of noise, one that will become important for horizontal tanks that are much larger than 3,000 gal, is the means by which the sensor inherently compensates for temperature, as discussed in Section 4.2. Calculations (not included here) show that the errors associated with this noise source are negligible for tanks as small as 3,000 gal.

The effects of variations in influence coefficient and sensor precision can be estimated from the evaluation. Since these factors are independent of tank capacity, orientation, and geometry, worst-case estimates of the variation in these quantities can be used together with the tank factors (capacity, orientation, geometry) to make an estimate of how well the method, evaluated in a 1,000-gal tank, would work in a 3,000-gal tank.

As described above (Table 2), the precision of the system is about 0.0032 in. Furthermore, analysis showed that the maximum uncertainty in the influence coefficient was about 0.003 in./°C, with an estimated standard deviation of approximately 0.001 in./°C. These errors can be converted to volume from the volume-to-height conversion factor, which can in turn be determined from the tank strapping tables [7,8]. The magnitude of both of these noise sources depends mainly on the duration of the test; the magnitude of the fluctuations in the influence coefficient also depends upon the difference between the air temperature at the beginning and end of the test.

Tables 7 and 8 give estimates, for a 24-h test duration in 1,000- and 3,000-gal horizontal and vertical tanks, of the magnitude of the contributing system and ambient noise due to the precision of the sensor and the uncertainty in the influence coefficient. The nominal diameter of the 1,000-gal tank was 64 in., and the nominal diameter of the 3,000-gal tank was 84 in. Table 7 shows the tank capacity, tank diameter, volume-to-height conversion, the system noise expressed in inches and gallons, and the magnitude of the noise expressed as a volume rate over the test duration, and for a two-point measurement. For a worst-case estimate, Table 7 shows that the system noise term increases from about 0.0045 to about 0.0085 gal/h in going from a half-filled 1,000-gal horizontal tank to a half-filled 3,000-gal horizontal tank. That is, the error due to sensor precision in the ORNL/LT-823DP method is less than 0.01 gal/h as tank size increases from 1,000 to 3,000 gal.

The magnitude of the noise due to the maximum uncertainty in the influence coefficient, expressed in gallons per hour, is presented in Table 8 for several differences in air temperature between the beginning and end of a test. This table shows that, for a 10°F temperature

difference, the maximum expected fluctuation in influence coefficient would be about 0.0316 gal/h in a 3,000-gal horizontal tank, compared to about 0.0167 gal/h in a 1,000-gal horizontal tank.

Table 5 showed that the standard deviation of the actual-minus-measured leak rate for the ensemble of the evaluation tests was about 0.016 gal/h. Using the equation for total noise shown above, and inserting the *differences between the 1,000-gal and 3,000-gal values for the noise terms*, shows that the standard deviation of the noise is expected to increase by about 0.014 gal/h to about 0.030 gal/h when the ORNL/LT-823DP method is used in the 3,000-gal LLLW tanks. If the value of 0.030 gal/h is used, and the P_D and P_{FA} of the method are calculated as described in Section 5.3 above, the extrapolation shows that the ORNL/LT-823DP method will detect a 0.2-gal/h leak with a P_D greater than 99.5% and a P_{FA} less than 0.05%. These results show that the performance of the method meets the regulatory requirements and that it can thus be used at ORNL to leak test LLLW tanks with capacities up to and including 3,000 gal.

Table 7. Precision Error in Tanks with Capacities of 1,000 and 3,000 Gal Installed Vertically and Horizontally (The duration of the leak detection test is 24 h.)

Orientation	Capacity (gal)	Diameter (in.)	V/H (gal/in.)	Precision (in.)	Volume Error (gal)	Volume Error (gal/h)	Two-Point Error (gal/h)
Vertical	1,000	64	13.926	0.0032	0.0446	0.0019	0.0026
Vertical	3,000	84	23.990	0.0032	0.0767	0.0032	0.0045
Horizontal	1,000	64	19.894	0.0032	0.0637	0.0027	0.0038
Horizontal	3,000	84	45.473	0.0032	0.1455	0.0061	0.0085

Table 8. Estimate of the Maximum Influence Coefficient Error in Tanks with Capacities of 1,000 and 3,000 Gal Installed Vertically and Horizontally (The duration of the leak detection test is 24 h.)

