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Standard Guide for Investigation of the Source and Cause of Releases from Underground Storage Tank Systems[1]

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INTRODUCTION

This guide provides a framework for the development of procedures and directions for the investigation of underground storage tank (UST) equipment problems and the source and cause of releases. Source and cause investigations are similar to origin and cause investigations in property insurance claims. It gives the user practical suggestions of how to investigate equipment and installation problems, document findings, collect and preserve failed equipment for forensic evaluation or laboratory analysis if necessary, and implement visual and analytical processes to document the source of a release. Use of this guide may result in the identification of equipment and installation problems that can be corrected in future tank system designs and equipment maintenance programs to prevent releases to the environment. Use of this guide may assist regulatory agencies to determine and document the source and cause of releases from UST systems.

1. Scope

1.1 *Overview*—This guide is an organized collection of information and series of options for industry, regulators, consultants and the public, intended to assist with the development of investigation protocols for underground storage tank facilities in the United States. While the guide does not recommend a specific course of action, it establishes an investigation framework, and it provides a series of techniques that may be employed to: identify equipment problems; in some cases collect and preserve failed equipment for forensic evaluation or laboratory analysis; identify the source of a release; and document the investigation. The guide includes information on methods of investigation, documentation, collecting and preserving samples; chain of custody; storage; shipping; working with equipment manufacturers; and notification of regulators and listing laboratories. The goal in using the guide is to identify the appropriate level of investigation and to gather and preserve information, in an organized manner, which could be used in the future to improve system design or performance. While this guide may act as a starting point for users with limited experience in failure investigation, the user is encouraged to consult with failure analysis experts for specific investigation procedures that may be needed for certain equipment and the investigation should be conducted by a qualified professional. As users develop their specific investigation protocols, they may find that the investigations can be streamlined for certain types of facilities.

1.2 *Limitations of This Guide:*

1.2.1 Given the variability of the different investigators that may wish to use this guide and the different types of facilities and failures that will be investigated, it is not possible to address all the relevant standards that might apply to a particular investigation. This guide uses generalized language and examples to guide the user. If it is not clear to the user how to apply standards to their specific circumstances, it is recommended that users seek assistance from qualified professionals.

1.2.2 This guide does not address safety issues associated with the investigation, taking samples and storing equipment. Users are cautioned to exercise proper care in handling equipment that was in contact with flammable and combustible liquids and vapors. Some of the activities described in this guide may be subject to OSHA (Occupational Safety and Health Administration) regulations or may only be conducted by individuals with appropriate HAZWOPER (Hazardous Waste Operations and Emergency Response) training certifications recognized by federal and state regulatory authorities, such as HAZWOPER training.

1.2.3 This guide does not address laboratory investigations of material properties and detailed failure analysis.

1.2.4 This guide does not cover underground storage tank systems storing liquefied petroleum gas (LPG).

[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.01 on Storage Tanks.

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1.2.5 This guide does not replace state-required closure assessments and investigations. Requirements vary from state to state and often include specific sampling requirements. The user should comply with the requirement of the authority having jurisdiction.

1.2.6 Prior to implementing the steps described in Section 5, users of this guide must determine if the authority having jurisdiction has any qualification requirements for the individual performing the investigation.

1.2.7 Investigations addressed by this guide may involve knowledge, skills, and abilities generally attributed to individuals certified as tank systems installers, inspectors, or removers, or those who are trained in soil and groundwater sampling protocols (for example, geologists, groundwater professionals, or engineers).

1.3 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1188 Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator

E1990 Guide for Performing Evaluations of Underground Storage Tank Systems for Operational Conformance with 40 CFR, Part 280 Regulations

E2681 Guide for Environmental Management of Underground Storage Tank Systems Storing Regulated Substances

F1127 Guide for Containment of Hazardous Material Spills by Emergency Response Personnel

2.2 *Other Standards:*

STD 2015 Requirements for Safe Entry and Cleaning of Petroleum Storage Tanks, 6th Edition—August 2001[3]

RP 2016 Guidelines and Procedures for Entering and Cleaning Petroleum Storage Tanks, 1st Edition—August 2001[3]

PEI/RP 100 Recommended Practices for Installation of Underground Liquid Petroleum Storage Systems[4]

PEI/RP 1700 Tank Closure and Removal[4]

NFPA 30 Flammable and Combustible Liquids Code[5]

2.3 *Federal Regulations:*[6]

§49 CFR §172 Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, and Training Requirements

§29 CFR §1910.146 Occupational Safety and Health Standards, Subpart J, General Environmental Controls, Permit-required Confined Spaces

3. Terminology

3.1 *Definitions:*

3.1.1 *compromised, adj*—a loss of structural integrity or diminished ability to perform as designed.

3.1.2 *equipment problems or problem equipment, n*—any failure, malfunction, compromised condition or other issue that has resulted in impairment, abnormal equipment condition or operation or that has resulted in a release or suspected release.

3.1.3 *free product, n*—a regulated substance that is present as a nonaqueous phase liquid (for example, liquid not dissolved in water).

3.1.4 *release, v*—any spilling, leaking, emitting, discharging, escaping, leaching or disposing from an UST into groundwater, surface water or subsurface soils.

3.1.5 *release prevention, n*—activities that reduce the risk of human and environmental exposure to petroleum or hazardous substances. In the United States, underground storage tank and toxic use reduction regulations are examples of such requirements.

3.1.6 *regulated substance, n*—Any substance defined in section 101(14) of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 (but not including any substance regulated as a hazardous waste under subtitle C); and Petroleum, including crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure (60 degrees Fahrenheit and 14.7 pounds per square inch absolute).

