United States
Environmental Protection
Agency

Office of Research and
Development
Washington, DC 20460

EPA/600/2-90/061
January 1991

EPA

# State-of-the-Art Procedures and Equipment for Internal Inspection of Underground Storage Tanks

EPA/600/2-90/061
January 1991

# STATE-OF-THE-ART PROCEDURES AND EQUIPMENT FOR INTERNAL INSPECTION OF UNDERGROUND STORAGE TANKS

By
S. E. Boone, P. J. Mraz and
J. M. Miller
PEI Associates, Inc.
Washington, DC 20036

and

J. J. Mazza and M. Borst
CDM Federal Programs Corporation
Edison, NJ 08837

Contract Number 68-03-3409

Project Officer

Robert W. Hillger
Releases Control Branch
Risk Reduction Engineering Laboratory
Edison, NJ 08837

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OH 45268

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

Printed on Recycled Paper

## NOTICE

The information in this document has been funded entirely by the United States Environmental Protection Agency under Contract No. 68-03-3409 to CDM Federal Programs Corporation. This document has been subject to the Agency's peer and administrative review and has been approved for publication as an EPA document.

This report is intended to present information on procedures and equipment used to conduct internal inspections of underground storage tanks. The study from which this report was developed characterized the state-of-the-art in internal inspections. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

# FOREWORD

As industrial products and practices continue to rapidly develop and change, the generation of solid and hazardous wastes is frequently increased. If improperly dealt with, these materials can threaten both public health and the environment. Underground storage tank (UST) systems have been identified by the U.S. Environmental Protection Agency (EPA) as a significant source of contamination to surrounding soils and groundwater. Failure to monitor UST systems and control and mitigate releases may result in health and safety problems affecting surrounding populations. Consequently, EPA has promulgated regulations that prescribe performance standards and financial responsibility requirements for owners and operators to remediate sites where contamination from existing USTs has been detected. These regulations implement technical requirements designed to reduce the possibility of leaks from developing in new or existing tank systems.

The Risk Reduction Engineering Laboratory plays a critical role in further defining the technical standards set forth in the Federal regulations and in the development of information to facilitate the implementation of state and local UST programs. One aspect of UST management for which little information is available pertains to tank inspections and their potential in fostering an overall reduction of contamination. Clearly, early detection by regular inspection is a key step in the prevention of releases to the environment. The objective of internal inspection is to identify weakness of tank walls, presence of corrosion, quality of lining material, and suitability of cleaning techniques prior to closure. The study focused on inspection methods that evaluate the structural integrity of the tank interior. This report presents the results of a review of state-of-the-art internal inspection procedures and equipment for underground storage tanks.

For further information, please contact the Releases Control Branch of the Risk Reduction Engineering Laboratory.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

# ABSTRACT

Preventing leaks from underground storage tanks is of paramount importance in this decade as environmental resources are seriously threatened by the release of toxic substances and costs of reparation are exorbitant. Inspecting underground storage tanks is one action that helps prevent and correct potential tank failures that could result in such release. This study identifies and characterizes the types of internal practices (current, emerging, and outmoded) to conduct internal inspections of underground storage tanks.

Professional and trade associations have developed some standards, guidelines, and recommended practices for conducting internal inspections of USTs for wall thickness, structural integrity and lining integrity. Industry is developing additional instruments and methods to conduct UST internal inspections. However, many of these procedures have overlapping or contradictory requirements. There are no data currently available to indicate how widely these procedures are understood or followed in the field.

EPA sponsored this survey of state-of-the-art internal inspection methods as an initial compilation of this important information, for dissemination to the regulated community. This document addresses those methods pertaining to tanks; description of the inspections performed on ancillary equipment (pipes, vents, etc.) of UST systems is not within the scope of this report. The report is the result of an effort to examine the various tools and techniques used for conducting internal inspections. This study documents the significant factors evaluated during an inspection. It examines the application of each inspection method by identifying the objectives of the technique, its procedural steps, the necessary equipment and instrumentation, the circumstances under which the method is performed, and any important considerations for use in the field.

Seventeen internal inspection methods were identified during this study. These methods fall into one of four categories: tank wall thickness, tank deflection, lining integrity, or tank integrity. Most methods are non-destructive, and while all evaluate components of the tank interior, not all methods require tank entry. The selection of a particular method is dependent upon the type of activity being performed (e.g., installation, upgrading, repair). The findings of this study have raised several key questions and clearly support further research.



This report was submitted in partial fulfillment of Contract No. 68-03-3409 by CDM Federal Programs Corporation under the sponsorship of the U.S. Environmental Protection Agency. The research was conducted in the period from December 1989 to April 1990, and work was completed May 30, 1990.

TABLE OF CONTENTS


| | Page |
|---|---|
| Foreword | v |
| Abstract | vi |
| Figures | ix |
| Tables | x |
| Abbreviations | xi |
| Acknowledgements | xii |
| 1.0 INTRODUCTION | 1 |
| 1.1 Background | 1 |
| 1.2 Purpose | 2 |
| 1.3 Approach | 3 |
| • Literature Search | 4 |
| • Industry Contacts | 4 |
| • Trade Association Contacts | 4 |
| • Standards Investigated | 5 |
| • State Surveys | 5 |
| 1.4 Definitions | 5 |
| • State-of-the-Art | 5 |
| • Internal Inspection | 5 |
| • Ancillary Equipment | 6 |
| • Destructive Testing | 6 |
| • Maintenance | 6 |
| • Non-Destructive Testing | 7 |
| • Operational Life | 7 |
| • Repair | 7 |
| • Tank | 7 |
| • Underground Storage Tanks or USTs | 7 |
| • Upgrade | 7 |
| 1.5 Summary of Findings | 7 |
| • Tank Wall Thickness | 8 |
| • Deflection | 8 |
| • Lining Integrity | 8 |
| • Tank Discontinuity | 8 |
| • Tank Integrity | 8 |
| 1.6 Selecting Internal Inspection Methods | 11 |
| 2.0 CONCLUSIONS | 13 |
| 3.0 RECOMMENDATIONS | 19 |

TABLE OF CONTENTS (Continued)

4.0 INTERNAL INSPECTION METHODS .......... 21
4.1 Tank Wall Thickness .......... 25
• Ultrasonic Testing .......... 25
• Hammer Testing .......... 34
4.2 Tank Deflection .......... 36
• Internal Tank Diameter .......... 36
4.3 Tank Lining Integrity .......... 39
• Holiday Tests .......... 41
• Dry Film Thickness Measurements .......... 44
• Lining Hardness Tests .......... 46
4.4 Tank Discontinuities .......... 50
• Visual Examination .......... 50
• Liquid Dye Penetrant .......... 53
• Magnetic Particle Testing .......... 59
4.5 Tank Integrity .......... 64
• Bubble Testing .......... 65
• Positive Pressure Testing .......... 68
• Vacuum Tests .......... 70

5.0 OUTMODED METHODS .......... 72
5.1 Radiography .......... 72
5.2 Eddy Current .......... 72

6.0 EMERGING TECHNOLOGIES .......... 74
6.1 Acoustic Emission .......... 74
6.2 Boroscope .......... 75
6.3 Microwave .......... 75

REFERENCES .......... 77

Appendices

A. Tank Emptying and Cleaning .......... 80
B. Tank Isolation and Tank Surface Preparation .......... 89
C. Standards Investigated .......... 91
D. Internal Inspections During Tank Remanufacture .......... 93
E. Safety Precautions .......... 96
F. Classification of Surface and Subsurface Discontinuities for Translucent Visual Examination of FRP Tanks .......... 111
G. Qualification Procedure for Non-Standard Temperatures for Liquid Dye Penetrant Tests .......... 115
H. Control Tests Recommended by ASME SE-709 for Magnetic Particle Tests .......... 117
I. Tank Integrity Test Method Summary .......... 119

FIGURES


| Number | Description | Page |
|---|---|---|
| 1 | Example of Wave Activity Through Tank Wall Using Ultrasonic Test | 26 |
| 2 | Relationship Between Transit Time and Thickness in Ultrasonic Test | 28 |
| 3 | Dual Transducer Nonlinearity | 29 |
| 4 | Tank Head Diagram | 31 |
| 5 | Tank Wall Grid Diagram | 32 |
| 6 | Two Drawings Showing Exaggerated Ellipitical Deflection in Cross-Section | 37 |
| 7 | Three Step Procedure for Measuring Internal Diameter | 40 |
| 8 | Elcometer Coating Thickness Gauge | 45 |
| 9 | Diagram of Barcol Impressor | 48 |
| 10 | Flowcharts of Three Different Visible Dye Penetrant Techniques | 55 |
| 11 | Localized Magnetization | 60 |
| 12 | Pressurization Setup of a Double Walled Manway Tank | 66 |
| E-1 | Confined Space Entry Permit: Operating Tanks | 101 |

## TABLES


| Number | Description | Page |
|---|---|---|
| 1 | Internal Inspection Methods Used for Different Types of Tanks and Inspections | 9 |
| 2 | Internal Measurements Employed During Inspections | 10 |
| 3 | Summary of Internal Inspection Methods | 16 |
| 4 | Internal Inspection Methods and Environmental Considerations | 22 |
| 5 | Suggested Weights of the Oil Couplants for Surface Roughness | 33 |
| 6 | Maximum Allowed Single-Walled Tank Deflection At Installation | 38 |
| 7 | Suggested Voltages For High Voltage Spark Testing | 43 |
| 8 | Recommended Samples Sizes to Equalize the Variance Of the Average | 49 |
| 9 | Liquid Dye Penetrant Techniques and Equipment | 57 |
| 10 | Specifications of Magnetization Instruments | 63 |
| 11 | Remanufacturing Steel/FRP Composite Tanks | 94 |

## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AC | -- | Alternating current |
| ACT | -- | Association of Composite Tanks |
| API | -- | American Petroleum Institute |
| ASME | -- | American Society of Mechanical Engineers |
| ASTM | -- | American Society for Testing and Materials |
| AWS | -- | American Welders Society |
| CFR | -- | Code of Federal Regulations |
| CRT | -- | Cathode ray tube |
| DC | -- | Direct current |
| DFT | -- | Dry film thickness |
| DRI | -- | Direct reading indicator or instrument |
| EPA | -- | U.S. Environmental Protection Agency |
| F | -- | Fahrenheit |
| fc | -- | foot-candles |
| FPTPI | -- | Fiberglass Petroleum Tank & Piping Institute |
| FR | -- | Federal Register |
| FRP | -- | Fiberglass-reinforced plastic |
| ft/s | -- | feet per second |
| HWDC | -- | half-wave rectified direct current |
| kPa | -- | kilo Pascals |
| mm | -- | millimeters |
| mm Hg/m | -- | millimeters of mercury per meter |
| m/s | -- | meters per second |
| NACE | -- | National Association of Corrosion Engineers |
| NDTA | -- | Non-Destructive Testing Association |
| NFPA | -- | National Fire Protection Association |
| NLPA | -- | National Leak Prevention Association |
| NTIS | -- | National Technical Information Service |
| oz. | -- | ounces |
| PEI | -- | Petroleum Equipment Institute |
| psi | -- | pound per square inch |
| psig | -- | pound per square inch, gauge |
| QA/QC | -- | Quality assurance, Quality control |
| µm | -- | micrometer |
| RCRA | -- | Resource Conservation and Recovery Act |
| SOTA | -- | State-of-the-art |
| STI | -- | Steel Tank Institute |
| UL | -- | Underwriters Laboratories |
| UST | -- | Underground storage tank |
| V | -- | Volts |

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge the guidance received over the course of this project from several monitors at the EPA Office of Research and Development. The continuing contributions of Robert W. Hillger and Anthony N. Tafuri, Releases Control Branch, Risk Reduction Engineering Laboratory, U.S. Environmental Protection Agency, have been invaluable throughout this project. Mr. James Yezzi, Mr. Thomas Schruben, and Mr. Richard Koustas served as peer reviewers for ORD.

In addition, the guidance from Joan O. Knapp, CDM Federal Programs Corp.; Warren Lyman, Camp, Dresser, & McKee, Inc.; and John P. Murphy and Roy Chaudet, PEI Associates, Inc., is appreciated. Information obtained both formally and informally from a number of tank manufacturing companies, lining contractors, and independent consultants was instrumental for the development of the subject matter and the completion of this report. In particular, the authors would like to thank the extra efforts of George Crosby and Michael Messner from O/C Tanks Corporation and Craig Peterson from Xerxes Corporation.

# SECTION 1.0

# INTRODUCTION

## 1.1 BACKGROUND

Underground storage tank (UST) systems have been identified by the U.S. Environmental Protection Agency (EPA) as a significant source of contamination to surrounding soils and groundwater. Underground storage tanks (USTs) systems are routinely used to store petroleum products and hazardous materials and are likely to remain in common use for the foreseeable future. Failure to monitor UST systems and control and mitigate releases represents a significant threat to human health and the environment because of the millions of USTs in active use, and the potential for each leaking UST to affect a large number of people through contaminated drinking water supplies. Consequently, EPA has promulgated regulations that prescribe performance standards and financial responsibility requirements for tank owners and operators to remediate sites where contamination from existing USTs has been detected. These performance standards implement technical requirements designed to reduce the possibility of leaks from developing in new or existing tank systems. In support of these regulations, EPA is working to identify or develop sound engineering practices which can be implemented to minimize the probability of leaks from developing, and the size and duration of leaks should they occur.

As methods to detect releases from underground storage tanks continue to be developed, the number of releases being detected are rapidly increasing nationwide. Internal inspection fulfills an important role in release prevention from tanks during installation, repair, maintenance, and upgrading. Inspection methods range from the simple (visual) to the complex (e.g., ultrasonic and magnetic testing). A common inspection method (that is, one that is used most commonly), for example, involves striking a ball peen hammer on the interior wall of a tank and making a determination of its thickness based on the ringing sound produced.

Unless underground tanks are contained in an accessible vault, external visual inspections are not possible without unearthing the tank. However, internal inspections may be performed if the tank is equipped with a manhole. The techniques that may be used in such instances include ultrasonic tests and radiation-type tests. Spark tests may also be used in tanks that do not contain flammable or combustible materials.

Internal tank inspection is inherently hazardous. The tank must be emptied of liquid, freed of gases, washed and cleaned prior to entering. (Details on tank emptying and cleaning procedures appear in Appendix A. A summary of tank isolation and surface preparation activities appears in Appendix B.) As an added precaution, a breathing apparatus and fire-resistant clothing should be worn when entering a tank that contained flammable material. It should be noted here that it is sometimes a clumsy and difficult task to enter a tank with a breathing apparatus. However, it is more difficult to remove a body where such apparatus was not worn. All activities should be conducted in such a fashion as to minimize the creation of static electricity.

Federal regulations raise the issue of inspections only as they pertain to the operation and maintenance of corrosion protection equipment. During the rulemaking process, EPA determined that general inspections were duplicative of leak detection measures and that inaccessibility of USTs further made inspections impractical. The resulting regulations refer tank owner/operators to standards developed by nationally-recognized associations for activities pertaining to tank upgrade and repair. The subject of internal UST inspections has not yet been fully addressed by EPA. However, many of the associations identified by EPA have developed procedures for conducting examinations of tank interiors. The impetus for the study was to characterize internal inspections.

EPA sponsored this project through the Risk Reduction Engineering Laboratory, to identify, catalogue, and characterize the procedures and equipment used for internal inspections. This report describes the procedures, equipment, and techniques; it does not provide a comparison of methods. It is intended to serve as a broad review of current practices and emerging technologies rather than an evaluation of the specific approaches.

## 1.2 PURPOSE

This report is the result of an effort to examine the various tools and techniques used for conducting internal inspections of underground storage tanks. It documents the significant factors evaluated during an inspection, and examines the application of each inspection method by identifying the objectives of the technique, its procedural steps, the necessary equipment and instrumentation, the circumstances under which the method is performed, and documents important considerations for use in the field. This is a survey of all methods which could be identified; it is not an evaluation of the performance of a given device. No conclusions about the performance of any protection method (e.g., cathodic protection) should be inferred.

In order to develop this report, a number of specific task activities were identified.

- Identify the state-of-the-art (SOTA) for internal inspection methods.
- Determine the impact, if any, of size of tank on the performance of the method.
- Provide recommendations regarding the SOTA and the need for further investigation of existing technology.

Internal tank inspection is frequently used with other investigatory methods to determine whether a tank is leaking or in need of upgrading or repair. There are numerous ways to internally inspect a tank. The overall objective of this project is to identify the methods and equipment used to conduct internal inspections of underground storage tanks.

In order to accomplish this goal, a number of specific task activities were identified.

- Identify the state-of-the-art for internal inspection methods.
- Determine the impact, if any, of size of tank on the performance of the method.
- Provide recommendations regarding the state-of-the-art (SOTA) and the need for further investigation of existing technology.

This study identifies and characterizes current techniques used for conducting internal inspections of underground storage tanks. The study investigated the state-of-the-art (SOTA) for internal inspection methods. The term "state-of-the-art" is defined as the current level of development and capability in terms of procedure, process, and technique. Generally, this refers to methods which are commercially available, but technically advanced procedures and equipment have also been addressed. This study includes a review of existing industry standards and practices and a review of applicable non-destructive test methods.

Seventeen methods that apply to internal inspections have been identified during the course of this study. Each method has been presented in detail in Sections 4.0, 5.0, and 6.0. Discussions with industry experts and practitioners indicate that only a few of these methods (i.e., visual observation, hammer testing) are widely used. Many others are applied infrequently throughout the country. In addition, the research identified a few speculative technologies (e.g., acoustic emission) with potential for internal tank inspections that are not in current practice.

## 1.3 APPROACH

The research effort involved consisted of a review of available literature, and conversations with manufacturers and vendors, trade and professional associations, and independent consultants. A description of these efforts follows.

## Literature Search

An extensive review of the current literature dealing with USTs was conducted. This review included accessing the National Technical Information Service (NTIS) and Applied Science and Technology computerized data bases. The libraries accessed included:

- University of Cincinnati Engineering Library
- USEPA/Risk Reduction Engineering Laboratory Technical Library
- University of Maryland Engineering Library
- Rutgers University Library

## Industry Contacts

Representatives of the industries that manufacture tanks, apply linings, and provide inspection services were contacted to obtain details on particular inspection methods. The following companies were contacted:

- Armor Shield
- Bridgeport Chemical Company
- Buffalo Tank Company
- Certified Coating Inspection
- Highland Tank and Manufacturing
- M.W. Farmer and Company
- Owens-Corning Fiberglass
- Permaseal
- Physical Acoustics Corporation
- Tank Liners Inc.

## Trade Association Contacts

Professional and trade associations were contacted to obtain information on state-of-the-art inspection practices. The following organizations were contacted:

- American Petroleum Institute
- American Society for Testing & Materials
- Association of Composite Tanks
- Fiberglass Petroleum Tank & Piping Institute
- National Association of Corrosion Engineers
- National Leak Prevention Association
- Non-Destructive Testing Association
- Petroleum Equipment Institute
- Steel Structures Painting & Coating
- Steel Tank Institute

Standards Investigated

Section 9005 of the Resource Conservation and Recovery Act (RCRA) encourages the use of inspection methods developed by professional societies, trade associations, and testing laboratories. Standards relevant to tank inspections were identified and reviewed. Numerous standards were investigated and are presented in Appendix C.

State Surveys

A few states were contacted as part of this study. Rather than conduct a comprehensive survey, an attempt was made to broadly ascertain the level of state involvement in requiring or supervising the performance of internal inspections. Representatives from the states of New Jersey, New York, Massachusetts, Missouri, Iowa, and California were contacted for information. Additional input was solicited from EPA Regions I, III, and VII. The representatives were either UST program coordinators, Regional Project Monitors (RPMs), or On-Scene Coordinators (OSCs).

At this writing, all data suggest that state agencies are not actively involved in the application of internal inspection methods. State or Regional EPA personnel rarely enter or inspect tanks internally. This activity is generally left up to the manufacturers or to firms that provide installation, cleaning, and lining services.

## 1.4 DEFINITIONS

This project, from the beginning, required definitions and careful selection and use of nomenclature. This subsection presents definitions of all applicable terminology. Where possible, regulatory definitions were used.

State-of-the-Art

The project reviewed the overall practice of internal inspections in current practice. The project was not intended to only summarize technically advanced methods. Advanced tools identified during the course of the study are included for general information only in Section 6.0. The term "state of the art" therefore, has been conceptualized to describe methods commercially available in current practice. This study was restricted to tanks that routinely contain petroleum products. This restriction was placed on the scope because the majority of USTs are used for this purpose.

Internal Inspection

40 CFR 280.11 of the technical standards and corrective action requirements for UST owners and operators does not define the terms "internal inspection" or "inspection". Therefore, for purposes of this study, the term "internal inspection" has been defined as any non-volumetric determination of one or more internal attributes of

a tank in an underground storage tank system by destructive or non-destructive methods. Such internal measurements may be obtained by direct or indirect means. This includes activities designed to:

1) verify the structural integrity of the tank prior to and after installation;

2) detect structural discontinuities, ascertain structural strength, and determine structural deflection prior to a change in service, tank reuse, or the application of an internal lining material;

3) detect lining discontinuities, measure hardness, and determine lining thickness; and

4) verify the cleanliness of the tank at closure or removal from service.

While volumetric tests evaluate the overall integrity of a tank as a means of leak detection, they do not provide any kind of detail on the cause or location of the leak. One can make an argument that non-volumetric methods, such as inventory reconciliation, could be classified as internal inspections because they are designed to detect leaks. However, this study addresses only those methods which meet the four criteria described above. For a comprehensive discussion of the state-of-the-art of leak detection methods, refer to ("Underground Tank Leak Detection Methods: A State-of-the-Art Review. Prepared by S. Niaki and J. Broscius, IT Corporation. Prepared for U.S. EPA, ORD, Cincinnati, Ohio. Contract No 68-03-3069. EPA/600/2-86/001. January 1986.) Pipes, vents, valves, pumps, and other ancillary components of the UST system are excluded by restricting the examination in this study to the tank only. Site monitoring, site remediation, or site assessment activities are also excluded.