Orientation	Capacity (gal)	Diameter (in.)	V/H (gal/in.)	Maximum Error Due to Influence Coefficient as a Function of Temperature Difference			
				(in./°C)	(gal/h/1°F)	(gal/h/5°F)	(gal/h/10°F)
Vertical	1,000	64	13.926	0.001	0.00097	0.0048	0.0097
Vertical	3,000	84	23.990	0.001	0.0017	0.0083	0.0167
Horizontal	1,000	64	19.894	0.001	0.0014	0.0069	0.0138
Horizontal	3,000	84	45.473	0.001	0.0032	0.0158	0.0316

6 CONCLUSIONS AND RECOMMENDATIONS

A performance evaluation of the ORNL/LT-823DP leak detection method was carried out over the period from 30 September 1991 to 5 November 1991. The evaluation was conducted using both vertical and horizontal tanks at the Liquid Low-Level Waste Simulator located at EPA's Underground Storage Tank Test Apparatus in Edison, New Jersey. The evaluation was based upon an analysis of data from 29 tests. During these tests, tap water was used to simulate the liquid waste product in the ORNL tanks. Levels ranged from about 50% of tank height to about 70%, with temperature conditions ranging from -15°F to about +12°F, and leak rates consisting of 0.0, 0.1, 0.2, and 0.3 gal/h.

The EPA's performance standards require that a monthly monitoring method be able to detect a leak of 0.2 gal/h with a P_D of not less than 95% and a P_{FA} of not more than 5%. Analysis of the data from the 29 leak tests in this evaluation, using a threshold of 0.1 gal/h, showed that this method has a P_{FA} of much less than 0.5%. The corresponding P_D of a 0.20-gal/h leak is much greater than 99.5%. The results of the evaluation show that the performance of the ORNL/LT-823DP method meets the EPA's performance standards for a monthly monitoring device.

The ORNL/LT-823DP is an automatic system designed to perform a monthly monitoring test. The performance evaluation followed the procedures established by the EPA for an automatic tank gauge, a monthly monitoring method. As noted in the text, some minor modifications to EPA's standard test procedures were made, in order to realistically reflect the manner in which the LLLW tanks are used at ORNL.

During the evaluation period, two Foxboro 823DP differential pressure cells were used to measure changes in level in the LLLWSIM tanks. It was determined that each of the DP cells had a slightly different influence coefficient (the factor that relates the change in measured level to the change in temperature). The sensor used in the vertical tank had an influence coefficient of 0.011 in./°C, while the sensor used in the horizontal tank had an influence coefficient of 0.017 in./°C. While some effort was expended to attempt to correlate the influence coefficient with other known parameters of the 823DP, no such correlation was found. Since the influence coefficient is used to compensate the raw level readings from the sensor for the temperature of the DP cell, and since it does not appear to be a deterministic quantity, it is recommended that the influence coefficient be determined for each DP cell used as part of the ORNL/LT-823DP method.

An initial database of results of all product-level monitoring tests should be gathered over a period of at least 12 months. This database will establish a baseline of the expected annual variation in test results, and will be used to more closely examine the performance of the system used on each tank under field conditions.

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Appendix A

EVALUATION DOCUMENTS (EPA FORMS)

Results of U.S. EPA Standard Evaluation Automatic Tank Gauging System (ATGS)

This form tells whether the automatic tank gauging system (ATGS) described below complies with the performance requirements of the federal underground storage tank regulation. The evaluation was conducted by the equipment manufacturer or a consultant to the manufacturer according to the U.S. EPA's "Standard Test Procedure for Evaluating Leak Detection Methods: Automatic Tank Gauging Systems." The full evaluation report also includes a form describing the method and a form summarizing the test data.

Tank owners using this leak detection system should keep this form on file to prove compliance with the federal regulations. Tank owners should check with State and local agencies to make sure this form satisfies their requirements.