3.1.6.1 *Discussion*—The term regulated substance includes but is not limited to petroleum and petroleum-based substances comprised of a complex blend of hydrocarbons, such as motor fuels, jet fuels, distillate fuel oils, residual fuel oils, lubricants, petroleum solvents, and used oils.

3.1.7 *tightness test, n*—a procedure capable of detecting a 0.1 gallon per hour leak rate from any portion of the tank that routinely contains product while accounting for the effects of thermal expansion or contraction of the product, vapor pockets, tank deformation, evaporation or condensation, and the location of the water table.

3.1.7.1 *line tightness test, n*—A periodic test of piping that can detect a 0.1 gallon per hour leak rate at one and one-half times the operating pressure.

3.1.7.2 *tank tightness test*—includes a wide variety of test methods that must be able to detect a leak at least as small as 0.1 gallon per hour with certain probabilities of detection and of false alarm.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Petroleum Institute (API), 1220 L. St., NW, Washington, DC 20005-4070, http://www.api.org.

[4] Available from Petroleum Equipment Institute (PEI), P. O. Box 2380, Tulsa, OK 74101-2380, http://www.pei.org.

[5] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

[6] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

3.1.8 *underground storage tank, n*—a tank and any underground piping connected to the tank that has at least 10 % of its combined volume underground.

3.1.9 *waste*—discarded solid or liquid materials that may be hazardous to public health or the environment. Solid and hazardous waste require controls on handling, transport, storage treatment, and disposal.

4. Significance and Use

4.1 This guide may be used in the investigation of underground storage tank systems for equipment problems in a wide variety of applications. Use of this guide is voluntary. It is intended to assist users who want to investigate equipment failures, malfunctions, and other potential causes of suspected releases.

4.2 The following groups of users may find the guide particularly helpful:

4.2.1 Storage tank system designers and manufacturers;

4.2.2 Storage tank installers, testers, and inspectors;

4.2.3 Storage tank maintenance contractors;

4.2.4 Storage tank removal contractors;

4.2.5 Federal, state, tribal or local regulators, including departments of health, departments of environmental protection, and fire departments;

4.2.6 Petroleum release remediation professionals;

4.2.7 Insurance adjusters;

4.2.8 Storage tank owners and operators;

4.2.9 Consultants, auditors, and compliance assistance personnel.

4.3 This guide is intended to assist in the development of protocols for determination of source and cause of a release and the investigation of a malfunction or failure of any component of a UST system and the implementation of said protocols. This guide outlines steps that may be necessary and include, but are not limited to initial evaluation of the UST system to determine if there has been a component failure preparation of samples of failed or compromised equipment for laboratory analysis; visual; and analytical evaluation of release indications; and documentation of the investigation. The guide provides a series of investigation options from which the user may design failure investigation protocols. The guide describes common investigation techniques in the order in which they might be employed in an investigation.

4.4 A user may elect to utilize this guide for a number of reasons, which include, but are not limited to:

4.4.1 To differentiate new releases from new discovery of old releases;

4.4.2 To establish malfunction and failure rates of various UST system components;

4.4.3 To determine expected life spans of various UST components;

4.4.4 To identify opportunities for improving the performance and reliability of storage tank equipment;

4.4.5 To focus inspection and maintenance efforts on those component of the UST system that are most prone to compromise, malfunction and failure;

4.4.6 To identify those components of the UST system that require more frequent maintenance;

4.4.7 To reduce equipment replacement costs;

4.4.8 To prevent petroleum releases;

4.4.9 To identify those conditions that may cause or contribute to equipment or component compromise, deterioration or other cause of malfunction or failure of the UST system;

4.4.10 To comply with environmental regulations that require the investigation of suspected releases and determine the source and cause of releases; and

4.4.11 To identify conditions that may cause or contribute to nonsudden releases that may not be detected by other leak detection methods.

4.5 This guide may be used to establish a framework that pulls together the common approaches to investigation. The framework will allow the user to establish an investigation protocol to meet the user's specific requirements. Specific user requirements will vary depending upon the purposes of the data collection and the decisions that the investigation is intended to support. This guide does not provide methods to establish specific user investigation requirements nor does it establish minimum levels of documentation.

4.6 This guide will acquaint users with methods and tools that may be used in investigations of equipment problems associated with USTs. The user may include a subset of the methods described in this guide in their investigation. The user may consider a variety of factors in determining which combination of the methods to employ.

4.7 This guide is not intended to require the user to conduct a failure investigation.

4.8 This guide is focused on the identification, documentation, and preservation of compromised UST system equipment. It does not provide guidance on establishing root causes of compromise, malfunction or failure. The identification of root causes of compromise, malfunction or failure may require further expert analysis of the data and equipment collected during the failure investigation.

4.9 Determination of equipment failures and evidence of the source and cause of a release are often unavailable due to the loss of critical information necessary to pinpoint equipment failures and conduct an investigation. Adjustment, repair or removal of failed equipment before determining and documenting the cause of the failure may interfere with the failure investigation. Failures may be caused by compatibility issues, manufacturer defects, corrosion, degradation, improper installation, damage, age, misuse, use or other causes. This guide may be used to identify techniques and procedures applicable to maintenance personnel and equipment vendors that will allow an investigator to evaluate possible equipment failures before equipment is adjusted, repaired, replaced or destroyed.

4.10 This guide does not address all the safety measures that must be taken when removing and disassembling UST systems. Because most UST systems have contained flammable or combustible liquids special precautions should be taken to prevent fire, explosions and exposure to toxic vapors. API standard STD 2015 and RP 2016 address some of the safety considerations as do many of the procedures available from fire departments.