Internal inspection procedures generally require a man or machine to enter the tank, in almost all cases, to conduct the inspection. This document addresses all inspection scenarios identified to date. The definition is not restricted to inspections requiring physical entry of the system. A few methods described here do not require physical entry.

<u>Ancillary Equipment</u>
Any devices including, but not limited to, such devices as piping, fitting, flanges, valves, and pumps used to distribute, meter, or control the flow of regulated substances to and from an UST.

<u>Destructive Testing</u>
Destructive testing methods involve examination procedures that result in permanent physical or structural damage to the object undergoing testing.

<u>Maintenance</u>
The normal operational upkeep to prevent an underground storage tank system from releasing product.

Nondestructive Testing
A nondestructive testing method does not require damaging or destroying the object undergoing testing through microscopic or macroscopic examinations of the physical structure, a nondestructive test will detect a potential structure failure or weaknesses.

Operational Life
The period beginning when installation of the tank system has commenced until the time the tank system is properly closed under 40 CFR 280 Subpart G. The operational life of the UST as defined here, is the period which has been defined to include all internal inspections. Inspections that occur before and after the operational life of the tank are not included.

Repair
To restore a tank or UST system component that has caused a release of product from the UST system.

Tank
A stationary device designed to contain an accumulation of regulated substances and constructed of non-earthen materials (e.g., concrete, steel, plastic) that provide structural support. The inspection of USTs as described in this document is specific to the tank portion of the system. Pipes, vents, pumps, valves and other ancillary equipment are not included in the scope of this report. Beyond this limitation, the terms "UST and "tank" are used synonymously.

Underground Storage Tanks or USTs
Any one or combination of tanks (including underground pipes connected thereto) that is used to contain an accumulation of regulated substances, and the volume of which (including the volume of underground pipes connected thereto) is 10 percent or more beneath the surface of the ground.

Upgrade
The addition or retrofit of some UST systems with features such as cathodic protection, lining, or spill and overfill controls to improve the ability of an underground storage tank system to prevent the release of product.

## 1.5 SUMMARY OF FINDINGS

A total of seventeen internal inspection methods were identified during this study. Each method is designed to evaluate a particular characteristic of the tank. There are five key categories of characteristics whereby the methods identified are classified: tank wall thickness, deflection, lining integrity, tank discontinuities, and tank tightness. Deterioration of the tank in any of these categories will result in risk of the development of a leak or complete failure.

Tank Wall Thickness

This parameter refers to the thickness of a steel tank's shell. A minimum wall thickness must be maintained at all times in order for any tank to remain operational. Corrosion is the principal culprit in reducing wall thickness.

Deflection

All tanks (steel and FRP) change in shape as product is added or removed. However, the ability to repeatedly accommodate a change in shape while supporting the load of the surrounding backfill is crucial to preventing failure of the entire tank. Measurements are obtained and calculations performed to evaluate whether deflection is within normal limits.

Lining Integrity

Many tanks are lined with epoxy or fiberglass resin to further protect against the development of leaks and cracks in the outer tank shell. It is therefore necessary to monitor the lining itself both after application and at regular intervals during the tank's life. Various methods exist to inspect the lining thickness, hardness, and integrity (cracks, pinholes, air bubbles).

Tank Discontinuity

Inspections designed to identify discontinuities are checking for surface or subsurface flaws which develop as a result of corrosion, stress, improper welding (of steel) or improper lamination of lining material. A variety of methods exist to assess the presence of any such discontinuities.

Tank Integrity

Examination of tank integrity is generally required or recommended by UST manufacturers, trade organizations, and Federal regulations. Test methods in active practice indicate the presence of leaks or provide information about structural strength.

Table 1 presents the internal inspection methods that were identified during this study which have been organized according to their use for different types of tanks and inspections.

Internal inspections can be categorized into four critical phases during the operational life of a tank: installation, upgrading and repair, maintenance, and closure. Table 2 lists the internal inspection methods that are used during each type of inspection for both steel and FRP tanks. Any of the internal inspections methods discussed can be used for a multitude of inspections. These methods have been categorized according to the four phases of tank life to assist inspection personnel in identifying which method(s) might be most appropriate under the circumstances.

## TABLE 1. INTERNAL INSPECTION METHODS USED FOR DIFFERENT TYPES OF TANKS AND INSPECTIONS

| METHOD | INSTALLATION | | UPGRADING & REPAIR | | MAINTENANCE | | CLOSURE | |
|---|---|---|---|---|---|---|---|---|
| | Steel | FRP | Steel | FRP | Steel | FRP | Steel | FRP |
| **TANK DISCONTINUITIES** | | | | | | | | |
| Visual Test (Human Eye) | X | X | X | X | X | X | X | X |
| Visual Test (Boroscope); | | | X | X | X | X | | |
| Liquid Dye Penetrant Test | | | X | X | X | X | | |
| Magnetic Particle Test | | | X | | X | | | |
| Eddy Current •• | | | X | | X | | | |
| Radiography •• | | | X | X | X | X | | |
| Acoustic Emission • | | | X | X | X | X | | |
| Microwave • | | | X | X | X | X | | |
| **TANK TIGHTNESS** | | | | | | | | |
| Bubble Test | X | X | X | | X | X | | |
| Pressure Change | X | | X | X | X | X | | |
| Vacuum Test | | X | X | X | X | X | | |
| **TANK WALL THICKNESS** | | | | | | | | |
| Ultrasonic Test | | | X | X | X | X | | |
| Hammer Testing | | | X | | X | | | |
| **TANK LINING** | | | | | | | | |
| Holiday Test | | | X | X | | | | |
| Lining Hardness Test | | | X | X | | | | |
| Dry Film Thickness Test | | | X | X | | | | |
| **TANK DEFLECTIONS** | | | | | | | | |
| Internal Tank Diameter | | X | | X | | X | | |

• Technically advanced methods, not commercially available
•• Applicable technologies not practiced

TABLE 2. INTERNAL MEASUREMENTS EMPLOYED DURING INPECTIONS

| INSTALLATION | UPGRADING & REPAIR | MAINTENANCE | CLOSURE |
|---|---|---|---|
| **Steel** | **Steel** | **Steel** | **Steel** |
| 1. Visual Inspection<br>2. Positive Pressure Test<br>3. Bubble Test | 1. Tank Cleaning<br>2. Ultrasonic Test<br>3. Hammer Test<br>4. Visual Inspection<br>5. Liquid Dye Penetrant Test<br>6. Magnetic Particle Test<br>7. Holiday Test<br>8. Dry Film Thickness Test<br>9. Lining Hardness Test (optional)<br>10. Positive Pressure Test | 1. Visual Inspection<br>2. Liquid Dye Penetrant Test<br>3. Magnetic Particle Test<br>4. Ultrasonic Test<br>5. Hammer Test<br>6. Positive Pressure Test<br>7. Bubble Test | 1. Visual Inspection |
| **FRP** | **FRP** | **FRP** | **FRP** |
| 1. Visual Inspection<br>2. Vacuum Test<br>3. Bubble Test<br>4. Internal Tank Diameter Measurement | 1. Tank Cleaning<br>2. Ultrasonic Test<br>3. Vacuum Test<br>4. Internal Tank Diameter Measurement<br>5. Visual Inspection<br>6. Liquid Dye Penetrant Test<br>7. Holiday Test<br>8. Dry Film Thickness Test<br>9. Lining Hardness Test (optional)<br>10. Bubble Test | 1. Visual Inspection<br>2. Liquid Dye Penetrant Test<br>3. Vacuum Test<br>4. Ultrasonic Test<br>5. Internal Tank Diameter Measurement<br>6. Bubble Test | 1. Visual Inspection |

Installation inspections are designed to identify structural damage immediately before and after the tank is in place and to check tank tightness. Upgrade or repair inspection activities are designed to evaluate a tank's lining, discontinuities, wall thickness, tightness, and deflection. Routine maintenance activities provide an excellent opportunity for determining the overall integrity of the tank. The final regulations provide for internal inspection for upgrade or repair. The maintenance aspect appears to have little interplay with inspection. All experts contacted agreed that owners tend to ignore the installed UST until evidence of a leak is detected. There is no preventive maintenance inspection procedure in common use. By definition, the UST must leak for a repair to be initiated. Inspections at closure assist in ascertaining the level of cleanliness before removal or abandonment-in-place. A new element in internal inspections is the remanufacture of tanks that have been taken out of service. Information is still being collected on this very new and rapidly evolving business area.

Procedures to empty and clean tanks, which are a necessity when performing internal inspections, have been researched and documented. Appendix A has been created for this report to present essential information pertaining to tank emptying and cleaning activities.

Frequently a tank's surface must be prepared after cleaning and before the internal inspection can be performed. A general discussion on procedures associated with tank surface preparation is presented in Appendix B. Information relative to tank isolation procedures is also addressed in Appendix B. The reader is encouraged to obtain comprehensive information on both tank cleaning and surface preparation.

Many methods necessitate tank entry. Entry is an inherently hazardous activity. There are risks posed by the inspection of confined spaces including chemical exposure, fire, and explosion. Additionally, standard health and safety procedures call for extra precautions when working in contaminated environments. While many health and safety plans exist for internal inspection methods, their quality was found to vary dramatically. Although the quality of health and safety procedures is beyond the technical scope of the project, its importance cannot be overstated nor ignored. Appendix E has been developed to introduce critical issues pertaining to safety precautions, but is not intended to replace an in-house safety program.

## 1.6 SELECTING INTERNAL INSPECTION METHODS

Information gathered throughout this study indicates that the selection of inspection methods is dependent upon several factors. The selection process is a tiered one, however, and is presented here only as a general guide. Further investigation is needed to validate the parameters in this process. A brief summary of the selection process is presented below.

The primary consideration in the selection process is the type of activity occurring at the tank (i.e., installation, upgrading/repair, maintenance, closure). With the exception of visual inspection, internal inspection methods are categorized by the particular activities associated with the unique phases of a tank's operational life as shown in Table 2.

The second consideration in the selection process is the construction material of the tank. Many methods that are designed for steel tanks would result in structural damage if performed on FRP tanks. The application of a hammer test would be futile on an FRP. A third consideration in choosing an appropriate inspection method is the type of equipment used to perform the test. It is important to identify and evaluate the potential for a particular instrument to compromise the integrity of the tank surface or subsurface.

After the third phase of the method selection process has been completed, other factors can narrow the choices. Six such factors include: 1) the cost associated with the required downtime, 2) the availability of experienced inspectors/testers, 3) ease of entry into the tank with equipment, 4) the effect of residues and product and test results, 5) location of tank entry way, and 6) whether the tank is surrounded by fill material (or enclosed in a vault).

# SECTION 2.0

# CONCLUSIONS

Literature reviewed in this study suggests that no compilation of internal inspection methods has been prepared to date. The identification and description of these methods in a single document serves to educate owner/operators in selecting the most appropriate type of inspection under specific phases (e.g., installation, closure) of the operational life of the tank. Several methods have also been identified during the pre-installation and post-removal phases of the tank's life. However, since the focus of the study is on the operational life of the tank, inspections associated with manufacture and remanufacture are not emphasized in this study. Refer to Appendix D for further discussion on inspections at remanufacture.

Little information is available on the impact of tank size on the performance of the tests. Most methods require testing on a unit-surface-area basis. Tests are repeated at regularly defined intervals over the entire internal surface of the tank. Without the benefit of further investigation, this suggests that tank size has little influence on the performance of tests or their results. One possible exception is that of tank size versus size of the inspector and the impact it has on performing the test as required. This information also indicates that tank size has little bearing on the selection of the test method.

No information is currently available which provides an understanding of key factors which affect the application and performance of each method. Only a comprehensive study and comparison of the methods would provide this information.

Some standards contradict others, and, on occasion, there are conflicting directions within individual standards. Vacuum tests and tank deformation tests, for instance, are not explicitly required by EPA in the preamble to the regulations, but referenced standards use these methods. Tanks that are repairable under API 1631 may not be repairable under NLPA 631. More common than outright contradictions are instances where technical details are so subtle that they are probably beyond the engineering expertise of the typical owner/operator. There is a clear need for a cohesive, coordinated set of rules and standards that apply to UST inspections.

Based on results of the study, the methods most often used were found to be:

- Ultrasonic test
- Hammer test
- Internal tank diameter
- Holiday test
- Lining hardness test
- Visual (human eye) examination
- Bubble test
- Positive pressure test

Two methods were practiced as internal inspection techniques for USTs in past years, but their frequency of use has been found to have dropped off significantly. Radiography and eddy current technologies are no longer widely practiced for the reasons described in Section 5.0. Among them are cost and the generation of wastes which require special handling.

The remaining three methods have been used widely in applications other than UST internal inspections which require further research, development, and demonstration to adapt them for use as specific UST inspection methods. This work may involve modifying the existing method to be less expensive and easier to conduct or may require the development of performance standards for sensitivity, precision and accuracy. These are acoustic emission, boroscope, and microwave technologies. Further discussion of these technically advanced methods appears in Section 6.0.

In order to reduce the potential for tank failure and increase the life span of tanks, EPA may need to develop performance standards, or guidelines for internal inspection during two key stages of a tank's operational life: 1) at installation to ensure proper seating and anchoring of tanks; and 2) at upgrade/repair to ensure that lining materials are installed properly and are compatible with tank contents.

EPA recognizes that the majority of tank failures and petroleum releases occur at these phases as a result of the absence or inappropriate use of internal inspections or universal performance standards for a particular internal inspection method. However, research does not reveal any mechanisms designed to enforce established requirements which trigger inspections.

Research conducted in this study has resulted in the consolidation of a body of knowledge which raises questions about how this information can best be disseminated. Clearly, additional investigation and evaluation would benefit the regulated community by promoting the implementation of preventive programs (proactive maintenance). Specific recommendations are provided in Section 3.0 of this report.

Internal inspections fall into four categories: installation, upgrading and repair, maintenance, and closure. Table 3 is a compilation of the internal inspection methods identified in this study and a summary of pertinent application and industry standards.

## TABLE 3. SUMMARY OF INTERNAL INSPECTION METHODS

| Inspection Method | Tank Material | Application | Standards |
|---|---|---|---|
| Ultrasonic Test | Steel | Upgrade / Repair<br>Maintenance | UL 58<br>NLPA631<br>ASTM E 797-87<br>ASTM E 114-85 |
| | FRP | Upgrade / Repair<br>Maintenance | UL 1316<br>NLPA631<br>ASTM E 797-87<br>ASTM E 114-85 |
| Hammer Test | Steel | Upgrade / Repair<br>Maintenance | NLPA 631<br>UL 58 |
| Internal Tank Diameter | FRP | Installation<br>Upgrade / Repair<br>Maintenance | NLPA 631 |
| Holiday Test | Steel | Upgrade / Repair | NLPA 631<br>NACE RP0188-88 |
| | FRP | Upgrade / Repair | NLPA 631<br>NACE RP0188-88 |
| Lining Hardness | Steel | Upgrade / Repair | NLPA 631<br>ASTM 02583-87<br>FPTPI T-90-01 |
| | FRP | Upgrade / Repair | NLPA 631<br>ASTM 02583-87<br>FPTPI T-90-01 |
| Dry Film Thickness | Steel | Upgrade / Repair | NLPA 631<br>FPTPI T-90-01 |
| | FRP | Upgrade / Repair | NLPA 631<br>FPTPI T-90-01 |

TABLE 3. SUMMARY OF INTERNAL INSPECTION METHODS (continued)

| Inspection Method | Tank Material | Application | Standards |
|---|---|---|---|
| Visual Examination | Steel | Installation<br>Upgrade / Repair<br>Maintenance<br>Closure | ASTM D2563-70 |
| | FRP | Installation<br>Upgrade / Repair<br>Maintenance<br>Closure | ASTM D2563-70 |
| Liquid Dye Penetrant | Steel | Upgrade / Repair<br>Maintenance | ASTM E 165-80 |
| | FRP | Upgrade / Repair<br>Maintenance | ASTM E 165-80 |
| Magnetic Particle | Steel | Upgrade / Repair<br>Maintenance | ASTM S 269-84a |
| Eddy Current | Steel | Upgrade / Repair<br>Maintenance | NA |
| Radiography | Steel | Upgrade / Repair<br>Maintenance | NA |
| | FRP | Upgrade / Repair<br>Maintenance | NA |
| Acoustic Emission | Steel | Upgrade / Repair<br>Maintenance | ASTM E 610-82 |
| | FRP | Upgrade / Repair<br>Maintenance | ASTM E 610-82 |

## TABLE 3. SUMMARY OF INTERNAL INSPECTION METHODS (continued)

| Inspection Method | Tank Material | Application | Standards |
|---|---|---|---|
| Microwave | Steel | Upgrade / Repair<br>Maintenance | NA |
| | FRP | Upgrade / Repair<br>Maintenance | NA |
| Bubble Testing | Steel | Installlation | UL 58<br>NLPA631<br>NFPA 30 |
| | FRP | Installation | UL 1316<br>NLPA631<br>NFPA 30<br>FPTPI RPT-89-1<br>ASTM D4021-81 |
| Positive Pressure Test | Steel | Installation<br>Upgrade / Repair<br>Maintenance | UL 58<br>NLPA631<br>NFPA 30 |
| | FRP | Installation<br>Upgrade / Repair<br>Maintenance | UL 1316<br>NLPA631<br>NFPA 30<br>FPTPI RPT-89-1<br>ASTM D4021-81 |
| Vacuum Test | FRP | Installation<br>Upgrade / Repair<br>Maintenance | UL 1316<br>NLPA631<br>NFPA 30<br>FPTPI RPT-89-1<br>ASTM D4021-81 |
| Boroscope | Steel | Installation<br>Upgrade / Repair<br>Maintenance | ASTM D2563-70 |
| | FRP | Installation<br>Upgrade / Repair<br>Maintenance | ASTM D2563-70 |

# SECTION 3.0

# RECOMMENDATIONS

While the research conducted in this study has resulted in findings and conclusions pertaining to the state-of-the-art in internal inspection methods, new questions are raised relative to how this knowledge can best be used and what additional information should be collected. In order to establish a full understanding of the range of internal inspection applications and performance, several tasks have been identified to undertake further research and evaluation.

- Obtain data concerning inspections applied by tank owner/operators as part of a comprehensive maintenance program. Specifically, a determination should be made from the information gathered in this study on the identification of routinely-performed inspections as they may relate to a comprehensive maintenance program.

- Develop protocol manuals to ensure that there is a standard application of each internal inspection method for determining tank integrity. These manuals should include both a protocol for conducting each method as well as a decision tree for the selection of a method with respect to the phase of operational life of the tank (e.g., installation, upgrading).

- Design and execute a bench-scale program to evaluate the key factors affecting the application and performance of each test method. Such a program would investigate variable parameters such as temperature, pressure, and lining material and their impact on various standards and methods employed by tank lining contractors.

- Develop procedures to improve the performance of several SOTA internal inspection methods and validate more reliable protocols for those methods.

- Contact state regulatory agencies to ascertain which internal inspection methods are used or permitted. A determination should then be made as to the following:

  - Frequency of inspections.
  - Selection criteria for a particular inspection method.
  - Effectiveness of the chosen method.

- Because disposal of tanks that are taken out of service is costly, there is increasing interest in the reuse and remanufacture of tanks. The Association for Composite Tanks (ACT) is currently developing standards for Fiberglass-reinforced plastics (FRP)/steel clad tanks and is currently lobbying Underwriters' Laboratory (UL) for an appropriate standard. Further research and development of performance standards for remanufactured tanks may support this new market.

# SECTION 4.0

# INTERNAL INSPECTION METHODS

Of the seventeen internal inspections identified, twelve are used regularly by tank owners and operators and constitute the "state of the art." Table 4 presents a summary of internal inspection methods in light of various environmental considerations.

This section contains detailed descriptions of those methods commonly used to inspect tanks internally. These methods have been organized into groups based on the primary objective of the inspection.

- Tank Wall Thickness
  - Ultrasonic testing
  - Hammer testing
- Tank Deflection
  - Internal tank diameter measurements
- Tank Lining
  - Holiday testing
  - Barcol testing
  - Dry film thickness testing
- Tank Discontinuities
  - Visual examination
  - Liquid dye penetrant testing
  - Magnetic particle testing
- Tank Tightness
  - Bubble testing
  - Positive pressure testing
  - Vacuum testing

For each of these methods, the fundamental operating principles, procedural description, method performance and field considerations are discussed.