ATGS Description

Name ORNL Differential Pressure Leak Testing Method for Liquid Low-Level Waste Tanks

Version number Model: ORNL/LT-823DP Version: November 1991

VENDOR Oak Ridge National Laboratory

(street address)

<u>Oak Ridge</u>	<u>Tennessee</u>	<u>37831</u>	<u>(615) 574-3121</u>
(city)	(state)	(zip)	(phone)

Evaluation Results

This ATGS, which declares a tank to be leaking when the measured leak rate exceeds the threshold of 0.1 gallon per hour, has a probability of false alarms [P(FA)] of <<0.1 %.

The corresponding probability of detection [P(D)] of a 0.20 gallon per hour leak is >>99.9%.

The minimum water level (threshold) in the tank that the ATGS can detect is N/A inches.

The minimum change in water level that can be detected by the ATGS is N/A inches (provided that the water level is above the threshold).

Therefore, this ATGS does does not meet the federal performance standards established by the U.S. Environmental Protection Agency (0.20 gallon per hour at P(D) of 95% and P(FA) of 5%), and this ATGS does does not meet the federal performance standard of measuring water in the bottom of the tank to the nearest 1/8 inch.

Water Bottom Standard N/A

Test Conditions During Evaluation

The evaluation testing was conducted in a 1,000 gallon steel fiberglass tank that was 64 inches in diameter and 72 inches long, vertical and Horizontal Tank

The temperature difference between product added to fill the tank and product already in the tank ranged from + 12 °F to -15 °F, with a standard deviation of 7.28 °F.

The tests were conducted with the tank product levels 50% and 70 % full.

The product used in the evaluation was tap water (To simulate LLLW liquid was

Limitations on the Results

The performance estimates above are only valid when:

- The method has not been substantially changed.
- The vendor's instructions for installing and operating the ATGS are followed.
- The tank contains a product identified on the method description form.
- The tank is no larger than 3,000 gallons.
- The tank is at least 10 percent full. (Sufficient to cover end of bubble tube)
- The waiting time after adding any substantial amount of product to the tank is 12 hours. (Nominal; reduced waiting time for small tanks)
- The temperature of the added product does not differ more than 15 degrees Fahrenheit from that already in the tank. (11.1° per test procedure but is for large volumes)
- The total data collection time for the test is at least 24 hours. (nominal; reduced data collection time for small tanks)
- Other limitations specified by the vendor or determined during testing:
 - a) Temperature sensor measures DP cell body temperature

> Safety disclaimer: This test procedure only addresses the issue of the ATG system's ability to detect leaks. It does not test the equipment for safety hazards.

Certification of Results

I certify that the ATGS was installed and operated according to the vendor's instructions and that the results presented on this form are those obtained during the evaluation. I also certify that the evaluation was performed according to one of the following:

- standard EPA test procedure for ATGS
- alternative EPA test procedure for ATGS

Dennis G. Douglas
(printed name)


(signature)

13 November 1991
(date)

Vista Research, Inc.
(organization performing evaluation)

Mountain View, CA 94041
(city, state, zip)

(415) 966-1171
(phone number)

Description
Automatic Tank Gauging System

This section describes briefly the important aspects of the automatic tank gauging system (ATGS). It is not intended to provide a thorough description of the principles behind the system or how the equipment works.

ATGS Name and Version

ORNL Differential Pressure Leak Testing Method for Liquid-Low Level Waste Tanks

Version: November 1991

Product

> Product type

For what products can this ATGS be used? (check all applicable)

- gasoline
 - diesel
 - aviation fuel
 - fuel oil #4
 - fuel oil #6
 - solvents
 - waste oil
 - other (list) Liquid Low-Level Wastes
-

> Product level

What product level is required to conduct a test?

- greater than 90% full
 - greater than 50% full
 - other (specify) LLW Level above bottom of bubble tube
-

Does the ATGS measure inflow of water as well as loss of product (gallon per hour)?

- yes
- no

Does the ATGS detect the presence of water in the bottom of the tank?