5. Elements of Failure Investigation

5.1 *Failure Investigation Process*—The manner of discovering equipment problems or evidence of a release may influence the investigation methods employed. The qualifications of the investigator may depend upon whether the investigation occurs while the system is still operational or during system closure. Investigator qualifications are addressed in 5.18.

5.1.1 For all investigations, knowledge of the tank system obtained through review of 5.2 *General Records* is recommended. Knowledge of the age, material, and construction of the system prior to investigation will allow for a more focused investigation by an appropriately qualified investigator.

5.1.2 *Suspected Releases from Operational Systems.* If there is an indication of a release from unusual operating concerns such as inventory loss, failed or inconclusive leak detection or tightness tests, or receptor impacts, the user may select failure investigation methods that initially rely on records reviews and non-destructive tests identified in 5.3 *Release Detection Records,* and 5.4 *Release Preventions Records*. See Fig. 1.

5.1.2.1 . If release detection records are inconclusive or indicate a the release has occurred, 5.6.4 *tightness testing* may identify a tank or piping run as the source.

5.1.2.2 If tightness tests do not confirm a release, proceed with the inspection techniques of 5.5 and 5.6.

5.1.2.3 If a tank or piping run fails leak detection or a tightness test, the system should be shut down and the investigator should proceed with the investigation techniques of 5.7 and 5.8.

5.1.2.4 If release detection records and release prevention records do not indicate a release, proceed with the inspection techniques of 5.5 and 5.6.

5.1.2.5 If there is an indication of a release based upon a visually identified equipment leak or damaged component, proceed with the investigation techniques of 5.5 and 5.6. While continuous operation or return to normal operation may be a priority when an equipment problem is suspected, any condition that may be the source of a release should be investigated with the potential equipment failure fully documented before any equipment is adjusted, repaired or removed. If a release is suspected, maintenance personnel or service companies should not be allowed to adjust, repair or remove failed equipment without approval from the investigator.

5.1.3 *System closure.* Many releases discovered during system closure are the result of nonsudden releases which may not be identified by leak detection records, release prevention records or other investigative techniques. Tank and piping closures result in the discovery of a significant number of previously unidentified releases. Investigators should be prepared to conduct suspected release investigations during closure activities. Advance review of records identified in 5.5, 5.6 and 5.7 will prepare the investigator for possible indications of a release during closure activities. If a release is suspected during tank or piping closure, some equipment tests may not be possible, and the user may choose other visual examination techniques identified in 5.7.

5.1.3.1 If there is an indication of a release, the investigation techniques of 5.8 may be applicable.

5.1.3.2 If the review of records in 5.5 and 5.6 do not provide indications of a release, the user may choose to employ visual examination techniques in 5.7 and field screening techniques from 5.8 to determine if there are indications of soil or groundwater (if encountered) contamination associated with specific components of the tank system. If closure sampling requirements of the authority having jurisdiction do not indicate a release has occurred, no further investigation is required.

5.2 *General Records*—Gathering and reviewing records prior to the physical investigation may help focus the investigation and make the investigation run smoothly. Reviewing records from the following categories may help inform the user what types of equipment to expect, where the equipment can be found, the repair and maintenance history and prior releases. These records may be in the possession of the owner(s) of the petroleum underground storage tank system; a third party consultant or maintenance contractor; or one or more regulatory entities. The user may find that it is beneficial to organize the records and bring them to the field investigation for reference. Installation, repair, maintenance and testing records should be retained in accordance with the guidance in Guides E1990 and E2681.

5.2.1 Equipment purchase records.

5.2.2 Installation records:

5.2.2.1 "Record" or "as-built" drawings and /or site plans;

5.2.2.2 Installation check lists;

5.2.2.3 Pre-operation leak checks;

5.2.2.4 Regulatory registration data;

5.2.2.5 Warranty registration data;

5.2.2.6 Photos and videos of the original installation;

5.2.2.7 Compatibility records for all products stored; and

5.2.2.8 *Operating and Maintenance Manuals*—Some equipment manufacturers make copies of operation and maintenance manuals available in printed or electronic form. The user can check the manufacturers' web sites for ordering or downloading manuals.

5.3 *Release detection records.* Regulated UST systems in the United States are required to perform monthly release detection that is able to detect a release from any portion of the tank or piping that routinely contains product. There are several possible methods of release detection with specific record keeping requirements. Review of release detection records may assist to identify a suspected release. Release detection alarms may indicate that a system is leaking. They can also indicate that the release detection equipment is malfunctioning. Some state regulations require that the owner or operator determine the source of a suspected release following a release detection alarm. In addition to required release detection records, other operational records may assist to identify a suspected release:

5.3.1 Inventory control records. Inventory records may indicate if there is a significant loss in one or more stored products. Inventory records are often not accurate and should not be relied upon alone to indicate that a release did or did not