TABLE 4. INTERNAL INSPECTION METHODS AND ENVIRONMENTAL CONSIDERATIONS

| Inspection Method | Tank Orientation | Ambient Conditions | Surface Conditions | Waste Streams |
|---|---|---|---|---|
| Ultrasonic Test | - Backfill material and groundwater depth may affect wave response. | - Calibration and examination temperatures should be within 14C to avoid wave velocity differences.<br>- Extreme temperatures, high humidity, and corrosive environments affect instrument performance. | - Excessive dirt, oil, loose scale and varying organic coatings will inhibit proper transducer contact. | - Waste from surface cleaning or sandblasting generated. |
| Hammer Test | - Non-homogenous backfill or groundwater depth may affect hammer response, vibrations, or ringing. | None | None | None |
| Internal Tank Diameter Measurements | None | None | None | None |
| Holiday Testing | None | - Temperature<br>- Moisture | - Solvents retained in the coating film can produce erroneous results.<br>- Sodium chloride should not be added to the wetting solution, salt may form a continuous conductive path producing false positive resluts. | None |
| Lining Hardness | None | - Temperature<br>- Moisture | - Test surface should be smooth and clean.<br>- Homogeneous and non-homogeneous lining materials produce variable results. | None |
| Dry Film Thickness | None | - Temperature<br>- Moisture | - Test surface should be smooth and clean. | None |

TABLE 4. INTERNAL INSPECTION METHODS AND ENVIRONMENTAL CONSIDERATIONS (continued)

| Inspection Method | Tank Orientation | Ambient Conditions | Surface Conditions | Waste Streams |
|---|---|---|---|---|
| Visual Examination | None | - Minimal ambient lighting required for interpretation of results. | - Dirt, oil, loose scale and varying organic coatings will mask discontinuities.<br>- Grinding the metal surface will "smear" over the discontinuities. | - Waste from surface cleaning or sandblasting generated. |
| Liquid Dye Penetrant | None | - Minimal ambient lighting required for interpretation of results when using visible dye penetrants.<br>- Moisture or high humidity will inhibit particle mobility.<br>- Ambient temperature must be between 15 and 38C or undergo qualification procedure. | - Dirt, oil, loose scale and varying organic coatings will mask discontinuities.<br>- Rough surface will produce false positives.<br>- Grinding the metal surface will "smear" over the discontinuities. - Surface of the tank is not to exceed 38C. | - Waste from surface cleaning or sandblasting generated.<br>- Solvent-removable aerosol cans are readily disposed in industrial dumpsters. |
| Magnetic Particle | None | - High humidity will cause particle agglomeration and reduce mobility. | - Dirt, oil, loose scale and sludge will restrict particle mobility.<br>- Rough surface will produce false positives.<br>- Grinding the metal surface will "smear" over the discontinuities. | - Waste from surface cleaning or sandblasting generated. |

TABLE 4. INTERNAL INSPECTION METHODS AND ENVIRONMENTAL CONSIDERATIONS (continued)

| Inspection Method | Tank Orientation | Ambient Conditions | Surface Conditions | Waste Streams |
|---|---|---|---|---|
| Bubble Testing | - Tank exterior to be tested must be exposed.<br>- FRP tanks swell and may inhibit detection of pinholes. | None | - Dirt, oil, grease, and paint may plug holes and mask leaks. | None |
| Positive Pressure Testing | - Increased pressure creates a volumetric change through tank deformations.<br>- FRP tanks swell and may inhibit detection of pinholes.<br>- Backfill material will provide resistance and requires greater test sensitivity.<br>- Tank deformation is more prominent in large tanks. | - Barometric change will affect internal pressure.<br>- Temperature change will affect the volume of the stored product in the tank (Hydrostatic Test)<br>- Temperature and pressure of a contained gas are directly proportional; temperature decreases are accompanied by pressure decreases. | - Dirt, oil, grease, and paint may plug holes and mask leaks. | None |
| Vacuum Testing | - FRP tanks swell and may inhibit detection of pinholes.<br>- Tank deformation is more prominent in large tanks. | - Barometric changes will affect internal pressure.<br>- Temperature variations influence detection. | - Dirt, oil, grease, and paint may plug holes and mask leaks. | None |

Two methods which are no longer in active practice are described in Section 5.0 and a discussion of three technically-advanced methods appears in Section 6.0.

## 4.1 TANK WALL THICKNESS

The thickness of the steel tank shell is a critical parameter in deciding if it is to be taken out of service. Both API 1631 and NLPA 631 require inspectors to identify areas where corrosion has reduced tank wall thickness to 3.2mm (1/8-inch) or less. The number, concentration, and size of these thin areas determine if a tank can be lined and/or repaired.

Periodic wall thickness measurements potentially enable the owner to project the remaining lifetime of an UST. This standard specifies that USTs must be taken out of service when the mean wall thickness compiled using spot and/or area-weighted averages reach specific values. Knowing that UL58 specifications control manufacturing, the procedures in API 510 can be used as input to a present value analysis of the alternatives. The owner/operator can make economic choices using one of two methods for wall thickness determination: the ultrasonic test, and the hammer test.

### Ultrasonic Testing

Ultrasonic testing can determine the wall thickness or locate surface or subsurface discontinuities of a steel or FRP UST. However, the use of ultrasonic testing to detect discontinuities is time consuming and expensive. Therefore, wall thickness determination is the primary use of ultrasonic testing for UST internal inspections.

Fundamental Operating Principle--

There are several ultrasonic techniques used for thickness determination. The most portable and widely used technique is the pulse-echo. This technique sends an ultrasonic pulse (wave) propagating from the surface of the tank through the tank wall at a constant velocity. The velocity of the pulse is dependent upon the physical properties of the tank (e.g., material, surface finish). The ultrasonic pulse is reflected back (echoed) to the instrument when it encounters a discontinuity or wall boundary. Figure 1 provides an example of the pulse-echo activity of an ultrasonic instrument. The transit time is the total time for the ultrasonic pulse to travel through the tank wall and reflect back. The tank thickness is determined by multiplying the transit time by the velocity of the pulse and dividing by two.[1]

A pulse-echo ultrasonic instrument measures the transit time of the ultrasonic pulse and calculates the wall thickness. This instrument uses a transducer to convert

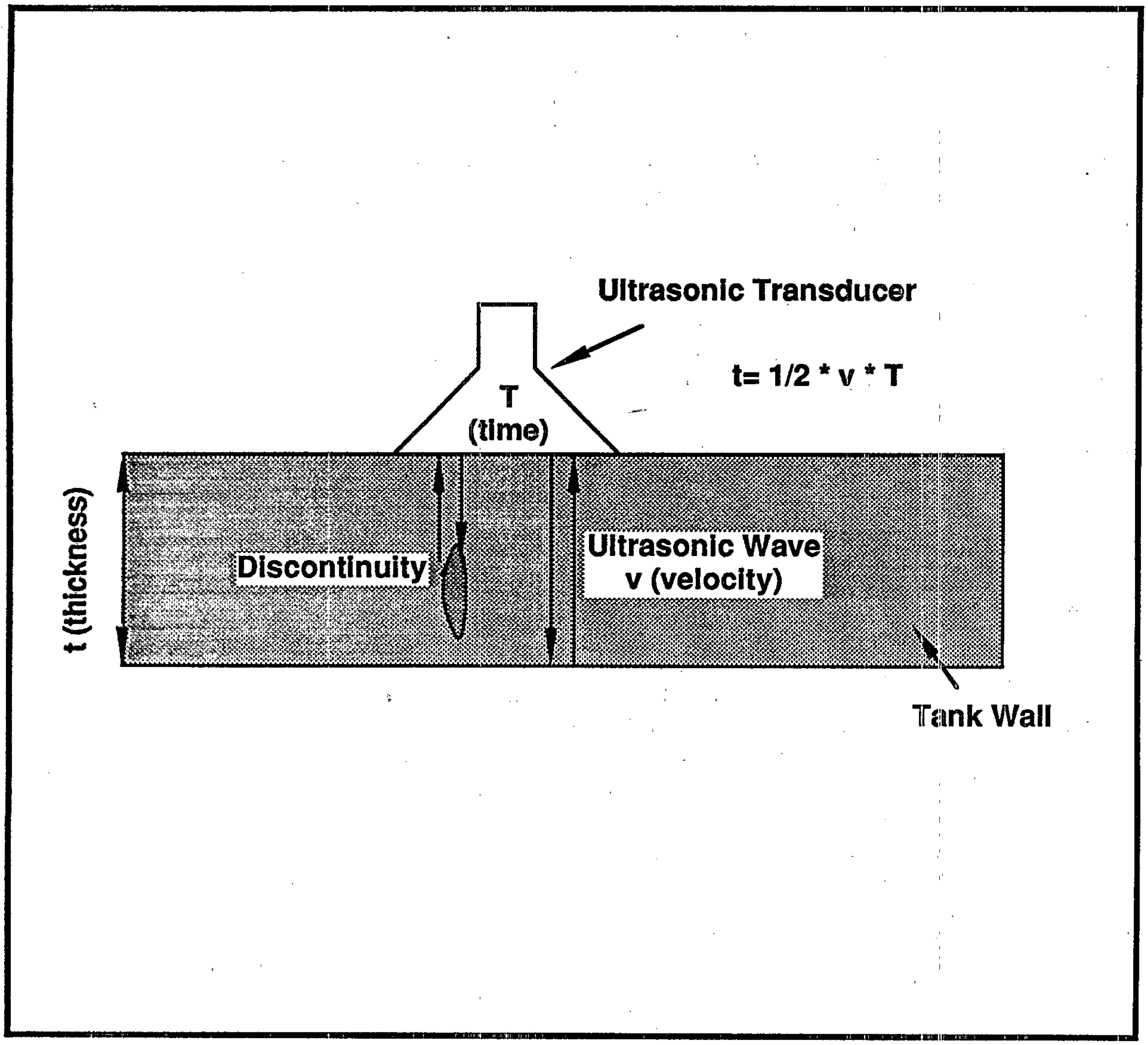



Figure 1. Example of Wave Activity Through Tank Wall
Using Ultrasonic Test

electrical energy to high-frequency mechanical vibrations (ultrasonic pulses). The echo or reflected vibration strikes the transducer which converts the vibration to a measurable electrical signal. The time between transmission and the echo return indicates the thickness of the medium or the depth of any discontinuities encountered. The amplitude of the echo allows the user to discern what caused the echo. The instrument can display the readings by digital readout or an analog meter. The velocity of wave is determined on site with calibration blocks. Figure 2 is taken from ASME SE-797 and graphically presents the relationship between the transit time and thickness for steel.[2]

Other instruments used to measure thickness incorporate a dual transducer that generates an inclined beam as seen in Figure 3 (Dual transducer nonlinearity). As compared to Figure 2, the angled-beam is less accurate as the thickness of steel becomes less than 2.5mm (0.10 in.). However, the angled-beam focuses the ultrasonic energy onto a smaller area of the back surface. This allows the instrument to measure the depth of corrosion pitting. Ultrasonic instruments that use the angled-beam technique automatically correct the longer ultrasonic path length to calculate the true wall thickness.[3]

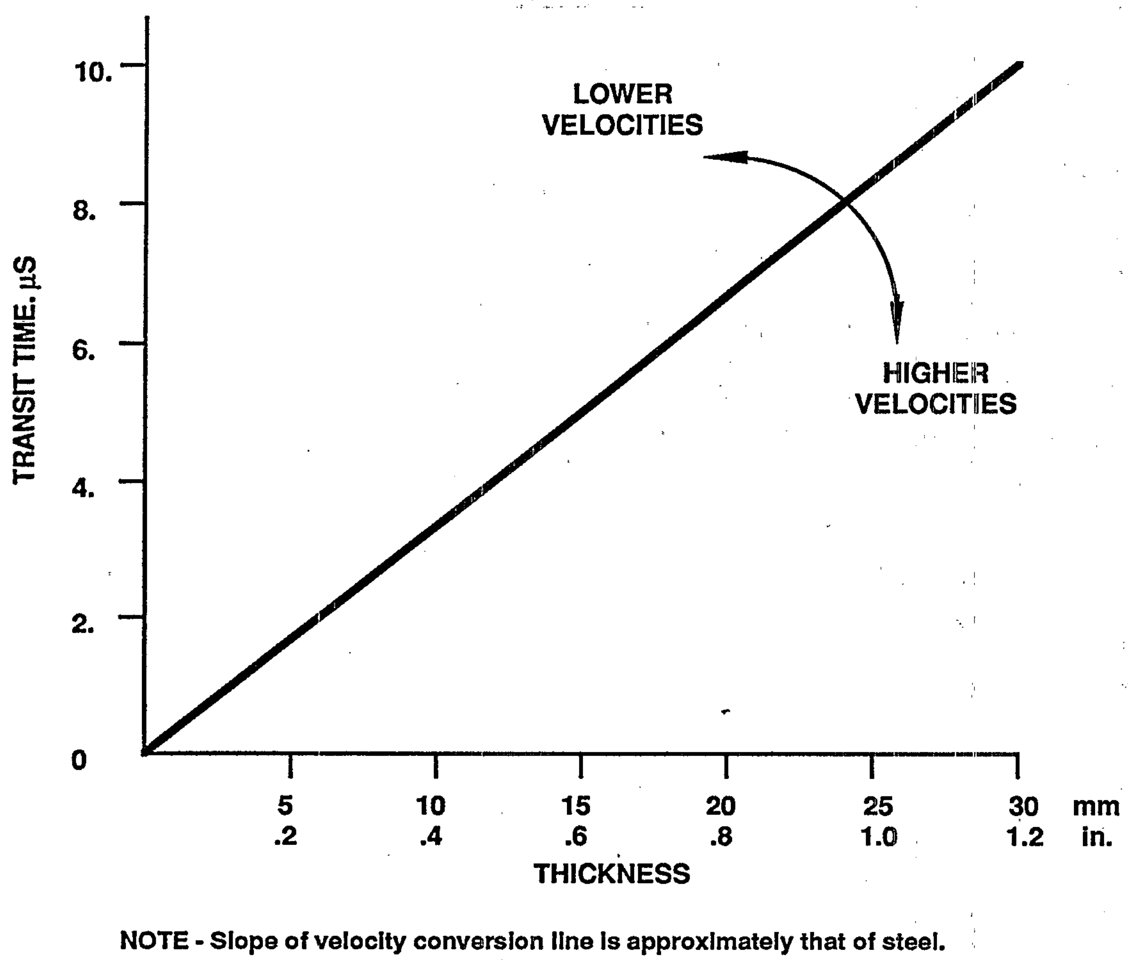
Procedure Description--

Before the thickness determination inspection begins, the instrument should be calibrated. Having a known velocity of the wave as it travels through the medium, the instrument is calibrated by using reference blocks of known thickness, in the range of the thickness to be measured. ASME SE-797 recommends that one block has a thickness near the maximum and the other block near the minimum range of thickness. Calibration and surface examination temperatures should be within 14C to avoid wave velocity differences.[4]

A couplant, a thin liquid film that is placed between the transducer and the tank wall, improves the transmittance of the ultrasonic waves. Examples of couplant liquids are water, oil, grease or corrosion inhibitors. It is important to use the same couplant that was used for the calibration process. Couplant variations in type and amount will reduce the examination sensitivity. The most common couplant liquid is medium-viscosity oil. Petroleum jelly is effective on vertical surfaces.[3]

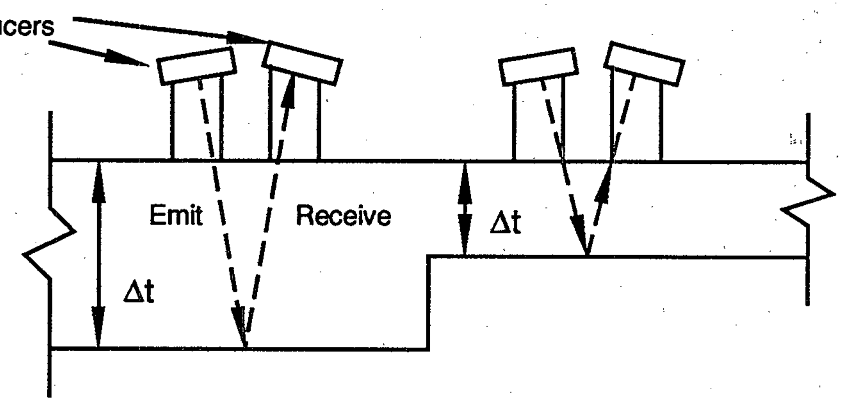
The surface of the tank walls are to be free of loose rust, scale, paint, dirt or other deposits that may interfere with the ultrasonic examination. Surfaces may undergo sandblasting, grinding or other machining operations that produce a smoother surface. Paint, epoxy, or organic coatings that exhibit strong adherence to the tank walls will not interfere with results if these coatings are uniform.[4]

As outlined in NLPA 631, the thickness determination of an UST requires the establishment of the original wall thickness followed by a gauging procedure. The original wall thickness is determined by obtaining measurements at the tank manway.

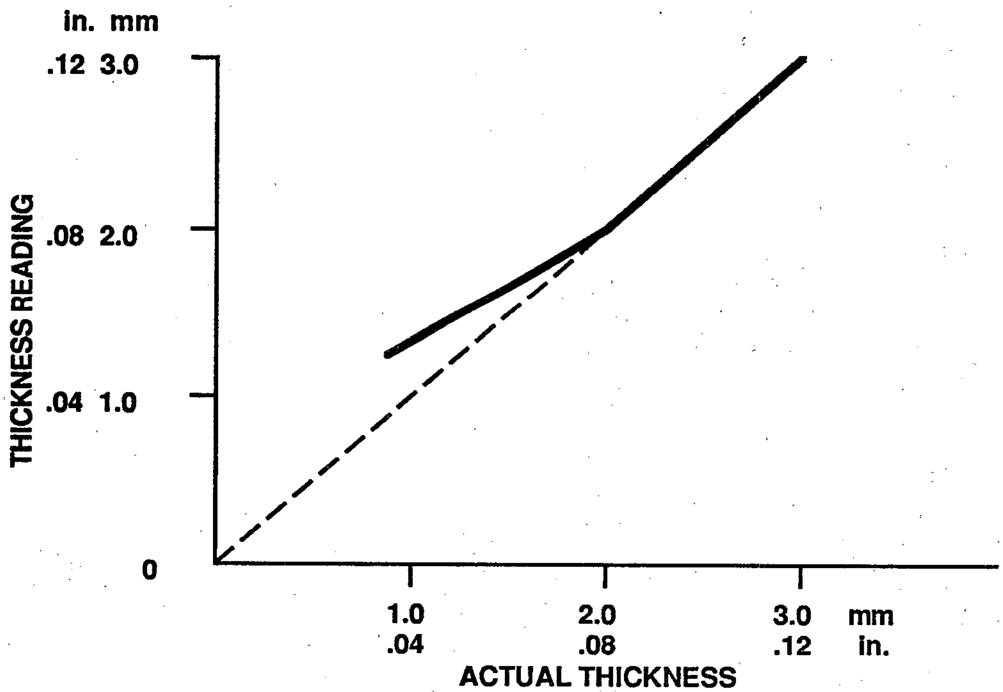



Source: American Society Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing: Standard Practice for Thickness Measurement by Manual Contact Ultrasonic Method. ASME SE-797. New York, New York, July 1989. Reprinted with permission.

Figure 2. Relationship Between Transit Time and Thickness in Ultrasonic Test




**(a) Proportional sound path increases with decrease in thickness.**




**(b) Typical reading error values**

Source: American Society Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing: Standard Practice for Thickness Measurement by Manual Contact Ultrasonic Method. ASME SE-797. New York, New York, July 1989. Reprinted with permission.

Figure 3. Dual Transducer Nonlinearity

The gauging procedure is performed on each head of the tank and the circumference of the walls for the length of the tank.

The heads of the tanks are divided into a minimum of 4 equal quadrants. The maximum size of these quadrants is 1m x 1m square (3 ft x 3 ft) (see Figure 4). The walls of the tank are divided into equal 1m x 1m square quadrants for the entire length of the tank (see Figure 5). For each quadrant along the walls and heads of the tank, a minimum of one thickness measurement is collected. As defined by NLPA 631, thickness measurements less than 75% of the original wall thickness require further subdivisions and measurements for that quadrant. Measurements greater than 75% of the actual wall thickness may be used as an average measurement for the quadrant.[5]

UL58 states that the minimum thickness allowable for a UST is 3.2mm (1/8 in.). API 1631 indicates that ultrasonic measurements are used for UST inspection for wall thickness determinations, but provides no guidelines for inspection. NLPA requires the inspector to report any pits or discontinuities greater than 20% of the original wall thickness. For example, an inspector will report discontinuities that measure 0.64cm (1/4 inch) or more in depth of an UST that was originally 3.2mm (1/8 inch) thick. In accordance with NLPA 631, a tank is acceptable for cathodic protection without interior lining if: 1) there is no internal or external pitting greater than 50% of the original tank wall thickness, and 2) the average metal wall thickness of each 1m x 1m square is greater than 85% of the original wall thickness.[6]

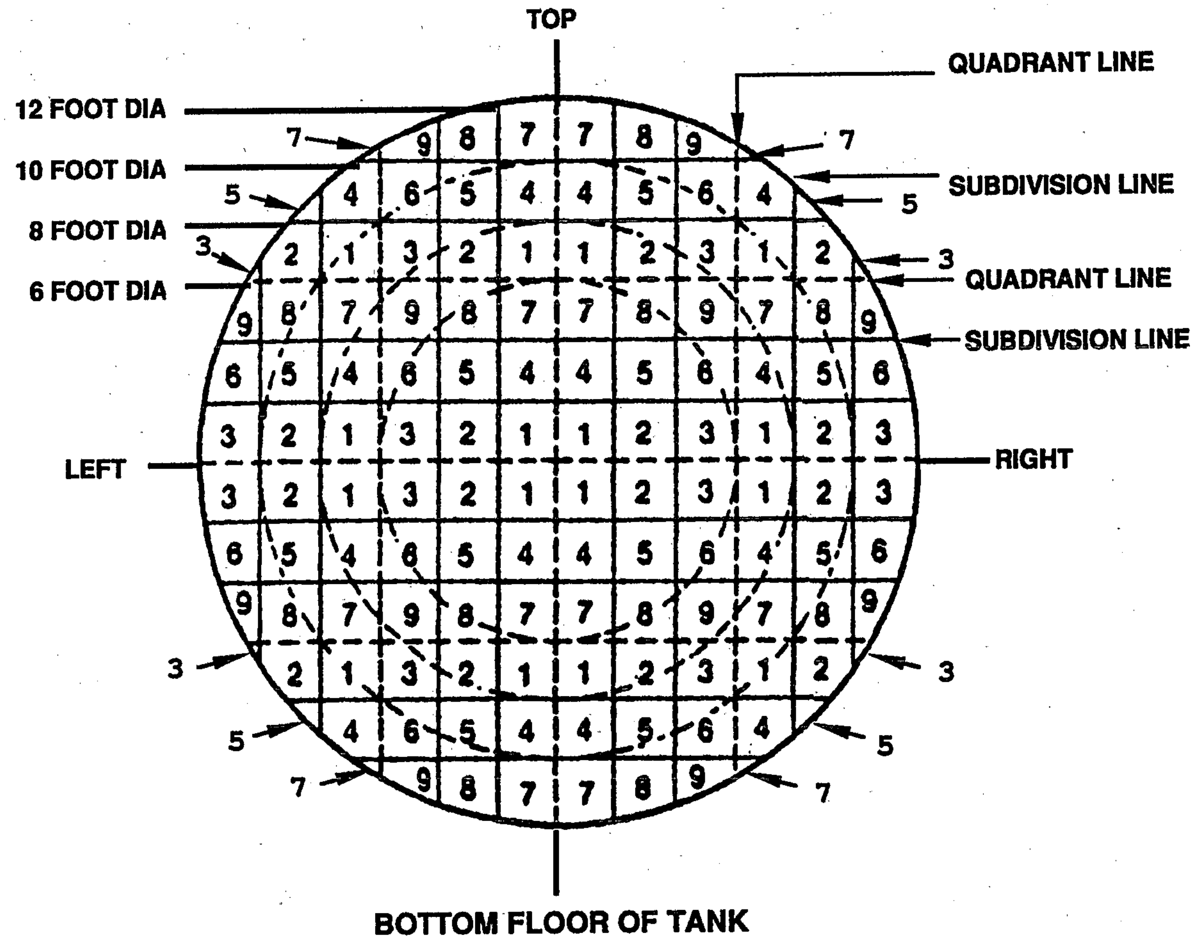
Equipment--

The instruments used to conduct an ultrasonic thickness examination vary in size and complexity. To perform an ultrasonic test on an UST, the instrument needs to be portable and versatile to accommodate the tank geometries. Considering these factors, the instruments commonly used to examine a tank are simple hand-held direct reading instruments (an example is shown in Figure 6). Such ultrasonic instruments employ the time-of-travel between the pulse and echo using a quartz clock. Built-in microprocessors allow the velocity value to be keyed in after being predetermined during the calibration exercise.[3]

Ultrasonic instruments that measure the thickness of steel in the presence of other materials are available. These instruments are useful for examining FRP-lined tanks. Equipment needed to perform ultrasonic thickness examinations include: 1) field notebook with a grid pattern; 2) a couplant (e.g., motor oil, petroleum jelly); 3) calibration blocks (see Figure 7); and 4) a qualified inspector.