- yes
- no LLW materials are aqueous, fully miscible with water bottom

Level Measurement

What technique is used to measure changes in product volume?

- directly measure the volume of product change
 - changes in head pressure
 - changes in buoyancy of a probe
 - mechanical level measure (e.g., ruler, dipstick)
 - changes in capacitance
 - ultrasonic
 - change in level of float (specify principle, e.g., capacitance, magnetostrictive, load cell, etc.) _____
 - other (describe briefly) _____
-

Temperature Measurement

If product temperature is measured during a test, how many temperature sensors are used?

- single sensor, without circulation
- single sensor, with circulation
- 2-4 sensors
- 5 or more sensors
- temperature-averaging probe

If product temperature is measured during a test, what type of temperature sensor is used?

- resistance temperature detector (RTD)
- bimetallic strip
- quartz crystal
- thermistor
- other (describe briefly) _____

If product temperature is not measured during a test, why not?

- the factor measured for change in level/volume is independent of temperature (e.g., mass)
- the factor measured for change in level/volume self-compensates for changes in temperature
- other (explain briefly) _____

Data Acquisition

How are the test data acquired and recorded?

- manually
- by strip chart
- by computer

Procedure Information**> Waiting times**

What is the minimum waiting period between adding a large volume of product (i.e., a delivery) and the beginning of a test (e.g., filling from 50% to 70% capacity)?

- no waiting period 12-hr waiting period for LLLW tanks with volume capacity between 500 gal & 3,000 gal:
- less than 3 hours
- 3-6 hours 2- to 4-hr waiting period for tanks with volume capacity less than 500 gal. (see leak testing plan*)
- 7-12 hours
- more than 12 hours
- variable, depending on tank size, amount added, operator discretion, etc.

> Test duration

What is the minimum time for collecting data?

- less than 1 hour 24-hr data collection period for tanks with volume capacity greater than 500 gal; 12-hr data collection period for tanks between 50 and 500 gal; 2-hr period for tanks < 50 gal. (see leak testing plan)*
- 1 hour
- 2 hours
- 3 hours
- 4 hours
- 5-10 hours
- more than 10 hours
- variable (explain) depends upon tank size

> Total time

What is the total time needed to test with this ATGS after a delivery?

(waiting time plus testing time) 4 hrs for smallest tank, single test
36 hrs for larger tanks, single test

_____ hours _____ minutes

* D. G. Douglas, J. W. Maresca, "Leak Testing Plan for the Oak Ridge National Laboratory Liquid Low-Level Waste System (Active Tanks)", Final Report, Volumes I and II, Report No. 2050-91-FR-001, MMES Purchase Order No. 41X-SH130 Vista Research, Inc., Mountain View, CA 94042 (September/October 1991).

What is the sampling frequency for the level and temperature measurements?

- more than once per second
- at least once per minute
- every 1-15 minutes
- every 16-30 minutes
- every 31-60 minutes
- less than once per hour
- variable (explain) _____

> Identifying and correcting for interfering factors

How does the ATGS determine the presence and level of the ground water above the bottom of the tank?

- observation well near tank N/A
- information from USGS, etc.
- information from personnel on-site
- presence of water in the tank
- other (describe briefly) _____
- level of ground water above bottom of the tank not determined

How does the ATGS correct for the interference due to the presence of ground water above the bottom of the tank?

- system tests for water incursion N/A
- different product levels tested and leak rates compared
- other (describe briefly) _____
- no action

How does the ATGS determine when tank deformation has stopped following delivery of product?

- wait a specified period of time before beginning test
- watch the data trends and begin test when decrease in product level has stopped
- other (describe briefly) _____
- no procedure

Are the temperature and level sensors calibrated before each test?

- yes
- no

If not, how frequently are the sensors calibrated?

- weekly
- monthly
- yearly or less frequently
- never

> Interpreting test results

How are level changes converted to volume changes (i.e., how is height-to-volume conversion factor determined)?