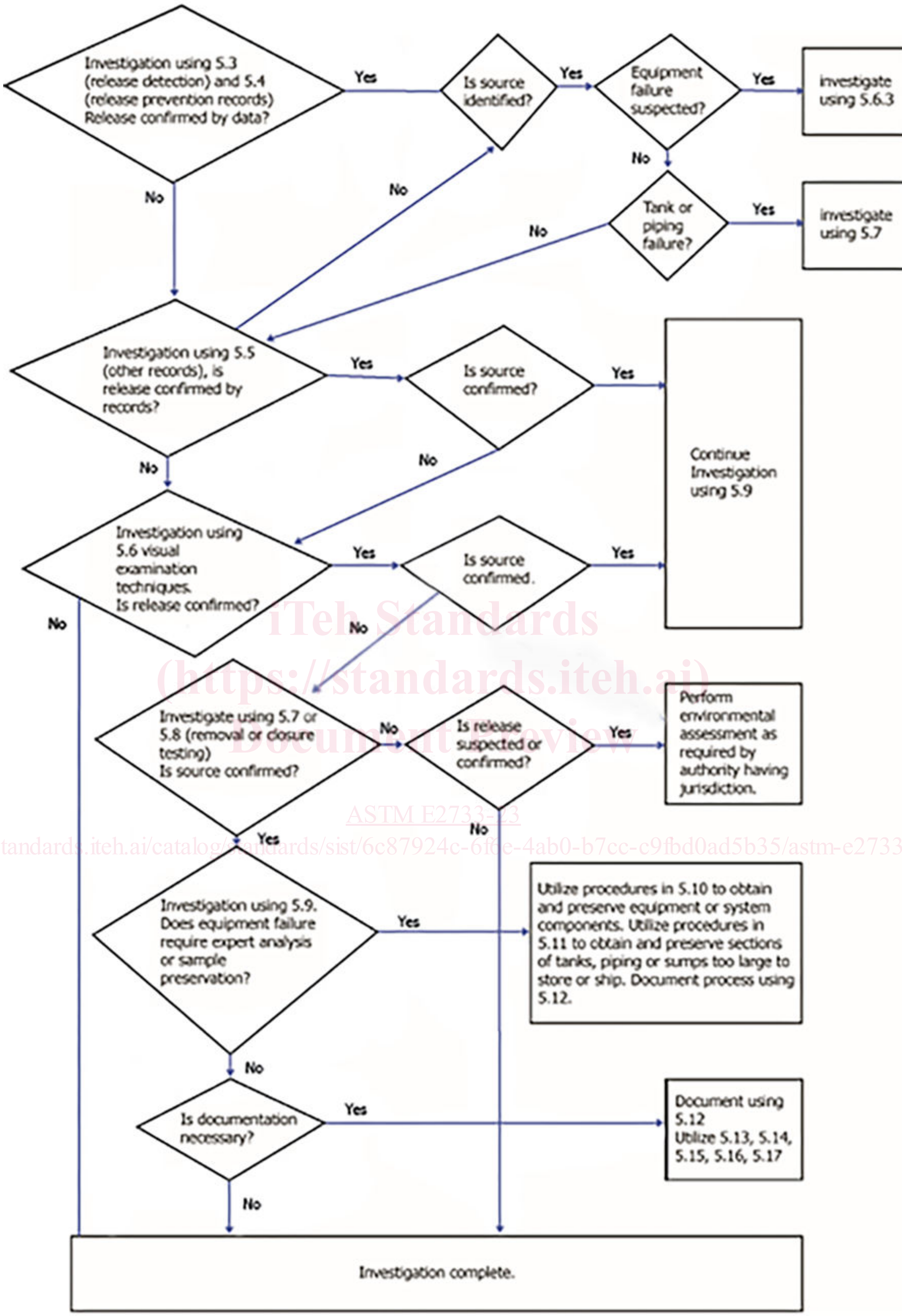

FIG. 1 Failure Investigation of Suspected Release

occur. Inventory records should be compared to delivery records, dispensing records and leak detection records;

5.3.2 Delivery records including invoices;

5.3.3 Dispensing or sales records;

5.3.4 Equipment alarm histories;

5.3.5 *Tank and piping tightness testing records.* Tightness testing may detect breaches in the underground storage tank system. A variety of methods are available with various degrees of accuracy and sensitivity. Tightness tests are generally divided into two categories: volumetric and non-volumetric. Some tightness testing methods detect breaches in specific portions of the underground storage tank system. The user should consider the characteristics of the tightness test when selecting a test method and evaluating the results of the test.

5.3.5.1 Volumetric tests apply pressure to the system and measure for an change in volume over time. Each test has requirements for the amount of fuel that must be in the system to obtain a valid test.

5.3.5.2 Non-volumetric tests use other methods to determine if the system is leaking. Some methods place a chemical marker or tracer in the system and then check for the presence of the marker outside the system. Some tracers may be able to permeate through some materials that are liquid tight and even some materials that are impermeable to most vapor components of motor fuel. The user should consider the characteristics of the tracer when selecting a test method and evaluating the results of the test.

5.4 *Release prevention records.* Regulated UST systems in the United States are required to comply with technical regulations that are designed to prevent releases. The regulations require operation and maintenance activities that must be documented and records maintained. These records may assist in the investigation if a release is suspected.

5.4.1 Cathodic protection installation, testing and maintenance records

5.4.2 Walkthrough inspection records:

5.4.2.1 30 day walkthrough;

5.4.2.2 Annual walkthrough;

5.4.3 Other periodic testing records:

5.4.3.1 Spill prevention equipment tests;

5.4.3.2 Liquid tight tests of containment sumps used for interstitial monitoring;

5.4.3.3 Leak detection equipment tests:

(1) Automatic tank gauge and other controllers;

(2) Probes and sensors;

(3) Automatic line leak detectors;

(4) Vacuum pumps and pressure gauges; and

(5) Hand-held electronic sampling equipment

5.5 *Other records:*

5.5.1 Prior monitoring well, site assessment and remediation records

5.5.1.1 An increase in a contaminant of concern may indicate a new release;

5.5.2 Maintenance and service records including any invoices

5.5.2.1 Recent maintenance activities may have disturbed existing components or created an equipment failure;

5.5.3 Inspection records and photos including inspection response documentation;

5.5.4 Repair records including repair invoices

5.5.4.1 Recent repairs may have addressed an equipment failure or created a new equipment failure;

5.6 *Pinpointing the Source of a Release and Identifying Equipment Problems During Excavation, Prior to Equipment Removal*—Most releases are not identified by leak detection methods. Components such as pumps, leak detectors and dispensers may leak and not be detected by traditional leak detection methods. Evaluation of tank top and dispenser components may identify failed equipment or other sources of leaks.