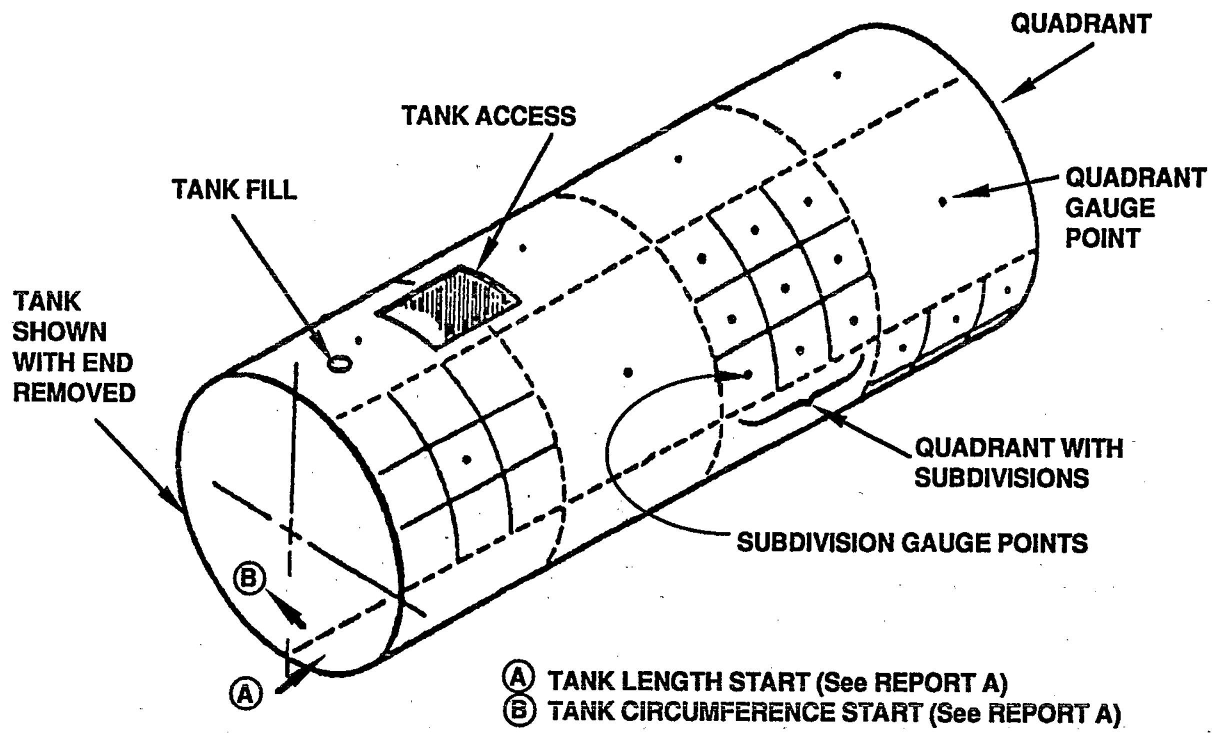
Method Performance--

The instruments in current use have a measuring thickness from 1.0 to 300.0mm with an accuracy or $\pm$0.1mm. Other factors that may affect the accuracy of an examination include the couplant used, the surface condition, and the inspector's ability to interpret the information.[3]




Source: National Leak Prevention Association. Internal Inspection, Repair and Lining of Steel and Fiberglass Storage Tanks. NLPA Standard 631, Second Edition, Cincinnati, Ohio, September, 1988. Reprinted with permission.

Figure 4. Tank Head Diagram




Source: National Leak Prevention Association. Internal Inspection, Repair and Lining of Steel and Fiberglass Storage Tanks. NLPA Standard 631, Second Edition, Cincinnati, Ohio, September, 1988. Reprinted with permission.

Figure 5. Tank Wall Grid Diagram

The couplant helps transmit the ultrasonic waves through amplification and minimizes the influence of surface roughness by providing a smoother contact surface for the instrument. Table 5 lists the suggested weights of the oil couplants best suited for approximate surface roughnesses.[4]

TABLE 5. SUGGESTED WEIGHTS OF THE OIL COUPLANTS FOR SURFACE ROUGHNESS

| Approximate Surface Roughness Average (Ra), µ in. | (µm) | Equivalent Couplant Viscosity, Weight Motor Oil |
|---|---|---|
| 5-100 | 0.1-2.5 | SAE 10 |
| 50-200 | 1.3-5.1 | SAE 20 |
| 100-400 | 2.5-10.2 | SAE 30 |
| 250-700 | 6.4-17.8 | SAE 40 |
| Over 700 | 18- | Cup Grease |

Source: ASTM Specification E 114-85. Recommended Practice for Ultrasonic Pulse-Echo Straight-Beam Testing By the Contact Method.

The contact area of the search unit or transducer are important test parameters. Large transducers allow the inspector to examine large surface areas at a faster rate, but they sacrifice sensitivity. Smaller transducers have higher sensitivity and greater accuracy, but require longer inspection durations.[7]

qThe accuracy of an ultrasonic examination depends heavily upon the inspector. The inspector must properly prepare the surface, calibrate the instrument, and interpret the readings and signals received during the examination. The accuracy of his or her interpretations develop over time and the amount of examinations performed. Professional societies and manufacturers require inspector certification for ultrasonic examinations. NLPA requires personnel to be certified in accordance with NLPA 632 or Level I Competence, Limited to Ultrasonic Testing, with the American Society for Non-Destructive Testing (SNT-TC-1A, Personnel Qualification and Certification In Non-Destructive Testing).

Field Considerations--

Ultrasonic equipment should not be subjected to extreme temperatures, high humidity, or corrosive environmental conditions. Manufacturers provide operating instructions and parameters for these instruments.[7] Other field conditions such as backfill material and groundwater depth were not addressed during the course of this study.

The pulse-echo ultrasonic thickness examination equipment is portable, accurate, and less expensive than other types of ultrasonic equipment. The instruments available for these examinations are simple to use, but a certified instructor is needed for proper examination and interpretation of results. Ultrasonic examinations may be used for discontinuity detection, but may prove to be time consuming and expensive. There are other highly developed ultrasonic examination methods that provide better accuracy. However, these methods are useful only for smaller tank geometries and are not portable.

The cost of an ultrasonic examination is based on the duration of the inspection. A certified ultrasonic examination technician costs about $28 per hour including materials. The overall cost of an ultrasonic examination is dependent upon the type of ultrasonic equipment used, the frequency of measurements, and the size of the tank being investigated. For example, a technician examining a 10,000-gallon tank with a large transducer at 1-by 1-meter increments is cheaper than the same investigation at 0.5 by-0.5 meter increments. Ultrasonic examinations may be used for discontinuity detection, but have proven to be time consuming and therefore more expensive.

<u>Hammer Testing</u>

Fundamental Operating Principle--

This test is analogous to the inspection procedures developed to detect the onset of rot or insect damage in telephone poles. For USTs, hammer testing is used to estimate the wall thickness and identify areas of severe corrosion. The sound produced, hammer rebound, and indentations generated after the wall is struck, are indicative of the tank's current condition. Hammer testing is a non-destructive examination that may only be used on steel tanks. Hammer testing may evolve into a destructive test. Depending upon the condition of the tank, the hammer blows may result in the creation of minimal or severe structural damage.

The hammer test is performed more frequently than any other wall thickness method and is heavily relied upon by the tank lining and remanufacturing industry. Ultrasonic testing (described earlier) provides more accurate results but is more time consuming and expensive. The experience and ability of the inspector are crucial elements in affecting the accuracy of the results of the hammer test inspection.

Procedure Description--

Hammer testing is performed after the interior surface of the tank has been cleaned and sandblasted. The inspector strikes the tank wall over the surface with a 16 to 18 oz. (454-510 gram) non-sparking hammer. The vibration, or rebound of the hammer and the sound produced are dependent upon the tank wall thickness. If the inspector feels no vibration from the 'normal' blows of the hammer, the inspector strikes the suspect area with a hard blow to assess the tank thickness. Indentations of 6.4mm (1/4 in.) or more by the hard blow indicate the wall has corroded to 1.5mm (1/16 in.) or less. Slight vibrations and shallow indentations indicate 3.2mm (1/8 in.) wall thickness. If a series of radial fracture lines develop from the hard blows; severe corrosion is present. A steel tank that is 6.4mm (1/4") thick will cause the hammer to rebound and create a "ringing" sound. Thinner steel walls will have a "ringing" sound, but the sound will not be as loud or as sustained.[5] Figures 4 and 5 (shown earlier) portray the grid patterns of the tank over which the hammer test is to be performed.

A complete description of hammer testing is provided in NLPA 631. While API Recommended Practice (RP) 1631, Internal Lining of Underground Storage Tanks, does not provide descriptive detail it suggests follow up testing in questionable areas. The suspect area can be drilled to physically measure the thickness, or ultrasonic measurements can be taken to provide precise data. Drilling a hole in the tank is a destructive method and inhibits the tank's future use. Drilling the tank wall to measure wall thickness should only be done as a last resort. All steps to avoid this action should be considered. Drilling the tank wall is destructive and will compromise the tank's integrity.

Equipment--

Instruments needed to perform hammer testing examinations include: 1) a 16 to 18 oz. brass hammer (454 to 510 grams), 2) a drill (for destructive determination of wall thickness); and 3) a field notebook.

Method Performance--

A hammer testing examination is entirely dependent upon the senses of the individual performing the test. The inspector uses a combination of sight, sound, and "feel" to identify thin areas of the tank. Data is available to evaluate the effectiveness of hammer testing. EPA concluded (Federal Register, Friday, September 23, 1989, vol. 58, no. 185, p. 37082-37247) that hammer testing in conjunction with lining has been proven an effective method.

Field Considerations--

Hammer testing is inexpensive and portable; a ball-peen hammer and an experienced field inspector are all that are required to perform this test. The experience of the inspector is the critical parameter of this examination. The time and labor effort is minimal but if tests are inconclusive, additional thickness measurements (e.g., ultrasonic, wall drilling) are needed. Hammer testing is applicable only for unlined steel tanks and is usually performed during tank lining procedures or remanufacturing.

Parameters such as backfill material and depth to groundwater may affect the ability of inspector to interpret hammer ringing or rebound. Non-homogenous backfill will produce variable responses and vibrations. These factors were not addressed during the course of this study. It is recommended that future studies consider the affect these factors may impose on inspection results.

Results of this study show that the hammer test is performed more frequently than any other and is relied upon heavily by industry. Like an ultrasonic examination , the cost of a hammer test is dependent upon the duration of the examination. Since hammer testing is faster, the overall cost is cheaper. A certified hammer test technician costs approximately $28 per hour. However, if the hammer test proves inconclusive and requires further testing (i.e., ultrasonic, drilling tank wall) the hammer test may become more expensive.

## 4.2 TANK DEFLECTION

The cross-sectional geometric shape of FRP tanks is subject to change while undergoing structural loading (e.g., backfill during installation). To a lesser degree, steel tanks also change shape during loading. Measurements of the geometry provide an indication of the tank's ability to support and distribute the necessary loads with the given backfill. Any inability to support this load will manifest itself as a change from an elliptical to an elliptical enhanced cross-section as the tank compresses (see Figure 6). Generally, this condition is found after a tank is filled with product. However, the possibility exists that an exaggerated elliptical cross-section may occur in empty tanks. This signals significant stress resulting from improper backfill or installation. Deflection measurements are required at installation and recommended before repair. Extreme deflection of UST tanks can allow the fill pipes to impact and potentially rupture the tank bottom. Deflections of this magnitude can also break welds and buckle tanks.

### Internal Tank Diameter

NLPA 631 requires internal diameter measurements before repair or lining of FRP USTs. The measurements are recommended after 1 year of service and at 10-year intervals thereafter. The same standard also recommends structural assessment within 20 years and at 10-year intervals after the initial inspection. O/C

Tanks and other manufacturers perform an internal deflection measurement as a required step during their installation procedure. Neglecting to perform this inspection could lead to violation of structural warranty.

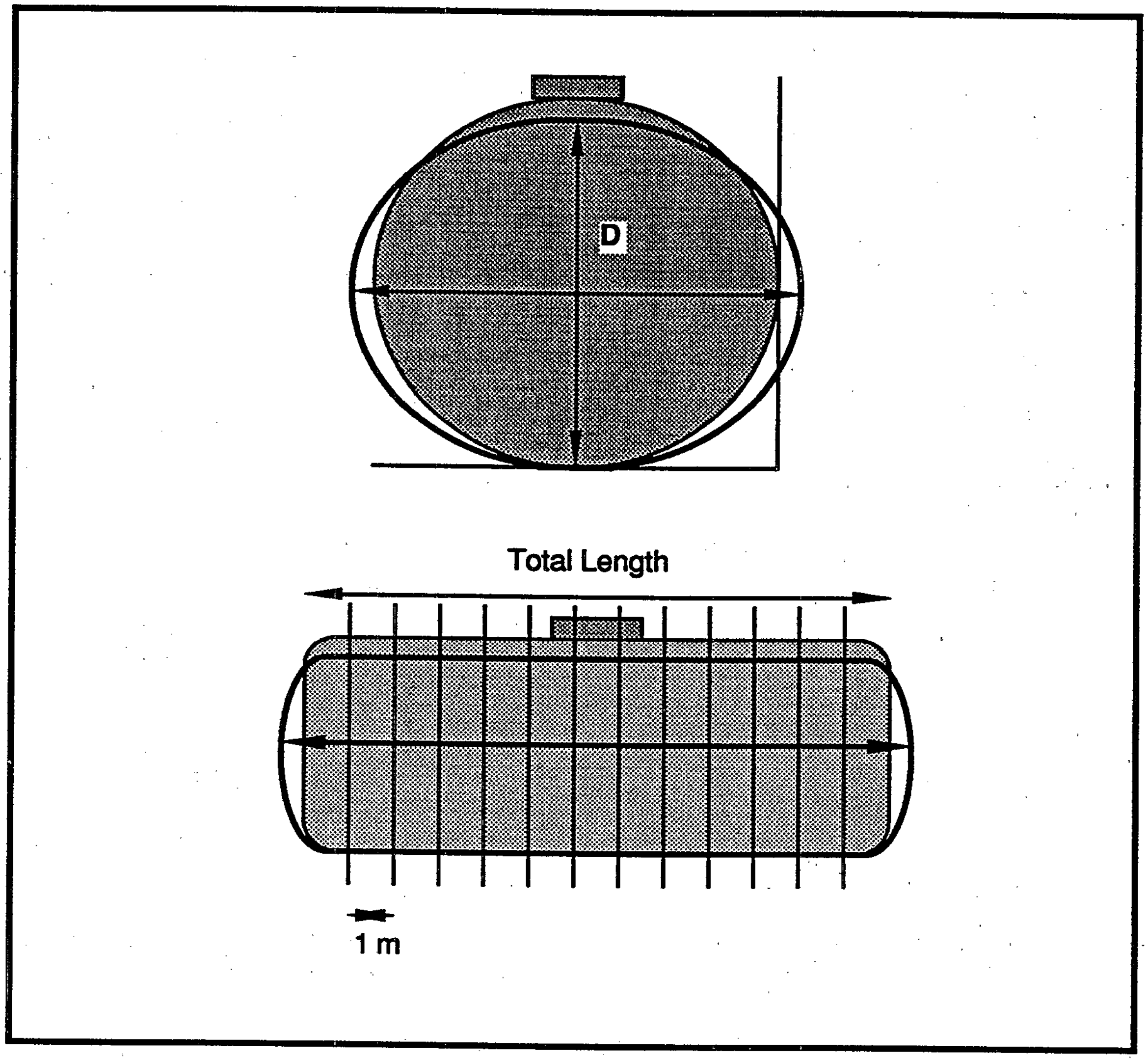



Figure 6. Two Drawings Showing Exaggerated Elliptical Deflection in Cross-Section

Fundamental Operating Principle--

During tank installation, the deformation measurements of the empty tank provide an immediate indication of the adequacy of the backfill to support the UST. Measurement of the vertical internal diameter indicators will determine if excessive deviations from the original tank structure exist.

Procedure Description--

The allowable deformation during installation is set by the manufacturer. Measurements are made through the top openings and recorded at three points during the fill process, when there is: 1) no fill on top of the tank; 2) partial fill material has been placed; and 3) all fill has been placed. Measurements are made with an everyday tank sounding dip-stick across defined datum planes. Table 6 lists representative values of maximum deflection at installation. If these values are exceeded, it is assumed that the backfill is not compacted properly, and the tanks must be reinstalled.

TABLE 6. MAXIMUM ALLOWED SINGLE-WALLED TANK DEFLECTION AT INSTALLATION

| Nominal Tank Diameter | | Maximum Allowable Change in Diameter | |
|---|---|---|---|
| (Ft) | (M) | (In) | (mm) |
| 10 | 3.05 | 1 1/2 | 38.1 |
| 8 | 2.44 | 1 1/4 | 31.8 |
| 6 | 1.83 | 5/8 | 15.9 |
| 4 | 1.23 | 1/2 | 12.5 |

Source: O/C Tanks Corporation, Publication 3-PE-7097. Reprinted with permission.

Tank deflection measurements are also made after the inspector enters the tank. Measurements of the vertical and horizontal "diameters" are made at one-meter (3 foot) intervals along the length of the UST and are used to determine the deflection, or the "out of roundness" of the UST. Tanks with less than 1% deflection are considered structurally sound. Tanks having a measured deflection of 1% are considered structurally sound but also require reinforcement. Tanks varying by more than 2% deflection are not considered structurally sound and cannot be repaired. NLPA 631 does not define the precise meaning of "1% out-of-round." Assuming the intuitive definition applies, (in which the difference between the two measure diameters must be less than 1% of the average), then a 2.4-m (96-in.) diameter tank will have roughly a 25mm (1-in.) deflection limit before reinforcement is required and a 50mm (2-in.) deflection limit before the tank is closed. These allowable deflection levels are not universally recognized values. The disparity between this value and Table 6 emphasizes this. State regulators can have more stringent values. New York State, for example, published recommendations applied within its jurisdiction. Figure 7 shows the three-step procedure for measuring internal diameter.

Equipment--

Instruments needed to measure tank deflection include: 1) a dipstick (measures internal diameter of the tank); 2) a nail (to act as a "pointer"); and 3) a calculator (to calculate the amount of structural deflection or tabulated values).

Method Performance--

The performance of this method is solely dependent upon the accuracy of the measurements taken and the experience of the individual performing the test.

Field Considerations--

An UST structure is not always symmetrical. For example, some FRP tanks are 25 to 50mm (1 to 2 in.) larger in diameter at the center of the tank than at the ends. It is important to refer to the original tank parameters prior to and during an internal deflection measurement.

This test is relatively inexpensive; a dipstick and an experienced field inspector are all that are required. The time and experience requirements are minimal.

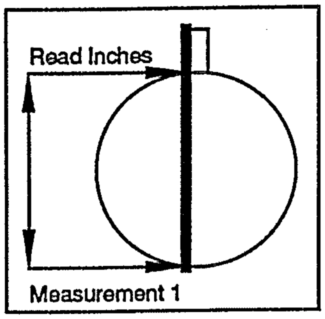
## 4.3 TANK LINING INTEGRITY

The application of tank linings (generally an epoxy compound) and coatings has become a major component of tank reconditioning and/or tank repair. Lining is an upgrade tool that allows tanks to meet the performance standards as required by the Federal regulations. For lining to be considered a permanent upgrade, cathodic protection should also be applied to the tank. Under Federal regulations, unless cathodic protection is applied, lined tanks must be inspected ten years after the lining was installed and every five years thereafter.[8]

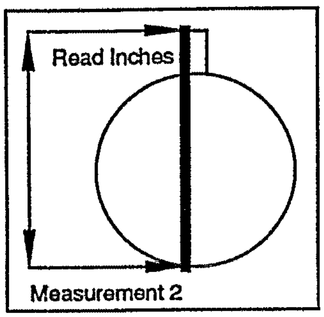
Linings applied to steel and FRP tanks achieve a number of objectives including:

- To protect from product release due to internal or external corrosion
- To repair existing perforations in otherwise structurally sound tanks

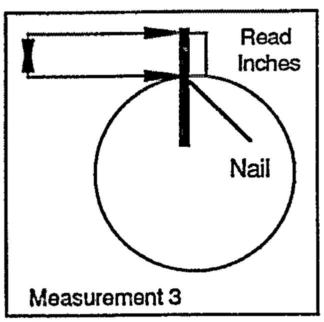
**Measurement Instructions**
All measurements for vertical deflections are made from the bottom of the tank to the bottom of the NPT fitting. All measurements should be made in inches using a standard gauging stick. Measurement 1 may be above ground or in hole prior to backfilling. Measurements 2 and 3 must be made in an unencumbered access fitting (no fill tube insert).