- actual level changes observed when known volume is added or removed (e.g., liquid, metal bar)
- theoretical ratio calculated from tank geometry
- interpolation from tank manufacturer's chart depending upon specific tank configuration
- other (describe briefly) _____
- not applicable; volume measured directly

How is the coefficient of thermal expansion (C_e) of the product determined?

- actual sample taken for each test and C_e determined from specific gravity
- value supplied by vendor of product
- average value for type of product
- other (describe briefly) _____

How is the leak rate (gallon per hour) calculated?

- average of subsets of all data collected
- difference between first and last data collected
- from data from last _____ hours of test period
- from data determined to be valid by statistical analysis
- other (describe briefly) _____

What threshold value for product volume change (gallon per hour) is used to declare that a tank is leaking?

- 0.05 gallon per hour
- 0.10 gallon per hour
- 0.20 gallon per hour
- other (list) _____

Under what conditions are test results considered inconclusive?

- too much variability in the data (standard deviation beyond a given value)
- unexplained product volume increase
- other (describe briefly) _____

Exceptions

Are there any conditions under which a test should not be conducted?

- water in the excavation zone
- large difference between ground temperature and delivered product temperature
- extremely high or low ambient temperature
- invalid for some products (specify) _____
- other (describe briefly) During periods of rainfall, if rain is known to affect tank volume.

What are acceptable deviations from the standard testing protocol?

- none
- lengthen the duration of test
- other (describe briefly) _____

What elements of the test procedure are determined by personnel on-site?

- product level when test is conducted
- when to conduct test (monthly schedule)
- waiting period between filling tank and beginning test (tank dependent--see leak testing plans for specific values)
- length of test (tank dependent--see leak testing plan for specific values)
- determination that tank deformation has subsided
- determination of "outlier" data that may be discarded
- other (describe briefly) _____
- none

Reporting Form for Leak Rate Data
ORNL Volumetric Tank Gauge Method

Method Name and Version: ORNL/LT-823 DP Version: November 1991

Evaluation Period: from 30 Sept. 91 to 5 Nov. 91 (Dates)

Tank: 1,000-gal vertical

Test No.	Date/Time of Addition/Withdrawal (mm/dd/YY hr:mm)	Quantity (gal)	Temp. Condition (°F)	Date/Time of Start of Test (mm/dd/YY hr:mm)	Date/Time of End of Test (mm/dd/YY hr:mm)	Planned Leak Rate (g/h)	Actual Leak Rate (g/h)	Measured Leak Rate (g/h)	Meas.-Actual Leak Rate (g/h)
1	10/02/91 0734	+10	0	9/30 2052	10/01 2052	0.0	0.0	-0.00025	-0.00025
2	10/04/91 0730	+10	+5	10/02 1134	10/03 1134	0.0	0.0	-0.00026	-0.00026
3	10/05/91 1530	0	0	10/04 1130	10/05 1130	0.0	0.0	-0.0004	-0.0004
4	10/07/91 0657	+10	+10	10/05 1530	10/06 1530	-0.2	-0.162	-0.1726	-0.0046
5	10/08/91 1127	+10	-5	10/07 1100	10/08 1100	-0.2	-0.230	-0.226	10.0040
6	10/10/91 1400	+10	+5	10/08 1530	10/09 1530	-0.3	-0.302	-0.268	10.034
7	10/11/91 1800	0	0	10/10 1800	10/11 1800	0.0	0.0	-0.0016	-0.0016
8	10/14/91 0830	+10	+5	10/11 1800	10/12 1800	0.0	0.0	10.0039	10.0039
9	10/16/91 0730	+200	-5	10/14 1230	10/15 1230	0.0	0.0	10.0058	10.0058
10	10/18/91 1401	+10	+10	10/16 2000	10/17 2000	0.0	0.0	-0.0058	-0.0058
11	10/19/91 1817	+10	-13	10/18 1800	10/19 1800	0.0	0.0	10.011	10.011
12	10/21/91 0739	+10	+10	10/19 2220	10/21 0654	-0.1	-0.091	-0.1008	-0.0098
13	10/22/91 1154	0	0	10/21 1140	10/22 1140	-0.1	-0.073	-0.1008	-0.00278
14	10/28/91 1109	+5	+12	10/22 1154	10/23 1140	0.0	0.0	10.0123	10.0123
15	10/30/91 1147	+10	-6	10/28 1511	10/29 1508	0.0	0.0	10.014	10.014
16	11/01/91 0730	+200	+7	10/30 1550	10/31 1550	0.0	0.0	10.005	10.005
17	11/04/91 0710	+10	-8	11/01 2000	11/02 2000	0.0	0.0	-0.0022	-0.0022
18				11/04 1142	11/05 1142				
19									
20									
21									
22									
23									
24									