5.6.1 *Dispenser evaluation.* Dispensers have been identified as a primary source of leaks. Dispensers and components located above the shear valve are not included in the definition of a UST system under federal regulations but may be regulated by the authority having jurisdiction. Dispensers may or may not have under dispenser containment (UDC) and the UDC may or may not be monitored for releases. Careful observation and photo documentation of the dispenser and connected piping under the dispenser before the dispenser is disconnected from the UST system and during the disconnection process may reveal improper installation or component compromise that may contribute to a release.

5.6.2 Tank top and other surface component evaluations. Containment sumps containing piping, pumps, leak detectors and other equipment may be sources of leaks. Careful observation and photo documentation of sumps, piping and other equipment before the sumps, piping or equipment are disconnected from the UST system and during the disconnection process may reveal improper installation or component compromise that may contribute to a release.

5.6.3 *Visual examination*—If a release is suspected, maintenance personnel or service companies should not be allowed to adjust, repair or remove failed equipment without approval from the investigator. Careful observation of the equipment may reveal misalignment of equipment and malfunctioning or compromised components. While not always the case, generally UST equipment is installed in alignment and should remain in alignment throughout the life of the system. Poor alignment of the installed equipment may indicate shifting, settling, creep, expansion, compromise or failure of components. Installation photos or inspection photos when compared to the current conditions may help determine if the condition of the UST system has deteriorated. Visual indicators of potential problems of system components include, but are not limited to:

5.6.3.1 Misalignment;

5.6.3.2 Equipment not performing to original specifications, for example loose, rattling or intermittent operation;

5.6.3.3 Indications of prior repairs;

5.6.3.4 Water intrusion into primary containment;

5.6.3.5 Drips and staining in sumps and beneath dispensers;

5.6.3.6 Stored product, water intrusion, stains and sheens in secondary containment;

5.6.3.7 Dead vegetation and staining of surface soil and pavement;

5.6.3.8 Unusual system operation (such as slow discharge of product from pumps), which may indicate a leak or a component failure in the system;

5.6.3.9 Lack of structural integrity including the existence of cracks, holes or physical damage ;

5.6.3.10 Indications of component compromise such as material degradation, corrosion, surface delamination, swelling, elongation or growth.

5.6.4 *Other indicators*—Soil and groundwater contamination testing conducted prior to or while removing an underground storage tank system component may help identify releases and in some cases may indicate the sourceproximity of the release. It is important to determine if a release is new or old, identify the presence of older releases and to determine if the release came from the the equipment currently in place or from older equipment that has been removed. Most authorities having jurisdiction require assessment or testing requirements including specific analytical testing methods to investigate suspected releases and for proper closure of tanks or piping of a UST system.

5.6.5 If an equipment problem is identified and responsibility for the cause may be disputed it is possible that documentation of the problem may be necessary. To properly document an equipment failure the investigator may refer to E1188 Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator.

5.7 *Pinpointing the Source of a Release and Identifying Equipment Problems During Excavation to Repair or Close, Prior to Equipment Removal*—Careful observation and tests during the removal of underground storage tank systems may yield valuable information on the proximity of a release, whether the release came from the equipment at the site, and conditions that may have contributed to equipment failure. The following observations and tests can be conducted during the excavation of UST equipment:

5.7.1 *Soil Staining*—Most regulated substances can stain soils and backfill materials when released from an UST system. In many cases, careful excavation in stained areas will help pinpoint sources of release. Careful observation, photo documentation, collection and preservation of potentially compromised or improperly installed equipment near or above staining, may provide valuable information on the source and cause of a release. Soil staining can also provide a rough indication of how long the released product has been in the ground, although this age indication is highly dependent on the product released and specific conditions at the location being examined. The soil color change is due, in large part, to changes in soil redoximorphology and geochemistry from degradation of the regulated substance. Colors can be recorded using a standard chart system such as Munsell and stratum colors at the point of the release. Documenting soil colors away from the point of release can be useful for comparison and to further document the cause of the staining. The user is cautioned that some soils are naturally mottled and that there are other sources of staining besides releases from UST systems, thus the user should investigate the source of the stain to determine if in fact it is the result of a release from the UST system.

5.7.2 *Visual Assessment of Equipment*—Careful examination of the UST system may help identify equipment problems.

5.7.2.1 Staining and discoloration may be caused by product releases;

5.7.2.2 Damage such as fractures, fatigue, and breaches;

5.7.2.3 Corrosion;

5.7.2.4 Material compromise or degradation;

5.7.2.5 Improper alignment.

5.7.2.6 Recent system service or repair work

5.7.2.7 Recent construction and other nearby subsurface utility installation or repair activity.

5.7.3 *Backfill Conditions*—Improper backfill can lead to many types of equipment failure. Excessive settlement in the backfill can lead to inadequate support for tanks. Signs of settlement and inadequate compaction may be observed during excavation. Settlement may also result from finer surrounding soil migrating into coarse backfills such as pea stone. Some types of equipment can be damaged by improper backfill including sharp backfill or backfill that contains trash, clumps of clay or large rocks. Unclean or varied backfill can lead to accelerated corrosion of metallic components. Backfill that is not adequate when compared to the equipment manufacturer's installation requirements may indicate that there is an increased likelihood of failure in the component.