**Measurement 1** is the inside diameter of the tank at a fitting opening. Measure from the bottom of the tank to the bottom of the fitting. This measurement should be taken prior to placing any backfill.




**Measurement 2** is the distance from the bottom of the tank to the top of the riser pipe. Backfill should be to subgrade at this time.




**Measurement 3** is the distance from the bottom of the fitting to the the top of the riser pipe. This measurement is taken by using a tape measure or by driving a nail into the 1" point at a right angle to the dipstick.
Lower the dipstick (or tape measure) down the riser pipe far enough to extend below the bottom of the fitting. Lift the dipstick until the nail catches on the lip of the fitting. Read measurement at the top of the riser pipe. If the dipstick method is used, subtract 1" to allow for the point where the nail is in the dipstick.

Source: O/C Tanks Corporation. Reprinted with permission.

Figure 7. Three Step Procedure for Measuring Internal Diameter

- To protect the internal surface of the tank (steel or fiberglass) from degradation by the stored product

- To perform long-term preventive maintenance

- To extend the short-term life of a tank (as long as necessary) before closure or temporary shutdown.[5,9]

- Tank linings are also being utilized to remanufacture steel tanks by creating a steel/FRP cladded tank (see Appendix D for further discussion).

A variety of materials may be used for the lining of tanks including epoxy-based resins, isophthalic polyester-based resins, neoprene, rubber, or urethane. Care should be taken to ensure that the lining material and storage product are compatible. If done properly, internal lining can extend the life of a steel tank at about one-third to one-half the cost of installing a new tank.[8]

Tank lining application involves three separate inspection procedures that ensure a proper lining cure and detection of lining discontinuities (holidays). A high voltage electrical inspection (i.e., Holiday test) detects void space between the lining and the original tank wall. A dry film thickness test measures the thickness of the lining applied, and a lining hardness inspection measures the hardness of the lining to ensure that the tank lining has cured properly. These three inspections are required by NLPA 631 during the application of a tank lining. The following subsections discuss these inspection methods in further detail.

Holiday Tests

Fundamental Operating Principle--

Holiday detectors locate discontinuities in protective coatings when applied to a conductive surface. Discontinuities or holidays in the lining of an UST provide specific sites for accelerated local corrosion. A discontinuity is defined as "a void, crack, thin spot, foreign inclusion, or contamination in the coating film that significantly lowers the dielectric strength of the coating. May also be identified as a holiday or pinhole."[10]

The recommended practice for detecting discontinuities includes two types of test equipment: 1) low voltage wet sponge testers, and 2) high voltage spark testers.[11] The low voltage holiday detector operates with voltages ranging from 5 to 90 V DC, and is powered by a self-contained battery. This instrument is used to determine the presence of discontinuities in protective linings that have a total thickness of less than or equal to 0.5mm (20 mils). High voltage detectors operate at voltages greater than 8800 V DC and are used to determine the presence of discontinuities in protective coating films of all thicknesses. Linings of less than 0.5mm may be damaged if tested with high voltage spark equipment (voltages of 10,000 to 70,000 V DC are commonly used to find flaws and deficiencies).

Procedure Description--

Low Voltage Wet Sponge Testing--Low voltage holiday detectors are used to locate discontinuities in a nonconductive lining applied to a conductive substrate. The device is self-powered, and, depending upon the equipment manufacturers' circuit design, has voltages ranging from 5 to 90 V DC.

The detector uses an open-cell sponge electrode saturated with a solution to probe the lining surface. A discontinuity is signaled by an audible and/or visual indicator. A ground wire from the instrument ground output terminal attached to the conductive substrate ensures electrical continuity. The sponge is saturated with a solution of tap water and a low sudsing agent. The sponge is moved over the surface of the lining at a rate of approximately 0.3 m/s (1 ft/s ). Each area is inspected twice to minimize the possibility of error.

High Voltage Spark Testing--The high voltage spark tester (>800 V) consists of an electrical energy source, an exploring electrode, and a connection from the indicator to the conductive substrate. Change in current flow through a lining indicates a discontinuity. Because of the voltages involved, high voltage detectors require an external power source.

Operation of this instrument is similar to that of the low voltage tester. The maximum voltage applied to the coating should be determined from the lining manufacturer to avoid excessive voltage that may result in holidays being produced in the lining. Table 7 contains voltages that can be used as a guideline. Dielectric strength of the lining film is another consideration in voltage selection.

TABLE 7. SUGGESTED VOLTAGES FOR HIGH VOLTAGE SPARK TESTING

| Total Dry Film Thickness (mils) | (mm) | Suggested Inspection (V) |
|---|---|---|
| 8 - 11 | 0.20 - 0.28 | 1,500 |
| 2 - 15 | 0.30 - 0.38 | 2,000 |
| 16 - 20 | 0.40 - 0.50 | 2,500 |
| 21 - 40 | 0.53 - 1.00 | 3,000 |
| 41 - 55 | 1.01 - 1.39 | 4,000 |
| 56 - 80 | 1.42 - 2.00 | 6,000 |
| 81 - 125 | 2.06 - 3.18 | 10,000 |
| 126 - 135 | 3.20 - 3.43 | 15,000 |

Source: NACE Standard RP0188-88

Description of Instrument--

Two wet sponge instrument designs are commonly used. One design uses either an electromagnetic sensitive relay or a solid-state electronic relay circuit. The circuit energizes when the sponge is in contact with a holiday and activates an audible or visual alarm. The second wet sponge design is based on the principle of an electronic relaxation oscillator circuit. This circuit reacts to an abrupt drop in electrical resistance between the high dielectric value of the lining and the conductive substrate at the point of a discontinuity.

High voltage electrical detectors may be either pulse or direct current types. The direct current instrument discharges continuous voltage, while the pulse type discharges a cycling, high voltage pulse.[12]

Method Performance--

The sensitivity of both the low voltage wet sponge and high voltage holiday detectors is very high providing the following conditions are met:

- The lining should be allowed sufficient drying or curing time prior to conducting the test. (Solvents retained in the coating film can produce erroneous results if the test is applied prematurely.)

- Sodium chloride should not be added to the wetting solution because drying salt may form a continuous conductive path, producing a false positive result.

- The wetting solution should be wiped dry from a previously detected discontinuity to prevent telegraphing (current traveling through surface moisture path to a discontinuity, resulting in a false positive reading).

- The low voltage wet sponge test is inaccurate for film thickness over 0.5mm (20 mils). Most tanks are lined with film thickness which exceeds 0.5mm.

- The high voltage detectors should not be used for linings of less than 0.5mm (20 mils) due to the possibility of producing a holiday from excess voltage. Both the low voltage and the high voltage detectors require an electronically conductive substrate. The test can only be applied to lining on steel USTs.

Field Considerations--

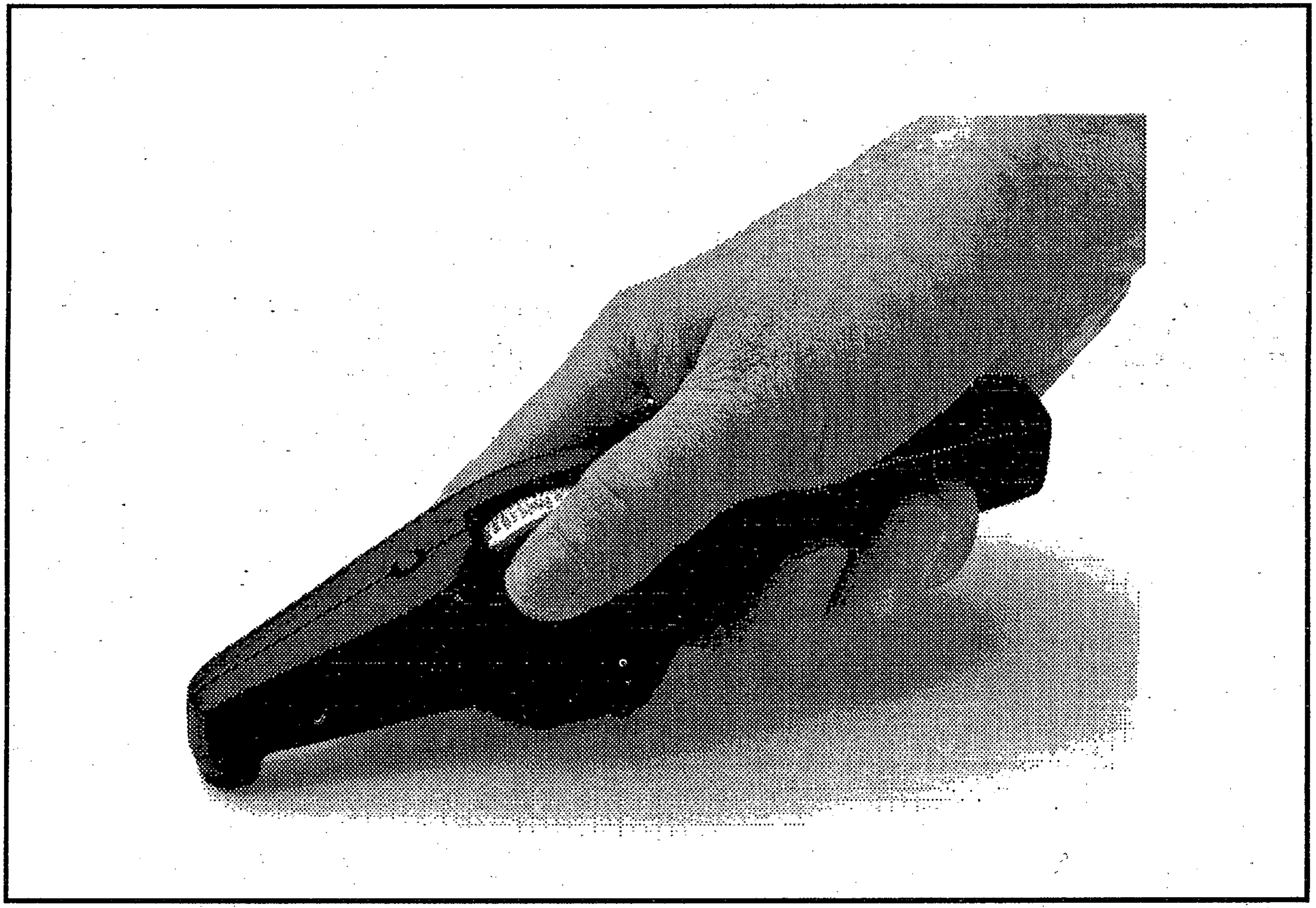
This method is fully portable and does not generate hazardous waste or require any additional safety considerations beyond those associated with normal tank entry. Care should be taken, however, to prevent electrical shock during holiday testing. Manufacturers' safety instructions should be carefully followed in order to prevent electrical shock (particularly when the test is powered by line voltage).

The cost of holiday detection using either of the described methods varies from between $1100 to $1400 depending upon conditions of tank (i.e., empty or filled), contents, and the accessibility, and the contractor's is labor.[13]

<u>Dry Film Thickness Measurements</u>

Fundamental Operating Procedure--

The Elcometer inspector coating thickness gauge measures non-ferromagnetic coating films, including paint, electroplating, galvanizing, powder, plastic, and rubber applied to a ferromagnetic base. This instrument can be used to measure the lining or coating thickness on steel tanks (see Figure 8). Branso® also manufactures dry film thickness measuring instruments, however, a physical description or other information



Source: Elcometer Inc., Rochester Hills, Michigan. 1990. Reprinted with permission.

Figure 8. Elcometer Coating Thickness Gauge

was not available. Lining thickness tests should be performed in order to comply with the requirements set forth in 40 CFR 280.33(a). NLPA Standard 631, which may be used to comply with this regulation, requires that linings should be a minimum of 2.5mm(100 mils) with an average of 3.125mm (125 mils) or greater.[5] A lining thickness test should be performed at 1 position for every 3.35m$^2$ (36 ft$^2$) of surface area.[15] At this time there is no standard for this inspection method.

Procedure Description--

The Elcometer uses magnetic principles to measure lining thickness. The instrument is placed so that the rubber housing makes contact with the lining surface. A knurled thumbwheel is depressed until the magnet makes contact with the surface. The thumbwheel is then rotated until the magnet breaks from the surface of the lining. A black indicator will appear and the gauge is read. The magnet arm is operated by frictional drive to reduce the risk of damage to the lining surface.[16]

Description of Equipment--

The Elcometer consists of a magnetic arm contained in a rubber housing and a calibrated indicator (Figure 8).

Method Performance--

The Elcometer has achieved wide use throughout the industry. Errors may arise from the inconsistencies in the surface profile or the substrate material. Recalibration of the instrument (by taking readings on a foil of known thickness) will compensate for errors associated with inconsistencies in the lining. Manual recalibration is possible for surfaces of different magnetic permeabilities.

Field Considerations--

The Elcometer is fully portable and will not generate hazardous waste. Tank entry is required to perform the method and no additional safety considerations beyond those associated with normal tank entry are required.

The cost of dry film thickness measurement using an Elcometer varies from between $1100 to $1400 depending upon the condition of the tank (i.e., empty or filled), contents, accessibility, and the cost of the contractor.[13]

<u>Lining Hardness</u>

Lining hardness tests are performed to determine that the protective coating film (lining) has cured to a hardness that meets the manufacturer's specifications. Improper or inadequate curing of the lining will result in a softening of the lining. Linings that have not achieved their specified hardness will be more susceptible to the formation of discontinuities, voids or bare spots (holidays).

Fundamental Operating Principle--

ASTM Standard D2583-87 covers the test method for the determination of indentation hardness of both reinforced and non-reinforced rigid plastics using a Barcol impressor (Model No. 934-1). This device utilizes manually-induced force using a hardened-steel truncated cone to determine the lining hardness in a steel or FRP tank. The barcol impressor does not completely penetrate the lining, but creates a small (less than 0.76mm) indentation.

Procedure Description--

The following operational procedure has been outlined in ASTM 02583-87 to measure lining hardness.

- The testing area must be smooth and free from mechanical damage.
- The impressor must be calibrated (using calibration disks) on a solid, flat, firm surface.
- The point sleeve shown in the diagram of a Barcol impressor (Figure 9) should be set on the surface to be tested. The point sleeve of the instrument should be grasped between the operator's legs and force should be applied by hand until the dial indicator reaches a maximum.
- The scale value is then read and recorded.[14]

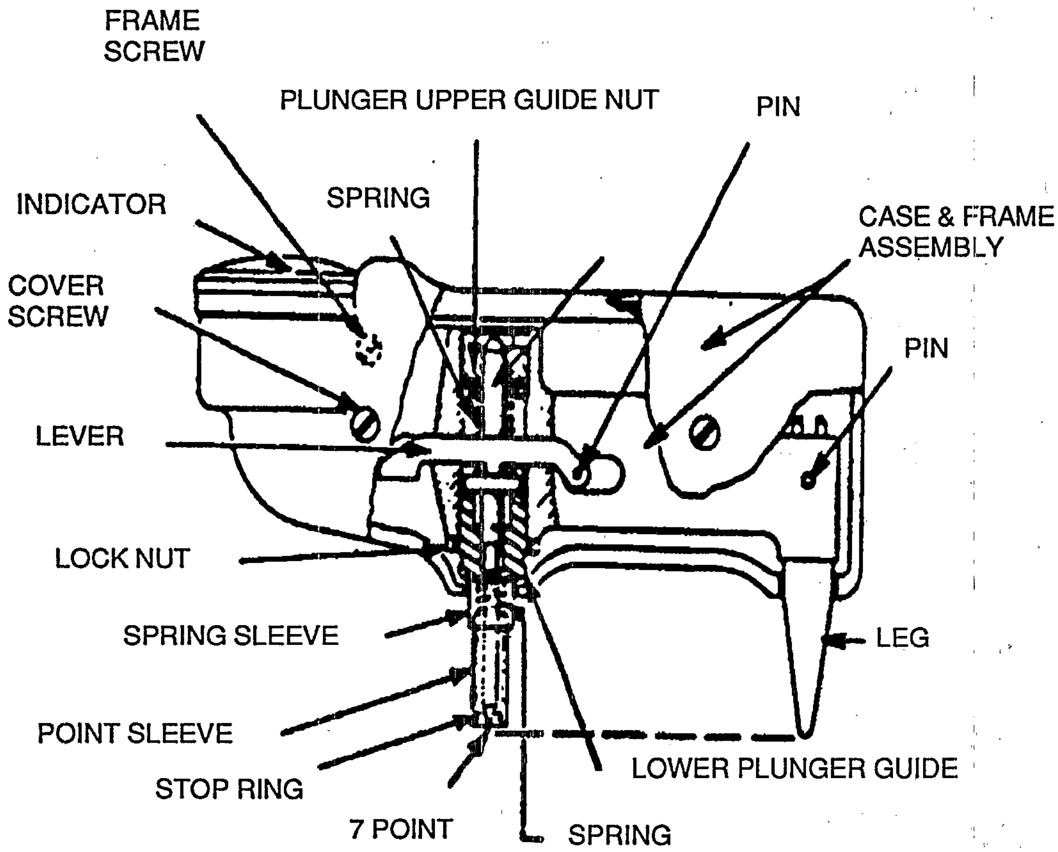
Description of Equipment--

This device has a hardened-steel indentor shaped like a truncated cone. The tip of the cone is flat and is 0.157mm (0.0062 in) in diameter. The tip is mechanically connected to an indicator. The indicator has 100 divisions each representing a cone penetration depth of 0.0076mm (0.00030 in). The maximum lining indentation created by this instrument is 0.76mm.

Calibration standards, consisting of hard and soft aluminum alloy disks, are supplied by the manufacturer. These disks have a known hardness that is correlated to the measured penetration. The lining hardness is interpolated based on these readings and the known hardness.

Method Performance--

This test method for gauging lining hardness has achieved widespread use. A distinction should be made, however, between reinforced (non-homogeneous) and non-reinforced (homogeneous) lining materials. A greater variation in hardness readings will be obtained for the reinforced materials. This variation may be caused




Source: Standards Test Method for Identation Hardness of Rigid Plastics By Means Of A Barcol Impressor. ASTM D2583-87. Reprinted with permission.

Figure 9. Diagram of Barcol Impressor

by the difference in hardness between resin and filler materials in contact with the indentor. Table 8 gives sample sizes necessary to equalize the variance-of-average for homogeneous and nonhomogeneous materials.

TABLE 8. RECOMMENDED SAMPLE SIZES TO EQUALIZE THE VARIANCE OF THE AVERAGE

| Hardness M-934 Scale | Reading Variance | Coefficient of Variation, % | Variance of Average | Minimum No. of Readings |
|---|---|---|---|---|
| **Homogeneous Material** | | | | |
| 20 | 2.47 | 2.6 | 0.27 | 9 |
| 30 | 2.20 | 1.7 | 0.28 | 8 |
| 40 | 1.93 | 1.3 | 0.27 | 7 |
| 50 | 1.66 | 1.1 | 0.28 | 6 |
| 60 | 1.39 | 0.9 | 0.28 | 5 |
| 70 | 1.12 | 0.8 | 0.28 | 4 |
| 80 | 0.65 | 0.7 | 0.28 | 3 |
| **Non-homogeneous Materials (Reinforced Plastics)** | | | | |
| 30 | 22.4 | 2.9 | 0.77 | 29 |
| 40 | 17.2 | 2.2 | 0.76 | 22 |
| 50 | 12.0 | 1.7 | 0.75 | 16 |
| 60 | 7.6 | 1.5 | 0.76 | 10 |
| 70 | 3.6 | 1.2 | 0.76 | 5 |

Source: ASTM D2583-87

Field Considerations--

This method is fully portable and will not generate a hazardous waste or require any additional safety considerations beyond those associated with normal tank entry.

Environmental conditions such as temperature, moisture, or lining material were not addressed during the course of this study. It is recommended that future field studies of this inspection method address these environmental conditions.

The cost of hardness testing using the Barcol impressor varies between $1100 and $1400 depending upon condition of tank (empty or filled), contents, accessibility, and contractor. [13]

## 4.4 TANK DISCONTINUITIES

A discontinuity is a surface or subsurface flaw created by corrosion, stress, improper welding of steels, or improper FRP laminations (i.e., delaminations). A discontinuity may appear in the form of a crack, hole, pit, delamination, blister or other imperfection that may directly impact the structural integrity of the tank. Surface discontinuities (open flaws that exist on the surface of the tank) are the most detrimental to the service life of the tank. Localized weak spots promote cracking, corrosion and trap corroding materials which may eventually create holes and cause tanks to leak. Criteria for discontinuities set by professional societies and standards, are based on size, location and frequency of occurrence.

A visual examination inspection is the most popular internal inspection for steel and FRP UST discontinuities. This inspection method is inexpensive, quick, and does not require extensive equipment. A visual inspection is limited to surface discontinuities both in size and in location. A liquid dye penetrant inspection requires solvent-based "penetrants and developers" for flaw detection and may be used to detect the surface and subsurface discontinuities of steel and FRP tanks. The method is a little more time consuming than a simple visual inspection, but can detect smaller surface discontinuities and estimate their depths. Depending on the technique used, a liquid dye penetrant test may be performed without the use of supporting utilities. The magnetic particle method, the most accurate of the three inspection methods for discontinuities, detects surface and subsurface discontinuities in steel tanks. However, this inspection method is less portable and more expensive than the visual and liquid dye penetrant inspection methods.

The cost of these inspection methods is based on time and materials. The cost of a certified technician to conduct a visual, liquid dye penetrant, or magnetic particle examination ranges from $28 to $30 per hour. Since the technician rates are relatively equal, the cost comparison of these examinations will be based on the time to perform the examination and any support equipment needed to conduct the inspection.