Reporting Form for Leak Rate Data ORNL Volumetric Tank Gauge Method

Method Name and Version: ORNL/LT-823DP Version: November 1991

Tank: 1,000-gal horizontal

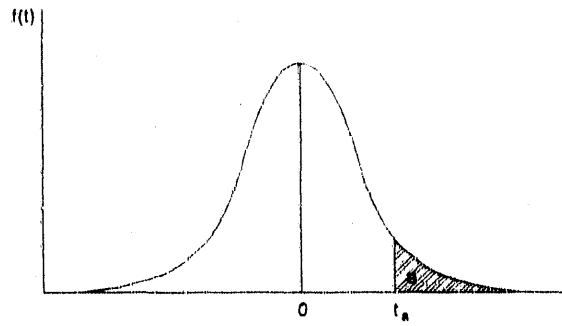
Evaluation Period: from 30 Sept '91 to 5 Nov '91 (Dates)

Test No.	Date/Time of Addition/Withdrawal (mm/dd/yy hh:mm)	Quantity (gal)	Temp. Condition (°F)	Date/Time of Start of Test (mm/dd/yy hh:mm)	Date/Time of End of Test (mm/dd/yy hh:mm)	Planned Leak Rate (g/h)	Actual Leak Rate (g/h)	Measured Leak Rate (g/h)	Meas.-Actual Leak Rate (g/h)
1	10/10/91 1353	+10	+5	10/10 1800	10/11 1800	0.0	0.0	-0.010	-0.010
2	10/11/91 1800	0	0	10/11 1800	10/12 1800	0.0	0.0	+0.0045	+0.0045
3	10/14/91 0835	+10	+5	10/14 1230	10/15 1230	-0.3	-0.307	-0.276	+0.031
4	10/16/91 0750	+200	-5	10/16 2000	10/17 2000	-0.3	-0.287	-0.278	+0.009
5	10/18/91 1359	+10	+7	10/18 1800	10/19 1800	-0.1	-0.060	-0.047	+0.013
6	10/19/91 1815	+10	-15	10/19 2220	10/21 0654	-0.1	-0.089	-0.061	+0.028
7	10/21/91 0740	+10	+7	10/21 1140	10/22 1140	0.0	0.0	-0.0349	-0.0349
8	10/22/91 1154	0	0	10/22 1154	10/23 1140	0.0	0.0	-0.0153	-0.0153
9	10/28/91 1114	+5	+9	10/28 1516	10/29 1508	-0.2	-0.162	-0.190	-0.028
10	10/30/91 1149	+10	-7	10/30 1550	10/31 1550	-0.2	-0.194	-0.220	-0.026
11	11/01/91 0755	+200	+5	11/01 2000	11/02 2000	-0.1	-0.060	-0.062	-0.002
12	11/04/91 0735	+10	-8	11/04 1142	11/05 1142	-0.1	-0.125	-0.131	-0.006
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24									

Appendix B

STUDENT'S t -DISTRIBUTION

Student's t-Distribution



df	$\alpha = 10$	$\alpha = .05$	$\alpha = .025$	$\alpha = .010$	$\alpha = .005$
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.333	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
30	1.310	1.697	2.042	2.457	2.750
40	1.303	1.684	2.021	2.423	2.704
60	1.296	1.671	2.000	2.390	2.660
120	1.289	1.658	1.980	2.358	2.617
∞	1.282	1.645	1.960	2.326	2.576

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9 / 25 / 92