5.7.4 Soap tests can be conducted on piping, tank connections and bungs after they have been exposed. In a soap test the pressure is raised inside the equipment to be tested and the outside is sprayed with a soap solution. Bubbles forming in the soap solution may indicate the location of a leak. Users of this guide are cautioned to use safe procedures when introducing pressurized gasses into an underground tank system that may still contain vapors. Inert gas may be required to safely conduct a soap test on an underground tank system that has contained petroleum.

5.7.5 Similarly to testing of an operating or undisturbed system, tracer tests can be conducted during and after removal using a variety of gases. Some tracers permeate through materials that are liquid tight and even some materials that are impermeable to most vapor components of motor fuel. The user should consider the characteristics of the tracer when selecting a test method and evaluating the results of the test.

5.7.6 *Age Regulated Substance—Releases may not be identified for extended periods of time after the release occurs*—In some cases, the age of the release can be estimated. There are a variety of techniques that can be used on free product, soil, and groundwater that might be sampled during excavation. Estimating the age of the release may help determine if more than one release has occurred or if the release occurred prior to a repair or replacement date. Various forensic analysis may be utilized for age dating. Some examples include gas chromatography and mass spectrometry (GC/MS), high resolution gas chromatographic (HRGC) identification and gas chromatography with electron capture detector (GC/ECD). The Appendix contains information on various techniques.

5.8 *Pinpointing the Source of a Release and Identifying Equipment Problems During and After Equipment Removal*—A number of observations can be made as the underground storage tank system is removed. Many of these are similar to the observations and tests described in 5.7 above. The user may conduct additional observations and tests on equipment as described below, Most of these observations can be made after the equipment is uncovered and before it is removed from the ground, although some of the items indicated below, such as 5.8.3 may be more appropriate after removal.

5.8.1 Soil staining.

5.8.2 Equipment Condition:

5.8.2.1 Staining;

5.8.2.2 Damage;

5.8.2.3 Corrosion;

5.8.2.4 Improper alignment;

5.8.2.5 Loose fittings can be observed as equipment is disassembled;

5.8.2.6 Softening of plastic materials may indicate that strength properties of the equipment have deteriorated. For example, soft and spongy pipe may indicate chemical attack and weakening; and

5.8.2.7 Excessive microbial growth on system components can indicate deterioration of plastics or rubber materials.

5.8.3 *Stored Product Trapped in Secondary Containment—* Product can build up in the secondary containment system if the primary containment is leaking faster than the secondary containment system. This can be detected by creating a small hole in the secondary containment system with a pocket knife or an awl. In some cases, particularly in certain models of thermoplastic pipe where the secondary containment pipe is in intimate contact with the primary pipe, the product can become trapped in the secondary containment and build up pressure. Trapped product can indicate that there is a breach in the primary containment in that section. This investigation technique may not be reliable if the secondary containment system is open to migration of releases from sumps unless the product trapped in the secondary is under pressure. The user should assess the potential quantity of product that could be trapped in the secondary containment and be prepared to capture the released product with absorbent pads and containers such as those described in Guide F1127.

5.8.4 *Soap Test—*Soap tests can be conducted using the manufacturer's recommended practice or standard industry methods such as those described in PEI and API installation guides (PEI/RP 100).

5.8.5 Groundwater and soil testing can be used to confirm that a release has occurred and to determine what product was released and when it occurred. There are a variety of field and laboratory techniques for assessing soil and groundwater constituent concentrations. The user should consult with a petroleum release remediation consultant to determine which techniques to employ and the skills and equipment needed. Most authorities having jurisdiction require assessment or testing requirements including specific analytical testing methods to investigate suspected releases and for proper closure of tanks or piping of a UST system. See Fig. 1.

5.8.5.1 *Source Area Identification—*Concentrations from several sample locations can be plotted on a map to indicate the likely area of highest concentration. The area of highest concentration is also often the area of the release. A three-dimensional plot method such as a box diagram may be helpful, particularly for analyzing the tank excavation area.

5.8.5.2 *Age of Regulated Substance—*In some cases the age of the regulated substance can be estimated. There are a variety of techniques that can be used on free product, contaminated soil, and groundwater. Estimating the age of the regulated substance may help determine if more than one release has occurred or if the release occurred prior to a repair or replacement date. Various forensic analysis may be utilized for age dating. Some examples include gas chromatography and mass spectrometry (GC/MS), high resolution gas chromatographic (HRGC) identification and gas chromatography with electron capture detector (GC/ECD). Appendix contains information on various analytical techniques. One of the techniques, "finger printing" attempts to estimate the age by relating the characteristics of the regulated substance in the investigation to known changes in formulations of fuels, refining practices and additives. The Appendix contains information on various techniques and test methods that may be used for forensic purposes.

5.9 *Identification of Suspected Equipment Problems—*UST equipment has changed considerably over the years. Manufacturers are constantly introducing new equipment and making changes to older equipment designs. Manufacturing defects are often isolated to one model or even one lot of a particular type of equipment. Complete identification of equipment problems from many sites can help the user identify trends in malfunctions and failures informing preventive maintenance programs and preventing future malfunctions and failures and improving tank system design practices.

5.9.1 *Make, Model and Serial Number—*The make and model number can help identify equipment design, manufacturing technologies used, general installation requirements, possible age, and so forth. The serial number can help identify manufacturing date, materials and manufacturing technologies used, age, and so forth.