The internal inspection methods for tank discontinuities in steel and FRP tanks are discussed in the following subsections. There are several other non-destructive methods for detecting surface and subsurface discontinuities in steel and FRP USTs (i.e., acoustic emission, eddy current, radiography) which are not in widespread use. Refer to Section 5.0 and 6.0 for further information about these methods. The methods discussed in this section are the primary internal inspection methods in common use for the inspection of USTs.

<u>Visual Examination</u>

Fundamental Operating Principle--

Visual inspection is often used for interpretation of results from specific testing methods for steel and FRP tanks. Visual examination is used to detect surface discontinuities such as cracks, holes, and other porosities in steel and FRP tanks. A visual examination may be used to determine the subsurface conditions of a FRP tank with the assistance of other instruments (e.g., artificial light) and tank placement (e.g., out-of-ground). The types of visual examinations discussed in this section do not involve the assistance of other inspection methods.

Manufacturers prepare written procedures for the inspector that list the components of the tank (e.g., surface, weld) to be examined and the acceptable environmental conditions (e.g., light intensity). These procedures list necessary equipment and arrangements for qualification. Personnel performing the inspection must have certifications documenting their ability to perform the inspection and make value judgements. Substitution of equipment or changes in test arrangement will not require requalification. The manufacturers may require a visual examination to keep the UST in compliance with valid structural or service warrantees.

The three types of visual examination recognized by the ASTM and ASME are: 1) direct visual examination, 2) remote visual examination, and 3) translucent visual examination. Direct visual examination incorporates the use of a magnifying glass, graphite mirrors, or other instruments to enhance visible flaws. Remote visual examination include not only mirrors, but also other visual aids such as boroscopes, telescopes, and microscopes. Translucent visual inspection entails the use of artificial directional light on the inside of the tank.

Of the three types of visual inspection, direct visual examination is the most frequently used for internal inspections of steel and FRP tanks because it is inexpensive and requires no equipment. Remote visual examination (e.g., boroscopes) is occasionally used for USTs systems that contain interstitial areas (i.e., double-walled tanks). Translucent examinations are limited to FRP tanks that have been removed from the ground.

NLPA 631 describes a direct visual examination method in which a graphite cloth is used to wipe the internal surface of an FRP to enhance the detection of any surface discontinuities. The graphite acts as a visual aid allowing easier and more precise flaw detection. Direct visual examination is a recognized test by professional organizations and is a current practice of several tank manufacturers and trade associations, but is currently in practice.

Procedure Description--

The procedure for a visual internal inspection of an UST is to be done in accordance to a written procedure provided by the tank manufacturer. Section V Article 9 of the ASME Boiler and Pressure Vessel Code which applies to the conduct of visual inspections of USTs among others. These procedures require that the written procedure address the following:

(a) how the visual examination is performed,
(b) surface condition (type),
(c) method for surface preparation (e.g., cleaning, sandblasting),

(d) type of viewing (i.e., direct, remote, translucent),
(e) equipment used,
(f) sequence of procedural steps,
(g) data required, and
(h) inspection reports.[17]

The procedural steps taken to perform a visual inspection are straightforward. The precision is limited by the level of experience and the training of the inspector(s). However, there are specific conditions necessary to perform a visual inspection. The conditions (e.g., lighting, viewing distance) are dependent upon the type of visual test performed.

For a direct visual examination, the area examined must be within 61cm (24 in.) of the human eye. The angle of the surface may not be less than 30 degrees. Visual aids such as mirrors and magnifying glasses may be used to detect discontinuities. The minimal level of lighting for a visual examination is 161 lumen/$m^2$ (15 fc); 537 lumen/$m^2$ (50 fc) is required for detection of small surface discontinuities. All sources of lighting must be intrinsically safe and effectively eliminate the risk of ignition. A visual inspector is required to have an annual visual checkup. Deficiencies must be corrected by prescription eyeglasses.[17]

Remote visual examinations substitute for direct visual examinations when the area of interest is inaccessible. Section V, Article 9 of the ASME Boiler and Pressure Vessel Code requires that the instrument have an equivalent resolution to a direct examination. Section 6.0 discusses the use of boroscopes for remote visual examinations. Use of other visual aids, such as telescopes and microscopes are not applicable to USTs.

A translucent visual examination is primarily used for classifying surface and subsurface defects in FRP tanks. The examination is performed inside the tank with an artificial directional light that provides enough illumination for classification of visual discontinuities. The artificial light must be intrinsically safe and be able to diffuse the light evenly over the surface area. Ambient lighting must be oriented in a fashion to eliminate any surface glare or reflections. The intensity of the ambient light must be less than the translucent light used to inspect the area of interest. A translucent visual examination may only be performed when a tank is out of the ground.

Before the visual inspection of a tank, the internal surface of the tank must be free of dirt, oil, grease, rust, or other matter that may inhibit flaw detection. The tank may be washed with soap and water following surface preparation (e.g., sludge removal, sandblasting). Refer to Appendix A for a discussion of tank cleaning procedures.

For FRP tanks, the classification of any internal discontinuities is designated by type and by level. Appendix F lists types of discontinuities and defines them in accordance to ASME SD-2563. If the type of flaw exceeds that of the level listed, it is rejected for that category. If the flaw exceeds all three categories it is then assigned to

Level IV. Level IV defects are to be described by a drawing stating size and location. No list of acceptable flaws specific to steel or FRP USTs has been identified.

Equipment--

Equipment varies for translucent and remote inspections, but generally the following are needed for visual inspections: 1) fluorescent lighting; 2) a graphite cloth; 3) a magnifying glass; and 4) mirrors. Translucent and remote visual inspections will require more specialized equipment (i.e., boroscope).

Method Performance--

The performance and accuracy of a visual inspection is dependent upon the expertise of the individual inspector. Insufficient lighting conditions may inhibit correct interpretation or detection of surface flaws. A direct visual inspection can only detect surface discontinuities for steel and FRP tanks. But if the tank is out-of-ground, a translucent visual examination may detect subsurface flaws for FRP tanks. Full face safety equipment can affect the ability to see defects.

Field Considerations--

Visual examination in the field is primarily affected by the lighting conditions and the experience of the inspector. The inspection does not generate any waste products nor does it require any extensive labor. It does, however, require safe health conditions for entry into the tank. A visual inspection is the cheapest method of discontinuity detection based on the fact that it is quick, intrinsically safe, and does not require extensive support equipment. However, a visual inspection cannot readily detect small surface or subsurface discontinuities. Remote and translucent visual examinations requiring the use of additional materials and obviously will cost more. How much more is dependent upon what is used to assist the examination or what is required as a preliminary step (i.e., translucent examination requires the tank to be out of the ground).

<u>Liquid Dye Penetrant</u>

Fundamental Operating Principle--

The liquid penetrant test is a simple non-destructive test used for detecting surface discontinuities on steel and FRP tanks. This inspection is performed prior to lining application or during tank remanufacture. The liquid penetrant is applied to a clean surface and is drawn into surface discontinuities by a capillary action. The capillary action continues for a period of time known as the "dwell time." After the prescribed dwell time, excess penetrant is wiped from the surface and a developer is applied. The developer draws the liquid dye penetrant out of the surface flaws. The liquid dye penetrant produces indications that are visible by normal or ultraviolet light, depending upon the class of dye penetrant used in the form of blotches at the locations of flaws.

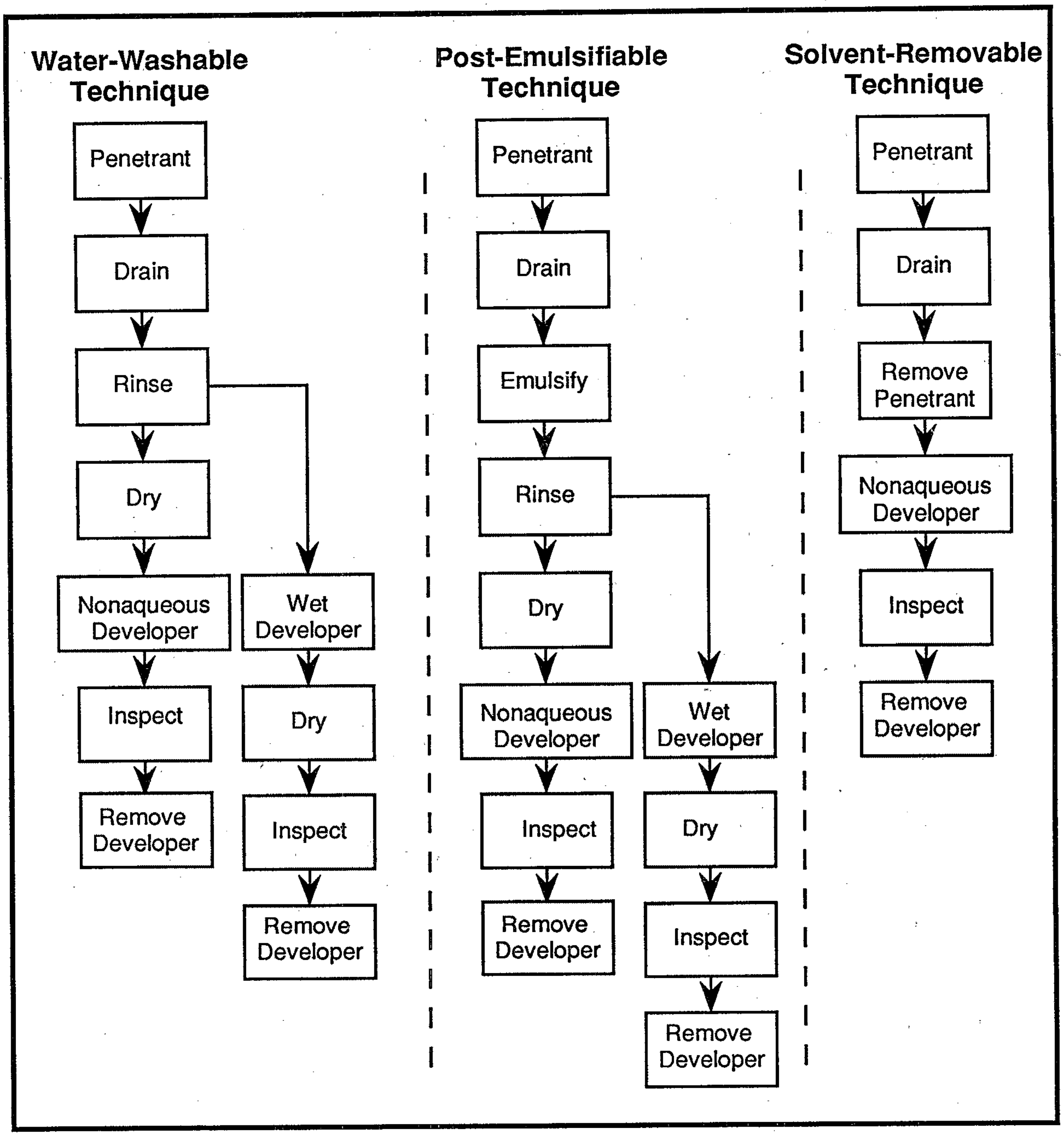
A liquid penetrant test may be performed using one of two classes of liquid dye penetrants. The dyes in the penetrants are either visible by color contrast in normal light (visible dye penetrant), or in fluorescent light (florescent dye penetrant). There are three penetrant techniques for the two classes of liquid dye penetrants. The individual techniques are: 1) water washable, 2) post-emulsifiable, and 3) solvent-removable. Figure 10 is a flow chart that plots the procedural steps for each technique using a visible dye penetrant. The procedures are similar for each technique when using a fluorescent dye penetrant. The visible dye penetrant and the solvent-removable technique are conventionally used in the field due to their portability (dyes are packaged in aerosol cans) and minimal labor.

Procedure Description--

Surface preparation is necessary since contaminants or deposits might mask the indications of unacceptable discontinuities, or interfere with the effectiveness of the examination. The accuracy of any dye penetrant inspection is influenced heavily by surface contaminants. All areas of the tank to be inspected must be clean (e.g., free of any rust, scale, welding flux, grease, oily films, dirt) and dry before application of the penetrant. For welds, the adjacent area within 25-mm (1 inch) must be cleaned.[18] Detergents, organic solvents, or chemical descaling solutions are used in the cleaning process. After cleaning, the area to be inspected is dried by applying induced hot air or by exposure to ambient conditions. Moisture or residue will obstruct the penetrant process if the surface is not dry.

After surface preparation, the penetrant is applied by brush or spray method. Aerosol cans have proven to be highly portable and effective for application to UST geometries. Care should be taken to avoid excess application and buildup (e.g., pools) of penetrant. The time the penetrant needs for penetration is dependent upon the manufacturer's specifications. Excess penetrant is removed as described for each type of technique (i.e., water-washable, post-emulsifiable, and solvent-removable). After cleaning and penetrant application steps have been completed, there are various procedures for performing dye penetrant tests. Different techniques are shown in Figure 10.

Water-washable penetrants are removed directly from the inspection area using water spray at a constant temperature, between 15 to 40C (60° to 104°F) and pressure (less than 7 kPa or 1.0 psia), or by wiping the surface with a clean damp cloth. If post-emulsifiable penetrants are used, the area is sprayed with an emulsifier that combines with excess penetrant and forms a water-washable mixture. The dwell time of the emulsifier is dependent upon the type of emulsifier applied (i.e., water-based, or oil-based) and the surface roughness. Rinsing the emulsifiable penetrant is done by a water spray at a constant temperature (between 15 to 40C or 60° to 104°F) and pressure (less than 50 kPa or 7.2 psia). The penetrant absorbed by the surface discontinuities is not emulsified. Excess solvent-removable penetrants are removed by using a clean, lint-free cloth until most traces of penetrant have been removed. A new, clean, lint-free, moistened cloth is used to remove any other excess penetrant




Source: Mix, Paul E., P.E., Introduction ot Non-destructive Testing A Training Guide. John Wiley & Sons Inc., New York, New York. © 1987. Reprinted by permission of John Wiley & Sons, Inc. Reprinted with permission.

Figure 10. Flowcharts of Three Different Visible Dye Penetrant Techniques

from the surface. Care should be taken to avoid the use of excess solvent. For each of these techniques, failure to remove excess penetrant will hinder the inspection performance.

For the water-washable and post-emulsifiable techniques, after the excess penetrant has been removed, the surface area is again dried by induced hot air or exposure to ambient conditions. Solvent-removable penetrant evaporates and does not require extensive surface drying.

There are two types of developers to be used with a dye penetrant. An aqueous developer consists of a suspension of developer particles in water and may be applied to either a wet or dry surface. The drying time of the aqueous developer may be shortened by the use of induced warm air. A non-aqueous developer consists of a suspension of particles in a solvent and is applied to only a dry surface. The non-aqueous developer dries through evaporation.

Aqueous developer application is done immediately after the excess penetrant has been removed. Application of developer (aqueous or non-aqueous) is done in accordance with the manufacturer's instructions in an evenly distributed manner. Excess aqueous developer is removed by spraying the surface with water. This action prevents pooling that may inhibit flaw detection. After application is complete, the surface area is dried using induced warm air or ambient air, not allowing the surface temperature to exceed 40C (140°F).

Non-aqueous developers are applied after the surface area has been dried. A thin film of developer is applied by using aerosol cans or dry powder spray guns in accordance with manufacturer's instructions. Excess non-aqueous developer will flush the penetrant from within the discontinuity and evaporate rapidly. The development time for both of these developers (aqueous and non-aqueous) begins immediately as soon as the surface area is dry. According to ASME, development periods more than 30 minutes are acceptable.

The developers create a white background to expose the dye in the presence of surface discontinuities. Large flaws will be visible immediately while smaller tighter flaws will develop over time. The intensity of the color and the velocity of the bleedout will help develop an indication of the flaw depth. Each of these visible dye penetrant techniques may be inspected in natural or artificial light. Minimum light intensity is 351 lumen/$m^2$ (33fc)

After the inspection is complete, cleaning the surface area is necessary in cases where the residue may inhibit service or repair proceedings. Developers should be removed immediately after inspection so that the residue does not fix onto the discontinuities.

Description of Instrument(s)--

Table 9 summarizes the techniques and equipment needed to perform the three liquid dye penetrant inspection techniques with a visible or fluorescent dye penetrant.

TABLE 9. LIQUID DYE PENETRANT TECHNIQUES AND EQUIPMENT

| Techniques | Penetrant/ Developer | Application | Removal/ Rinsing | Drying | Lighting | Utilities |
|---|---|---|---|---|---|---|
| Water-Washable | Visible Dye | Brush or Spray | Water Hose | Fan Ambient | Normal | Electric Water |
| | Fluorescent Dye | Brush or Spray | Water Hose | Fan Ambient | Artificial | Electric Water |
| Post - Emulsifiable | Visible Dye | Brush or Spray | Water Hose | Fan Ambient | Normal | Electric Water |
| | Fluorescent Dye | Brush or Spray | Water Hose | Fan Ambient | Artificial | Electric Water |
| Solvent Removable | Visible Dye | Aerosol | Lint Free Cloth | Evaporation | Normal | None |
| | Fluorescent Dye | Aerosol | Lint Free Cloth | Evaporation | Artificial | Electric |

Source: Mix, P.E. Introduction to Non-Destructive Testing, A Training Guide. John Wiley & Sons, Inc., New York, New York. 1987

Method Performance--

A liquid dye penetrant performance is dependent on the ability of the penetrant to enter the discontinuity, and the inspector to interpret the results. If performed properly, the inspection will detect surface and subsurface flaws that may be detrimental to the tank life span.

The penetrant performance is primarily affected by the existence of contaminations or deposits in the surface flaws. For example, scale, rust, and corrosion that usually occur within a tank not only blocks the penetrant from infiltrating the surface flaws, but may also trap the penetrant and produce false readings. Steel tanks, whose interior walls have an impermeable organic coating, can completely obscure the detection of surface discontinuities. Surface preparation and cleaning will influence the results of the liquid dye penetrant inspection. Effective removal of contaminants from the surface flaws may be performed using detergents, organic solvents, or pressurized water. The removal of coatings done by surface grinding operations will smear the surfaces of steel tanks and cover the openings to the surface flaws. It is imperative that these solutions are thoroughly removed after cleaning operations and that the surface is dried. Acidic or alkaline solutions that remain in surface flaws will inhibit the penetrant performance. The reliability of the results increases as surfaces are cleaner and drier.[7]

The characteristics of a good penetrant are related to surface tension, density, and wetting properties. Visible dye penetrants, due to their properties, are less vulnerable to contaminants than fluorescent dry penetrants. However, the fluorescent dye penetrants provide higher sensitivity to surface flaw detection.[7] Moisture or high humidity conditions will affect the penetrant performance. Test temperatures for a liquid dye penetrant inspection must be between 15 and 38C (60° to 100°F). For temperatures below this range a qualification procedure is required (see Appendix G). Liquid dye inspections are not recommended when the surface of the tank exceeds 38°C (100°F) due to a possible explosion or combustion hazard.[18]

The interpretation of the liquid dye penetrant inspection results is dependent primarily upon the inspector performing the examination. Recognition of surface flaws and eliminating the environmental interferences requires knowledge, experience, and discipline. The inspector must understand the material he/she is testing and the production process. Knowledge of the production process will help with interpretation of results and reinforce a discipline so results are not biased.

Field Considerations--

Proper health and safety precautions should be taken when liquid dye penetrant inspections are performed. Solvent-removable penetrants and developers may generate fumes that are highly volatile and may be harmful if inhaled or if direct eye contact occurs. Prolonged exposure to penetrants and developers may cause headaches, nausea, and/or tightness or pain in the chest. Proper ventilation throughout the tank is needed to maintain inspection safety. Prolonged hand contact to penetrants and developers may cause chapped hands which may be avoided by wearing rubber gloves.[7]

The technique and dye penetrant used most often in the field is the solvent-removable technique with a visible dye penetrant. The aerosol spray cans are portable, inexpensive, and can be readily disposed of in an industrial dumpster. The aerosol sprays are effective for UST geometries and provide good test reproducibility and sensitivity. A fluorescent dye penetrant may be used in the field with the solvent-removable technique when electricity is available for the required lighting.[7]

A liquid dye examination is more expensive than a visual examination because of the incurred material cost and longer inspection times. But, as discussed previously, a liquid dye penetrant examination can detect both surface and subsurface discontinuities. The solvent-removable technique is the cheapest method of conducting a liquid dye penetrant examination. The aerosol cans are readily disposable, requiring less process time, and are fully portable. The post-emulsifier technique provides maximum sensitivity, but like the water-washable technique, is expensive and not portable. Both of these techniques generate a waste water stream that may require proper disposal in accordance with local and state regulations.

Magnetic Particle Method

Fundamental Operating Principle--

Magnetic particle testing is a non-destructive test used for detecting surface and subsurface discontinuities on a steel tank interior surface. After the surface has been cleaned, a magnetic field is induced on a localized area of the tank surface while a magnetic powder is applied (see Figure 11). The "flux leakage" created by a discontinuity on the surface of the tank wall attracts the magnetic powder creating a visual indication. This method is not applicable to materials which cannot be magnetized (i.e., FRP tanks).

Magnetic particle inspections depend on four factors:

- the current used to induce magnetization (alternating current (AC), single phase half-wave direct current (HWDC), or three phase full-wave direct current (FWDC);
- the orientation of the magnetic field (i.e., circular, longitudinal);
- the selection of the magnetization method (e.g., coils, prods, yokes, or cables); and
- the type of magnetic particle used (wet or dry). These factors must be considered in magnetic particle testing to maximize performance and maintain portability.

The magnetic particles used for flaw detection must have high permeability to allow magnetization and low retentivity to minimize their mutual attraction.* Dry magnetic particles are cheaper and easier to use than the wet particles, but are not as sensitive or accurate. The dry magnetic particles may be gray, red, black or yellow. Fluorescent dry particles are more expensive and require specific artificial lighting conditions. Wet magnetic particles are suspended in a water or oil solution for application. These types of particles are used to detect localized discontinuities in smaller types of equipment.