5.9.2 *UL Listing—*Many underground storage tank system components carry a UL mark. The Underwriters Laboratory (UL) mark often includes lot numbers and date of manufacture. UL has a system for investigating malfunctions and failures of listed equipment that can aid in the improvement of their standards. A UL reporting form for underground piping is contained in X1.3. Contact UL at the number listed in the Underground Piping Field Report form to report other malfunctions and failures of listed petroleum equipment.

5.9.3 *Documentation—*Pictures and field notes of equipment model numbers, serial numbers and any other identifying marks can be valuable to inform later analysis of equipment problems. Equipment that may have contributed to a suspected or confirmed release should not be manipulated, dismantled or removed until visual inspection and photo documentation of the equipment as found is complete. The investigator may reference ASTM E1188 Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator. Before equipment and connected components are disturbed or removed.

5.9.4 *Working with Equipment Manufacturers—*Equipment manufacturers are often keenly interested in investigating equipment failures. They should be consulted as soon as possible when a piece of equipment is suspected of failing or malfunctioning. They may have specific removal and sample preparation recommendations. In some cases, the equipment manufacturer will send a representative to the site to observe or participate in the investigation.

5.10 *Removing Suspected Problem Equipment*—In some cases, the user may choose to collect and preserve failed equipment for evaluation or laboratory analysis. Laboratory analysis may be warranted if there is uncertainty in the mode of failure or the reason for the equipment problem. In preparing equipment for evaluation or laboratory analysis, it is important that equipment be removed in a way that does not cause further damage and allows for further testing. Users may refer to ASTM E1188 Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator. The following are some general guidelines for removing equipment that is intended to be subjected to further evaluation, laboratory tests and analysis. For some laboratory tests, samples of product, backfill, and equipment should be preserved in their as-removed condition as much as possible to more closely represent actual use conditions. For example, drying the hydrocarbons out of a plastic can cause dramatic changes in its physical properties. In some cases, this type of preservation is not practical due to packaging, storage and shipping constraints. The user should consult with the testing expert for specific removal requirements to meet the user's goals.

NOTE 1—User(s) should never attempt to cut samples from any tank or equipment that has not been thoroughly degassed or inerted. User(s) should never attempt to enter deactivated fuel tanks or contaminated sumps without proper confined space entry training. See 29 CFR 1910.146. Many states require special certifications for individuals to remove or repair petroleum storage tank equipment.

5.10.1 *Preparing Samples or Documenting the Equipment Problems*—The equipment should be removed carefully, and care should be taken to not damage or disturb it further. For example the equipment should not be wiped off. Equipment connected to pipes should be removed by cutting the pipe on either side of the problem equipment, if possible rather than unscrewing the pipe connections. In many cases it is helpful to prepare samples of similar, but properly functioning equipment at the site for benchmarking by the expert. Photographs and field notes are often used by experts to analyze the failure when it is not possible to preserve the equipment.

5.10.2 *Preparing Samples of Stored, Trapped, Released Product*—As discussed above chemical analysis of the released product can help estimate the date of the release. Chemical analysis of the product can also identify the mode of the malfunction or failure. For example the presence of plasticizers in released product can indicate that the product has attacked particular plastics or gaskets. It may be helpful to preserve stored product, product trapped in the secondary containment, as well as released product to make a complete analysis of the failure. The user should consult with the testing expert for specific sampling and preservation requirements to meet the user's goals. Generally chemical preservation of liquid product is not required for most analyses.

5.10.3 *Documentation*—Field notes, photos, and videos can all be used to show the condition of the equipment and released product. It is often important to document the removal and sample preparation process so the experts who conduct later analysis can trace the condition of the equipment.

5.11 *Removing Sections of Suspected Problem Equipment*—The user may sometimes need to save sections of equipment such as tanks, piping, and sumps because they are too large to store or ship. It is important to take the sections in a way that allows them to be useful in later analysis. Careful documentation of the sectioning process may help experts who conduct later analysis to trace the condition of the equipment.

NOTE 2—User(s) should never attempt to cut samples from any tank or equipment that has not been thoroughly degassed and inerted. User(s) should never attempt to enter deactivated fuel tanks or contaminated sumps without proper confined space entry training. See 29 CFR1910.146. Many states require special certifications for individuals to remove or repair petroleum storage tank equipment.

5.11.1 *Preparing Samples or Documenting the Malfunction or Failure*—Most laboratory analysis can be conducted on sections as described below. However, some types of analysis need larger sections or special sample preparation techniques. The user should consult with the testing expert for specific sectioning and preservation requirements to meet the user's goals. Samples of the product, residue or backfill that was in contact with the equipment section of interest may be needed for the testing expert to make a complete analysis. This is particularly true when investigating corrosion-related failures as certain chemicals and bacteria have been reported to accelerate corrosion,

5.11.1.1 *Tanks*—In many investigations of tank failures, both the exterior and interior of the tank is examined for signs of failure. Careful visual inspection of the tank may help identify areas of suspected corrosion or flaws. These areas may then be removed for laboratory analysis. Failed or flawed tank sections should be cut out using carbide, Carborundum, or diamond-tipped tools. Typically tank sections are at least 40 in. by 40 in. and include the jacket material on composite tanks and two ribs on fiberglass tanks when structural testing is planned. Smaller, 12 in. by 18 in. sections are generally sufficient for visual examination and compatibility testing. Sections should be taken where there is visual evidence of flaws or failures. In analyzing fiberglass tank failures, additional tank samples are often taken at the bottom of the tank (6:00) or near the bottom and at 3:00 or 9:00 positions. Samples at the top of fiberglass tanks (12:00) are sometimes taken for comparison purposes. Internal corrosion of steel tanks is generally most severe in the bottom of the tank near the striker plate and at the sludge line. However, in some cases internal corrosion occurs at the top of the tank. Documenting the suspected corrosion or flaws in the tank with notes, diagrams, measurements and pictures may help experts who were not present at the investigation analyze the failure when it is not practical or desirable to remove sections of the tank.