Because of their small size and versatility, flexible magnetic yokes and prods are the most popular methods of conducting a magnetic particle internal inspection of steel USTs. The yoke operates on a continuous 115 V alternating current or a pulsed 300 V direct current for magnetization. The probe spacing is adjustable from 0 to

---

*(Retentivity is the residual flux density that corresponds to the saturation induction of the magnetic particle).

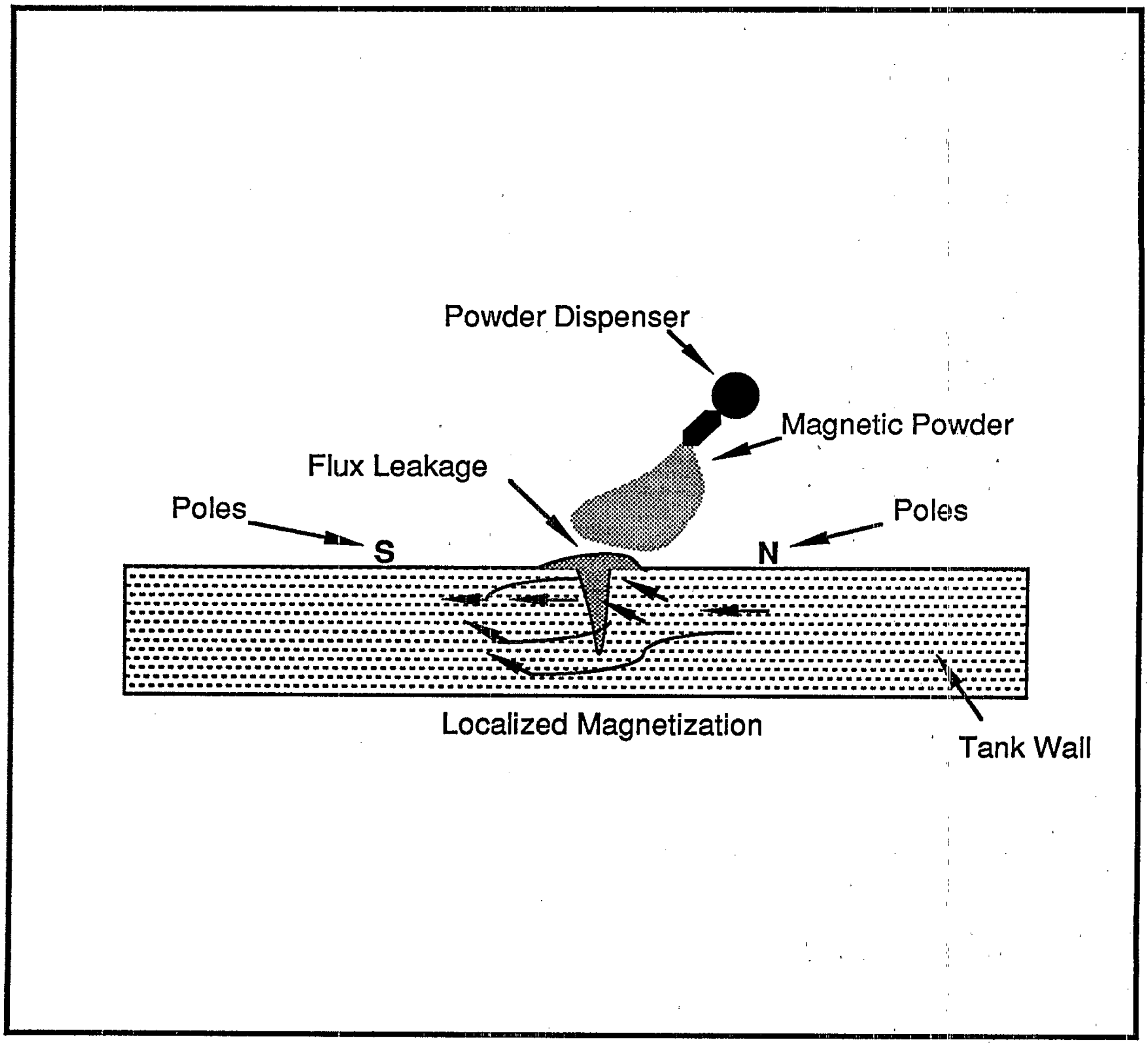



Figure 11. Localized Magnetization

305mm (0 to 12 in) and produces a longitudinal magnetic field. The yoke has the ability to contour itself to curved surfaces and difficult geometries. A second instrument, similar in portability and size, is the prod. The prod utilizes a continuous alternating current to induce a circular magnetic field. Both instruments utilize dry magnetic particles.

Procedure Description--

A magnetic particle examination is done in accordance with ASME SE-709 and ASTM E 709-80, "Standard Practice for Magnetic Particle Examination."

Prior to performing the actual instrument calibration, several control tests are performed on the instruments to ensure accuracy. The following control tests are recommended by ASME and ASTM:

1. ammeter accuracy check
2. timer control check
3. magnetic field quick break check
4. equipment current output check
5. internal short circuit check
6. electromagnetic yoke lifting force test[19]

In addition to these control tests (see Appendix H for description), the light intensity level used for detection of dry magnetic particles is checked before the inspection. The white light intensity at the surface of the tank is determined by the inspector. An 80 watt fluorescent light one meter from the surface is sufficient. It is imperative that this light is intrinsically safe.

The surface of the tank must be clean of all oil, grease, dirt, sand, or other non-ferromagnetic matter. Paint and weld spatter should also be removed because of its potential ability to inhibit the mobility of the magnetic particles. Thin paint (0.02 to 0.05mm) will not inhibit magnetic particle formations, but must be removed from areas where electrical contact is made. Surface cleaning is done with soap and water. Sandblasting the tank and creating a rough surface will make visual interpretation of the magnetic particles difficult. Rust, scale, and other tank debris will, if not removed, hamper the interpretation of the flux. When testing a weld, the surrounding area must also be cleaned. After cleaning, the surface area is dried by ambient conditions or with induced air. Surface moisture will inhibit dry magnetic powder mobility.

The area to be inspected is magnetized by direct or indirect magnetization. A prod is an instrument that magnetizes the surface area by inducting a circular magnetic field (known as direct magnetization). The two electrodes of the prod are pressed firmly against the inner wall of the tank which magnetizes the area between the electrodes. Prod examinations require a second examination of the same surface area with the electrodes rotated 90 degrees from the initial orientation. This technique will reveal all existing flaws in the localized area. It is important that the prod tips remain clean to deter any arcing or overheating effects that may affect the properties of the tank. Arcing is minimized by a remote switch that allows the inspector to induce and remove the magnetic field once the prod is in place. (It is important to verify that the tank has been properly inerted or degassed prior to performing this examination. Check the lower explosion limit of the tank prior to entry (see Appendix E). The arcing created by the magnetic instruments is an ignition source that poses an immediate safety concern.

The yoke, like the prod, has two electrodes and must be rotated 90 degrees to reveal all existing flaws. However, the yoke induces a longitudinal magnetic field (indirect magnetization) that runs parallel with the instrument. Yokes generally have a remote switch to eliminate arcing as the magnetic field is induced and removed. The type of instruments used to perform a magnetic particle examination may differ in magnetization and current, but they are similar to dry particle application.

For dry particle application, it is important that the area of interest remain magnetized as the particles are applied to the localized area in a dust-like manner. Hand-powered applicators or electric blowers are used to create the particle cloud. The magnetization will maintain the particles' mobility and allow the migration to surface discontinuities where flux leakage exists. After excess magnetic particles have been blown off with dry air, the magnetization is stopped and the results are interpreted with the assistance of light. The type of light is dependent upon the type (i.e., fluorescent or non-fluorecent particles) of dry particles used.[7]

The indications of discontinuities are formed by the presence of magnetic flux leakage. All magnetic particles held by ferromagnetic materials are a result of surface and subsurface flaws, or conflicting material properties. Magnetic particles trapped in weld depressions, scale, or rust must be recognized and disqualified as true indications. Other irrelevant indications may also form at the edge of cold-worked areas.

After an evaluation has been made, the localized area is demagnetized to eliminate the possible source of ignition (i.e., static charge, arcing). This may be done simply by magnetizing the area under the yoke or prod and slowly withdrawing the instrument while it is still energized. It is important to demagnetize with the same instrument that was used for magnetization (i.e., a yoke can be used to demagnetize if a prod was used to perform the inspection). The effectiveness of the demagnetization is measured by a magnetic field indicator or field strength measurement device.

After the magnetic particle inspection is complete, the surface area of the tank is cleaned with compressed air to remove the dry particles only if the tank is subject to further testing or processing actions.

Description of Instrument--

Table 10 lists the operating specifications of typical magnetization instruments used in the field.

TABLE 10. SPECIFICATIONS OF MAGNETIZATION INSTRUMENTS

| | Yoke | Prod |
|---|---|---|
| weight | 3.14 kg | (24 lbs.) 10.91 kg |
| voltage | 115 VAC or<br>300 VDC | 115 VAC |
| contacts (width) | 0 to 305mm | 76 to 203mm |
| cable (length) | N/A | 3.66m |

Source: Mix, Paul E., P.E. Introduction to Non-Destructive Testing. A Training Guide. John Wiley & Sons, Inc. New York, New York, ©1987.

Equipment--

Instruments needed for magnetic particle examinations include: 1) ammeter (checks level of magnetizing current); 2) a magnetic field indicator (for demagnetization purposes); 3) a magnetic powder shaker or blower (for application of magnetic powder); 4) a fan (to induce air for drying); and 5) an electric power source.

Method Performance--

Magnetic particle testing is most effective on surface discontinuities, somewhat less effective on discontinuities lying just below the surface, and ineffective on deep subsurface defects (6.4mm below surface). Defects open to the surface are the most detrimental to the service life of the tank because they are localized weak spots that promote cracking and trap corroding materials.

By far, the most important consideration for obtaining reliable indications of discontinuities and defects is the direction of the magnetic field. For greatest sensitivity, a leakage field must be created at right angles to the surface and subsurface discontinuities. If magnetic lines are parallel to the defect, there will be little or no indication of the defect. For this reason, a versatile (yoke or prod) instrument capable of rotating 90 degrees is used. Multidirectional magnetization is the most effective method for testing surface flaws of steel USTs. A sufficient number of lines of leakage flux must be produced for reliable defect indication, but the direction of the magnetic field, not its strength, is much more important.

The yoke and the prod may be used with two types of current: AC instruments are effective for surface discontinuities while HWDC instruments are effective for surface and subsurface discontinuities. The HWDC has a pulsating characteristic that provides additional mobility to the magnetic particles, which increases the sensitivity and level of detection. Magnetic yokes have the proven ability to detect a notch 1.5mm wide x 5.0mm deep.[7]

Magnetic indications may be sharp or blurred depending on the depth of the discontinuity. Subsurface flaws are only detectable when the tip of the crack is within a few millimeters of the surface. The indications are, at best, broad and diffused. False indications occur if magnetization is too high, or if the electrodes of the yoke or prod are too close to each other. A "furring" effect is created as magnetic particles build up around the electrodes or along edges and notches on the surface. Welds that have undergone cold-working can produce false indications.

Field Considerations--

The most effective instrument in the field is the magnetic yoke, which utilizes a HWDC current and dry magnetic particles. This system provides good results while minimizing waste and utility requirements. Dry magnetic particles are not affected by temperature but moisture, tank residue, and sludge will inhibit performance by creating particle agglomeration. This agglomeration will reduce particle mobility and directly affect the accuracy of the inspection.

To maintain a proper health and safety level, it is imperative that the tank is inerted or degassed prior to conducting a magnetic particle inspection. The magnetization instruments have the tendency to arc and act as a source of ignition. An explosimeter should be used to determine if the tank is safe for entry and operations (see Appendix E).

Of the three discontinuity inspection methods discussed, a magnetic particle examination is the most expensive. This inspection method is the most accurate and is also the most labor intensive. The materials, utilities, and instruments required are portable and may be commonly rented. The type of magnetic particles used also influences the cost of the examination. When using dry magnetic particles, the amount of waste generated is minimum. These particles are usually non-toxic, non-hazardous and do not pose a potential disposal problem. The certified inspectors required to perform these tests are readily available and usually require certification from the American Welders Society (AWS).

## 4.5 TANK INTEGRITY

Several methods are used to determine tank integrity as part of the inspection process required or recommended by UST manufacturers and the various trade organization standards for manufacturing and inspection of tanks. These include bubble tests, pressure change tests, and vacuum tests. These methods are used to indicate the presence of leaks or to demonstrate the structural strength of the tank as specified by the manufacturer or referenced code. All of these tests can be used for testing of both FRP and steel tanks to verify design criteria, as quality control checks at manufacture, for integrity testing during installation, repair or upgrade, and at closure of the tank. Other methods to determine tank tightness are available, however, those methods are generally used for precision leak detection and are applied when the tank is filled with product during its operational life.

## Bubble Testing

### Fundamental Operating Principle--

Bubble testing locates holes in the tank using a solution that will form bubbles when a pressurized gas passes through the solution. There are two bubble testing methods: positive pressure and vacuum box. For the positive pressure method, the tank is pressurized and the bubble solution is applied to the outer surface of the tank. The vacuum box method can be applied to either surface of the tank wall. The vacuum is created to generate the pressure difference across the tank wall which allows for detection of the leak after the solution has been applied to the tank surface.

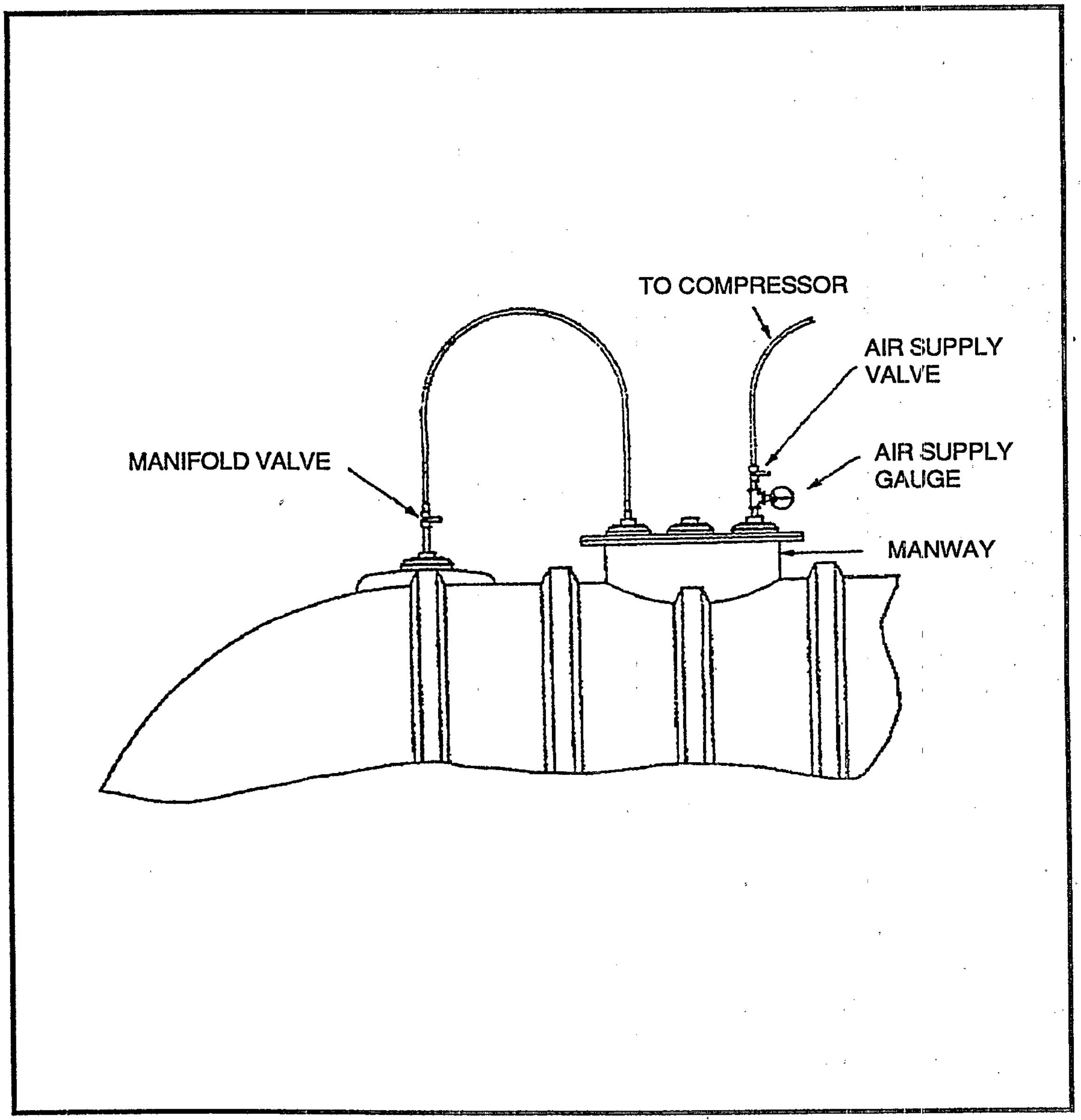
The vacuum box method uses a specially designed box contoured to the tank geometry. The box is equipped with a transparent viewing window, gasketed sealing surface, vacuum pump, and a vacuum gauge. The box sits on the surface with the bubble solution already applied and the gasket in position. A vacuum is created within the boxed volume using the vacuum pump. The surface is then observed through the viewing window for the formation of bubbles.[20,7]

The positive pressure bubble test is the more commonly used of the two methods. The direct pressure test can only be used when the exterior of the tank is exposed. As a result, this test is predominantly performed during tank installation. Bubble tests are also performed when there is a exposed exterior surface onto which a soap solution can be applied, such as repair of a crack, a fitting, or checking the seal of the manway. The vacuum box method is seldom used for tank inspections since it is generally easier to perform a positive pressure bubble test. However, a vacuum box test can be used to test the tank from the interior when access is provided.

### Procedure Description--

During a direct pressure bubble test, the tank is pressurized with air or an inert gas. The test pressure is 21 to 34 kPa (3 to 5 psig) for FRP tanks, and 34 to 48 kPa (5 to 7 psig) for steel tanks. The actual test pressure may vary depending upon the standard that is followed. Appendix I summarizes the test specifications required by the various standards. Extreme caution must be used so the tank is not over-pressurized which can cause the tank to rupture or explode. Figure 12 shows a typical setup for pressurization of a double walled Manway tank.

The tank walls must be free of oil, grease, paint, or other materials that might mask a leak. The tank is pressurized to the test pressure and is generally allowed to "soak" at the test pressure for a minimum of 15 minutes to allow the gas to work its way through any tiny cracks that may be present.[20] The pressure within the tank may drift initially while the internal temperature equilibrates with the environment. The pressure




Source: Xerxes Corporation, Minneapolis, MN, 1990. Reprinted with permission.

Figure 12. Pressurization Setup of a Double Walled Manway Tank

should be adjusted to maintain the required test pressure while the bubble test is being conducted. Some standards do not specify a soak period.

The bubble solution is applied to the outer surface of the tank. If no continuous bubble formation is observed, the tank is considered acceptable. Particular attention should be focused on tank welds and tank openings.

The surface tension of the bubble solution controls the bubble formation process. The surface tension must be low enough so that small leaks can be detected but not so low that the bubbles are allowed to break rapidly. The bubble solution is applied to form a film that does not break away from the area to be tested. The solution is also applied so that a minimal number of bubbles is produced by the application. The solution must be compatible with ambient conditions. Wind, rain, subfreezing conditions, and ambient light conditions affect the test's effectiveness in detecting leaks. The test can be repeated instantly on any area of the tank if there are doubtful results.

The tank may be pressurized using an air compressor or a compressed gas cylinder with an attached pressure regulator. The pressure gauges used generally have full-scale readings 1 1/2 to 4 times the nominal test pressure. Gauge accuracy is traditionally poor in the lower 10-20% of the full-scale value. All pressure gauges used during the tests must be calibrated against a standard dead weight tester, a calibrated master gauge, or mercury column and recalibrated annually unless specified otherwise by the referencing code. All gauges must be recalibrated any time that there is reason to believe they are in error.[20]

Method Performance--

The bubble test is the most commonly used tightness test due to its ability to detect relatively small gas leaks and its ease of application. Common applications for the bubble test to USTs include: design verification, manufacturer quality control before installation, to check the seals of openings such as manways in partially buried tanks, and following tank closure. A bubble test may also be performed in conjunction with a pressure change test. One source estimates that bubble tests can reliably detect leaks of air as small as 0.002 liter/hour.[21]

Field Considerations--

When performing a test that requires pressurization of a double-walled tank, the annular space pressurization must follow the manufacturer's explicit instructions. In some cases, not following the manufacturer's instructions will violate the manufacturer's warranty. The annular space can very rapidly be over-pressurized due to the much smaller volume of the annular space compared to the volume of the inner tank. If the annular space alone requires pressurization, great care must be taken to avoid rupture of the tank walls. When performing the test, adequate precautions should be taken to protect people and property should an accident occur. Soaping the

UST exterior wall and pressurizing the tank can only be completed as an integrity test when the UST wall is viewable. The application to installed tanks requires excavation. Bubble tests are very quick, typically requiring less than 1 hour for experienced technicians.

Positive Pressure Testing

Fundamental Operating Principle--

Two positive pressure integrity tests are performed as part of internal inspections of USTs. A pressure change test consists of pressurizing the tank and monitoring for change (i.e., decrease) in pressure that may be due to a hole. The second positive pressure test is an extreme of the pressure change test. This test consists of pressurizing the tank and looking for evidence of structural failure such as a rupturing of the tank wall. This application of the pressure test differs from the pressure change test only in that it is generally performed at a much higher pressure and failure results in a rapid or nearly instantaneous reduction in pressure. A positive pressure can be induced by pressurizing the tank with air or an inert gas, (usually $N_2$) or by filling it with water and topping off the tank with a water column. Tests using air or gas as the pressurizing medium are sometimes referred to as aerostatic tests and those using water are referred to as hydrostatic tests.

Procedure Description--

In most cases, a tank is tested by pressuring with air and monitoring for decrease in pressure or structural failure (i.e., rupture). The test pressure and period are determined by the specific code for which the tank is tested. When a water column is used to pressurize the tank, a pressure change is monitored by measuring for a decrease in the liquid column level. Appendix I lists the test requirements of the various codes.