5.11.1.2 *Pipe*—Typically, failed or flawed pipe sections are cut with 2 to 3 diameters of pipe before and after the failed or flawed section, or about ten (10) diameters overall to allow for test plugs to be inserted in the pipe during later mechanical testing. Pipe sections can be cut shorter if mechanical testing is not going to be conducted.

5.11.2 *Documentation*—Field notes, photos, and videos can all be used to show the condition of the equipment. It is often important to document the removal and preservation process so the experts who conduct later analysis can trace the condition of the equipment. The field notes should include a description of any fluid in the secondary containment.

5.12 *Documenting the Progress of the Failure Investigation*—As discussed in the above sections, documentation is important for experts to trace the condition of the equipment. Documentation is also important to help put together the pieces of an investigation and to substantiate the conditions that were observed during component removal through analysis of the preserved equipment. The following documentation is typically conducted at failure investigations. The user may collect additional documentation to meet specific goals. Practice E1188 provides guidelines for the collection and preservation of information and physical items by any technical investigator.

5.12.1 Notes should be kept to document the progress of the investigation. Notes that are taken in a way that can not be altered, such as in bound books or time-stamped electronic files may allow more reliable determinations of the sequence of events in the investigation.

5.12.2 *Logging Personnel on Site*—The notes should include a log of all personnel on the site during the removal and failure investigation. The names, employers, and contact information for each person should be noted. This may make it easier to contact individuals in the future if interviews are needed for the failure analysis.

5.12.3 *Weather and Surrounding Site Conditions*—Including the weather and surrounding site conditions may provide important information on the investigation process and on factors that could influence the investigation.

5.12.4 Pictures can be helpful in documenting the conditions at the site. The photographs should include date and time stamps. High-resolution photographs can be blown up for later expert analysis. Computer analysis techniques on digital photos can be especially helpful.

5.12.5 Video can be helpful as well, especially if it includes narration of the removal and investigation activities. Video is also valuable in documenting the site geography and the storage tank system layout. The video should include date and time stamps and some visual reference for hardware size, location, and orientation. Generally, video documentation compliments photographs rather than replacing them because video cameras do not have the level of resolution of photographs and are thus less useful for enlargement.

5.13 *Preparing Samples Equipment for Laboratory Analysis*—Samples and sections of equipment should be preserved as they are removed if they are intended for laboratory analysis. While it is not possible to fully duplicate the conditions at the site, preservation may allow for a wider range of tests and conclusions to be made by experts conducting analysis later. The choice of preservation technique depends upon the type of laboratory analysis that will be conducted later. Some container materials could interfere with planned chemical analysis. The user should discuss preservation requirements and the choice of containers with the laboratory that will be analyzing the samples prior to taking and preserving samples. The following preservation techniques are used in failure investigations.

5.13.1 Empty (unused) metal paint cans are available in a variety of sizes up to 5 gal from paint stores. In some cases, the plastic liner of the paint cans is soluble in the fuel and can interfere with later testing of equipment stored in the cans.

5.13.2 Sample jars are available in a variety of sizes from chemical supply houses or analytic laboratories.

5.13.3 Sample bags are available in a variety of materials and sizes. Polyethylene bags with zipper-type closures are sold in a variety of stores and are available in sizes less than a pint to 2 ft by 2.7 ft. While polyethylene bags are inexpensive and readily available, they are not as chemically inert as PTFE (polytetrafluoroethylene) or PVF (polyvinyl fluoride) bags, which can be obtained from chemical supply houses or analytic laboratories in a variety of sizes.

5.13.4 Wrapping in two layers of thick polyethylene sheeting or several layers of contractor's stretch wrap is an effective way to preserve large irregular pieces of equipment. The sheeting edges can be sealed with liberal application of duct tape. PTFE (polytetrafluoroethylene) or PVF (polyvinyl fluoride) sheeting can be used instead of polyethylene sheeting where the wrapping material needs to be chemically inert.

5.13.5 Wrapped, bagged, canned, or jarred samples can be protected further by wrapping them with absorbent, insulating padding prior to placing them in shipping boxes.

5.14 *Establishing Chain of Custody*—In some cases, a chain of custody is needed to establish the date the sample was taken, when it was shipped, and who was responsible for the package. The sample chain of custody form in X1.1 can be used to establish chain of custody for equipment. Laboratories as well as many state agencies have chain of custody forms available for use. Some of these forms have additional information to document sample preservation and holding times, which can be critical for determining contaminant levels, but are rarely needed for equipment samples that are going to be physically examined.

5.15 *Storing Equipment, Sections, and Samples*—Once the samples and equipment are obtained they should be stored securely in a well ventilated cabinet or in a limited access enclosure where they are protected from rain, heat, damage and direct sunlight. A cool storage temperature may preserve the in-ground condition of the samples longer. Sturdy wooden crates that are ventilated are often used to store sealed samples and equipment. The crates can make storage and moving the samples and equipment easier. Soil and water samples may need to be cooled or otherwise preserved while in storage.

NOTE 3—Explosive vapors can build up from equipment that was in contact with liquid product. The user should consult NFPA 30 for guidance in safe storage of equipment that contained liquid petroleum products.

5.16 *Shipping Equipment, Sections, and Samples*—Hazardous material regulations and special shipping instructions may apply to equipment, sections and samples removed from underground storage tank sites. Soil and water samples