Before pressurizing, all tank openings must be blinded and fittings must be tight and leak proof. The tank must be allowed to equilibrate (soak) for a set period of time while under pressure, to compensate for initial temperature changes and tank deformation. The soaking time will vary depending upon the size of the tank and the referencing standard used for the test. The tank is considered to have a leak when a certain percentage change in pressure has been observed as specified in the referencing standard.[20]

The tank is pressurized using an air compressor or a compressed gas cylinder with a pressure regulator. Pressure in the tank is monitored using a pressure gauge that has full scale readings 1 1/2 to 4 times the nominal test pressure. Gauge accuracy is traditionally poor in the lower 10-20% of the full-scale value. All pressure gauges used during testing must be calibrated against a standard dead weight tester, a calibrated master gauge, or a mercury column and recalibrated at least once a year, unless specified otherwise by the referencing code. All gauges must be recalibrated any time that there is reason to believe they are in error.[20]

Method Performance--

Pressure tests are commonly performed as part of routine inspections during the lifetime of a tank. They are easy to perform and can give a rapid indication of a very problematic UST. In general, pressure tests are only capable of detecting relatively large leaks (compared to bubble testing) and are seldom able to pinpoint the location of a leak.[21] Pressure tests are commonly applied during design verification, manufacturer quality control, and before installation and following tank closure. Under no circumstances should pressure tests be performed when product or residues are present in the tank.

Several environmental factors can influence the accuracy of a pressure change test. These include internal temperature changes, volume changes due to tank deformation and changes in barometric pressure. Temperature and pressure of a contained gas are directly proportional. Temperature decreases will induce pressure decreases. Tank deformation is a volumetric change that occurs when increased pressure causes the tank to expand slightly. Changes in barometric pressure will cause a change in the measurement gauge pressure (versus absolute pressure). Most tests will use pressure gauges that measure pressures above atmosphere pressure (gauge pressure).[20,7]

For purposes of internal inspection, a high degree of test accuracy is not normally required. Temperature, tank deformation and barometric pressure effects are generally considered negligible or short-lived phenomena. However, the effect of these phenomena becomes increasingly important when testing for very small leaks or very large tanks, due to the larger affected volume. In these cases, temperature and barometric pressure changes may have to be monitored and their effects compensated for in the determination of a pressure loss due to a leak.

Field Considerations--

As described in the previous section (Bubble Testing), when pressurizing a tank, particularly a double walled tank, the manufacturer's instructions should be explicitly followed.

The test conditions and environmental parameters can significantly affect the test results and must be recorded. For example, when testing a backfilled tank, the resistance to a leak is greater since the backfill material is in the leak path instead of the air that would be in the leak path if the test were conducted above ground. A test conducted after the tank has been backfilled requires greater sensitivity in the test measurements.

When a hydrostatic test is performed, an effort must be made to completely remove the water from the tank interior prior to filling with product. The effort required to remove the water from the tank will depend on the quality of the product stored in the tank and the incompatibility of the product with water.

## Vacuum Tests

Fundamental Operating Principle--

There are two types of vacuum tests: the pressure (vacuum) change test and the structural integrity vacuum test. The vacuum change test is not normally performed as part of internal inspection of tanks. In most applications the pressure change test is a positive pressure test. The vacuum change test procedure is virtually the same as the positive pressure change described earlier except that air is evacuated from the tank which creates a negative pressure or vacuum. The structural integrity vacuum consists of creating a vacuum within the tank and looking for evidence of structural failure such as a rupturing or collapse of the tank wall.

Procedure Description--

A vacuum test is performed by creating negative pressure within the tank by evacuating air from the tank using a vacuum pump. The test pressure and period are determined by the specific standard for which the tank is tested. Appendix I provides a list of test requirements as specified in various standards. Before testing, all tank openings and fittings must be closed tightly and leak proof.

The vacuum gauges used should have scales that allow easy readings of the vacuum change over the test range. All pressure gauges used during testing must be calibrated against a master gauge or a mercury column and recalibrated annually, unless specified otherwise by the referencing code. All gauges must be recalibrated any time that there is reason to believe they are in error.[20]

Underwriters Laboratories Standard UL 1316 and NLPA 631 for fiberglass tanks require that each tank should withstand, without rupture, a internal partial vacuum according to the equation:

$$V = (1/2\, D + h) \times 73.33 \text{mm Hg/m}$$

where:
V is the vacuum in mm Hg,
D is the tank diameter in meters, and
h is the maximum recommended burial depth in meters, but not less than 0.91m (3 feet).

Method Performance--

Common applications of the structural integrity vacuum test include design verification, manufacture quality control, and testing before and following the operation of the tank. Vacuum tests, in general, are not as accurate as bubble tests in determining leak rate and location, however, they can provide a rapid indication of a problematic tank.

All of the environmental factors that influence the accuracy of positive pressure tests also influence vacuum tests but in an inverse manner. These factors include temperature changes, volume changes due to tanks deformation and changes in barometric pressure. For tests requiring a high degree of accuracy and for tests on large volume tanks, these environmental factors must be monitored and their effects compensated for in the determination of a pressure loss due to a leak.

Field Considerations--

As described in the previous sections (Bubble Testing and Positive Pressure Testing), the manufacturers instructions should be explicitly followed when pressurizing a tank. Also as described in the previous sections, test conditions and environmental parameters can significantly affect the test results and must be recorded.

# SECTION 5.0

# OUTMODED METHODS

Radiography and eddy current tests are two methods of non-destructive testing applicable to USTs. However, due to factors such as cost, waste generated, tank geometry, and the availability of certified inspectors, these methods are no longer in active practice for internal inspection of steel or FRP tanks. These methods do not meet the definition of SOTA, but are discussed briefly as they are inclusive of the current commercial practice by definition.

## 5.1 RADIOGRAPHY

Radiography is the practice of creating a photographic image by passing a penetrating ionizing radiation beam (i.e., X-ray) through a specific object of interest. The photographic image, or radiography, will allow the inspector to locate surface or subsurface discontinuities, determine wall thickness, and identify localized corrosion areas. After the tank has been backfilled, radiography is not feasible without excavation.

To produce a radiograph, energy is projected through the film for an appropriate time depending upon the x-ray intensity, object material, and the film itself. The film is then processed (developed, fixed, washed and dried), so that the radiograph may be illuminated and examined.[3]

The availability of radiography inspectors is minimal due to the intensive training and education requirements for certification. The actual radiography procedure is labor intensive. Radiography also generates radioactive wastes that require proper regulated disposal and extensive permitting.[22]

## 5.2 EDDY CURRENT

Eddy current testing involves the use of alternating magnetic fields and can be applied to any conductor (e.g., steel). The alternating magnetic fields create circulating eddy currents in the test part. A crack in the test material obstructs the eddy current , lengthens the eddy current path, reduces the secondary magnetic field, and increases the coil impedance. The impedance increases with the severity of the discontinuity.[7] The eddy currents respond to surface dents, discontinuities, and changes in wall thickness.

Eddy current testing requires magnetization of the entire test part. This requirement is cumbersome and, due to topology may not be feasible for larger USTs. As with radiography, the testing procedure is labor intensive, slow, and expensive. There is only minimal availability of certified inspectors to conduct eddy current testing.

# SECTION 6.0

# EMERGING TECHNOLOGIES

Preliminary information on technically advanced methods which are emerging in the area of UST internal inspections is being collected by RREL, EPA to assist states and UST owner/operators in complying with future EPA regulations. Some emerging technologies have been developed for use in other applications and are not yet performed on underground storage tanks, for example a source of technologies that could be adapted to internal tanks is the pressurized vessel industry. The emerging technologies identified during the course of this project are acoustic emission, boroscope, and microwave. Brief descriptions of these technologies are presented in the following sections.

## 6.1 ACOUSTIC EMISSION

Acoustic emission testing is a non-destructive technique that is capable of revealing the presence of latent structural cracks, lining failure, thinning, pitting, blistering, deficient welds and corrosion by "listening" to the structure.[2] The sounds emitted by these flaws radiate throughout the structure and can be collected by piezoelectric sensors placed on the surface of the tank. A computer then analyzes signal severity and pinpoints the location of the leak.[23] A structure can be monitored in real-time to provide warning of impending failure. In general, this method relies on standard acoustic emission time-signal processing, coupled with advanced random signal correlation techniques.

Acoustic testing for leak detection is a common practice in the above ground inspection of both steel and FRP petrochemical vessels. This same methodology has been adapted for storage tanks as a cost-effective, in-service inspection tool. Currently, acoustic emission technology is being applied to petroleum tank railway cars and large aboveground tanks, by placing sensors on the outside of the vessel. However, sensors can be applied to interior tank walls using suction cups, avoiding the necessity to excavate the tank.

A minimum amount of training is required for the prospective technician to perform the test. A number of vendors have developed and refined the technology for performing acoustic emission tests on tanks and other vessels.

Acoustic has many features indicating that it might be a promising candidate for internal inspection. It is being used as a leak detection method for above ground tanks. Vendors are familiar with many of the signals of stress which the instrumentation will need to identify. Unlike all other methods currently in practice, acoustic emission does not require the removal of product and cleaning of the tank. This eliminates costly down time and labor charges. Additionally, acoustic emission technology is that it is a non-destructive method. This method not only confirms the presence of a discontinuity, but ascertains the location of the point(s) of stress.

## 6.2 BOROSCOPE

Boroscopes are optical instruments designed for remote visual examinations in inaccessible areas (such as military equipment). For example, this instrument would be used for inspecting the interstitial area of double-walled tanks and/or the structural ribs of FRP tanks. Boroscopes are produced in several variations due to their multiple applications. These instruments have either rigid or flexible components that are microscopic in diameter or extendable in length. Manufacturers are now offering boroscope instruments that may be incorporated with a high resolution video camera and a closed circuit television system. Systems can be constructed that are compatible with the needs of the object to be examined.

The performance of a boroscope is dependent upon the following optical components: 1) the objective lens; 2) the relay lenses; and 3) the eye piece. The objective lens transmits the primary image from the end of the boroscope to the relay lens. The relay lens "relays" the primary image to the eye piece. The longer the boroscope, the more relay lenses required. The last relay lens generates a final image for the human eye through the eye piece. The total magnification of the primary image is the product of the magnification of each lens.

There are no nationally recognized standards for remote visual examinations with a boroscope. All visual inspections are subjective, but the quality of interpretation of results may be enhanced by the use of video recording equipment. The results of visual examinations are dependent upon trained inspectors and the quality of their instruments.[7] The accuracy of the structural flaw measurements is dependent upon instrument-to-object distance and the inspector's experience. Magnification is highest at the closest viewing distances and decreases as the instrument-to-object distance grows. Optimal surface or subsurface flaw detection in a tank would occur when the instrument-to-object distance is minimal. This requirement creates a somewhat higher level of effort in terms of both labor and equipment.

## 6.3 MICROWAVE

Microwave testing is a non-destructive testing method that involves electromagnetic testing at frequencies in the microwave range. The microwaves are directed to a test object and an antenna (i.e., transducer) receives response signals. The interaction of microwaves with materials and test objects is described in terms of waves. The microwaves generated travel in straight lines, reflect, scatter and interfere with materials and structures at a microscopic scale.[25]

Microwave testing is primarily applicable for internal inspections of FRP tanks. This testing method may detect surface and subsurface flaws as well as determine physical characteristics of the FRP material (e.g., thickness, moisture, state-of-cure). Microwave testing may be used to detect surface discontinuities of steel tanks and, under certain conditions, wall thickness as well. Thickness determination of steel tanks is complicated and requires the use of multiple microwave instruments.

Microwaves and ultrasonic waves are similar in nature but not in ability. For example, ultrasonic waves can penetrate steel; microwaves cannot. This characteristic limits the use of microwave testing for steel tanks. Microwave testing can only be used to detect surface discontinuities of steel tanks. Ultrasonic transducers require direct contact with the test object; microwave transducers do not. One major distinction between ultrasonic waves and microwaves is the wave velocity. The slower ultrasonic waves with smaller spatial extents allow the inspectors to discriminate interferences. However, the higher-velocity and non-contacting transducer permits faster inspections.[25]

Microwaves are most effective with FRP materials due to phase measurements and polarization of the reflected waves, information about internal flaws, material orientation and structure, thickness, moisture content, and state-of-cure of the FRP tank. The data generated can be displayed using holographic techniques or other image reconstruction processes.[25]

Microwave testing is not commonly used, due to the low availability of non-destructive testing engineers and technicians who are familiar with the technology. However, with the current development of off-the-shelf instruments that incorporate microprocessors, microwave testing is being improved and simplified.

## REFERENCES

1. Sattler, F. J. Finding Below Surface Defects With Non-Destructive Testing. Chemical Engineering, September 1989, pp. 161-167.

2. American Society of Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing: Standard Practice for Thickness Measurement by Manual Contact Ultrasonic Method. ASME SE-797, New York, New York July 1989.

3. Halmshaw, R. Non-destructive Testing. Edward Arnold Ltd., Baltimore, Maryland, 1987.

4. American Society of Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing: Recommended Practice For Ultrasonic Pulse-Echo Straight-Beam Testing By the Contact Method. ASME SE-114, New York, New York. July 1989.

5. National Leak Prevention Association. Internal Inspection, Repair and Lining of Steel and Fiberglass Storage Tanks. NLPA 631, Second Edition, Cincinnati, Ohio, September 1988.

6. National Leak Prevention Association. Internal Inspection of Steel Tanks for Upgrading with Cathodic Protection Without Internal Lining. NLPA 632, Draft Report, Cincinnati, Ohio, January 15, 1988.

7. Mix, P. E. Introduction to Non-Destructive Testing, A Training Guide. John Wiley & Sons Inc., New York, New York 1987.

8. Leiter, J. L. Editor-in-Chief. Underground Storage Tank Guide. Thompson Publishing Group, Washington, D.C., March 1990.

9. American Petroleum Institute. Interior Lining of Underground Storage Tanks. API Recommended Practice 1631, Washington, D.C., December 1987.

10. National Association of Corrosion Engineers. Discontinuity (Holiday) Testing of Protective Coatings. NACE Recommended Practice RP0188-88, Houston, Texas, July 1988.

11. National Association of Corrosion Engineers. High Voltage Electrical Inspection of Pipeline Coatings Prior to Installation. NACE Recommended Practice RP0274, Houston, Texas, August 1974.

12. Elcometer, Inc. Non-Destructive Coating Thickness Measurement Mechanical Gauges. Rochester Hills, Michigan, 1989.

13. National Leak Prevention Association. Personal Communication with Tony Reich. Cincinnati, Ohio, January 15 & 20, 1990.

14. American Society for Testing and Materials. Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor. ASTM Standard 02583-87, Philadelphia, Pennsylvania, January 1989.

15. Tank Liners, Inc. Safety, Testing and Application Standards. Hillsboro, Oregon, Undated.

16. Elcometer, Inc. Non-Destructive Coating Thickness Measurement Mechanical Gauges. Rochester Hills, Michigan, 1989.

17. American Society of Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing: Article 9, Visual Examination. New York, New York, July 1, 1989.

18. American Society of Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing: Standard Practice for Liquid Penetrant Inspection Method, SE-165, New York, New York, July 1, 1989.

19. American Society of Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing, Standard Practice for Magnetic Particle Examination, SE-709, New York, New York July 1, 1989.

20. American Society of Mechanical Engineers. Boiler and Pressure Vessel Code, 1989 Edition. Section V, Non-Destructive Testing: Article 10, Leak Detection. New York, New York, July 1, 1989.

21. Dallum, B. J. Sensitivity of Leak Detection Methods: Vacuum and Soap Bubble Testing Prior to Installation. O/C Tanks Corporation, Technical Report 643, Conroe, Texas, April 3, 1989.

22. Non-Destructive Testing Association. Personal Communication with Ron Sever, Columbus, Ohio, January 17, 1990.

23. Eleftherion, P. M. Tank Bottom Testing: The AE Approach Unpublished Paper. Physical Acoustics Corporation, Princeton, New Jersey, undated.

24. Wolske, B. K. Acoustic Emission Test Improves Tank Car Safety. Chemical Processing, March 1988. Reprinted by Physical Acoustics Corporation, Princeton, New Jersey.

25. Bahr, A. J. Microwave Nondestructive Testing Methods. Gordon and Breach Science Publishers, New York, New York, 1982.

## APPENDIX A

## TANK EMPTYING AND CLEANING

NOTE: The material in this appendix has been excerpted from Background Report on Underground Storage Tank Closure: Current Practices (Prepared for U.S. EPA by PEI Associates, Inc., and Midwest Research Institute, 1988).

The regulations promulgated by EPA as well as the guidance documents issued by industry require tanks to be "emptied" prior to tank entry or cleaning. The term "empty" is not well defined and may represent from 1 to 7 inches of residual fuel, water, and residues. The two methods used for removing petroleum products from USTs are pumping and waterflooding; pumping is the most commonly-used method. These methods are covered in API 1604 and API 2015. The salient features of the guidelines are presented below.

### Pumping

Pumping is used to remove liquid-phase petroleum products but can also be used to remove some residual material (e.g., sludge or sediment.). Some information indicates that pumps should be shut off when sludge is encountered while other information indicates a substantial amount of sludge can be pumped out. It appears that the amount of residual material removed depends at least in part on the type of system used and the nature of the product being removed.

These products are usually pumped down to the lowest possible level in the tank with explosion-proof or air-driven pumps. The suction line that extends from the pump is manually placed through any opening, commonly the fill tube. In some instances the suction line is routed along the tank bottom to remove remaining liquid, as well as some residue. Pumping operations remove a large amount of petroleum products, but due to suction line design limitations, not all of these products can be removed by this method. Pumping systems that withdraw products through the fillpipe are limited by the fillpipe length and may leave as much as 15-17.5 cm (6-7 inches) of residual material in the tank.

## Water Flooding and Pumping

Pumping can be augmented by water-flooding. Water-flooding is a procedure whereby water is added through the fill pipe to remove products less dense than water. Water is introduced into the bottom of the tank to float liquid and residual hydrocarbons to the pump-out connection. The pumpout line is located above the tank bottom to remove the floating products. The rate that water is introduced into the tank is less than the pump-out rate. By introduction of water at the bottom of the tank, the risk of generating static electricity is decreased (due to a lower amount of friction) than when introduced at some distance from the tank bottom. Residues denser than water will not float and therefore are not removed by this process. Dense residues are removed during tank cleaning.

A major disadvantage to this technique is that the water used during removal operations may be considered to be hazardous waste. If it is treated as a hazardous waste, the waste water must be managed in an approved RCRA Treatment, Storage, or Disposal (TSD) facility. In order to limit the amount of water that must be hauled to a TSD facility, many contractors minimize the volume of water used to flood the tanks or reuse the same water in flooding other tanks. In some cases this may reduce the effectiveness of product removal. However, not all states or municipalities consider tank residues or waste water to be hazardous, and may be separated and treated as a waste oil rather than a hazardous waste.

# TANK CLEANING

After underground petroleum storage tanks have been emptied by a contractor, they must be cleaned prior to inspection. A variety of methods may be used depending upon the type of residuals remaining in the tank.

## Types and Amounts of Residues

Following product removal and tank "emptying," a composite of residual material remains in the tank. Based on phone interviews with tank lining contractors and cleaning firms and a limited amount of published literature, the fundamental components or types of residuals left in a tank appear to be: residual product or fuel; residual water; sediment; tank rust and scale; tank sludge; and micro-organisms.

Residual product or fuel remains after product pumping and removal operations have been completed. Water that remains in the tank will occur in a separate phase, and may also be partly dissolved and suspended in the fuel. Tank sediment can consist of fuel impurities introduced during tank filling, and rust particles and scale that may settle over time. Tank scale consists primarily of corroded or rusted interior tank surfaces that probably oxidized when in contact with water. Tank sludge is semi-solid material that may contain scale and sediment as well as water and by-products of the interaction or reaction of these residues.

The quantity of material that remains after initial product removal generally cannot be estimated because tank cleaners do not distinguish residue type. Tank cleaners commonly measure the amount of residual material that is removed to the drums that are filled during tank cleaning. Total residues may vary based on a number of factors, discussed in following subsections. Tanks that originally contained unoxygenated gasoline fuels but were changed to oxygenated fuels may have as much as 170 gallons of residual material removed from a tank.

Location of Residues

Scale occurs in the upper portion of the tank while sludge and residual fuel and water lie in the lower portion of the tank. Sludge has been observed in a number of tanks not as residue on the bottom center of the tank but rather in positions of 5 and 7 o'clock. Corroded areas above the maximum level of sludge-covered areas are referred to as "sludge-lines" or fingers and may possibly indicate the past location of sludge as it settled during formation. Overall, less sludge or "sludge-lines" have been noted in lined or FRP tanks than in steel tanks.

Scale and sediment are also more prevalent in steel tanks than fiberglass tanks. Some sediment and scale are usually incorporated into the sludge during its formation. Scale forms on the tank walls and can eventually accumulate in the residual "bottoms." Sediment usually accumulates in the lower part of the tank.

Variables Affecting Product Removal and Amount of Residues

As noted above, a number of variables influence the nature and amount of residues that remains in an UST after tank emptying operations are complete. Initial design constraints can limit the amount of product removed from the UST system.

- Tank Tilt - Underground storage tanks are designed to be installed with a slight tilt or slope in the direction of the fillpipe (the principal outlet by which product is removed when emptying and cleaning). When a tank is improperly sloped away from the fillpipe, residual product, water, and other material collects at the opposite end of the tank. An improperly sloping tanl may result from settling or incorrect installation and can make product removal and cleaning operations less effective. In some cases the pump suction line is fed in through the fillpipe or turbine pump hole and routed along the tank bottom to remove product in the downslope portion of the tank. It is not known which method is the most commonly used technique.

- Fuel Type - A general relationship exists between the amount of residual material and fuel type. Higher molecular weight, more viscous fuels (e.g., diesel) tend to have more residual material than less viscous, lighter-molecular weight fuels (e.g., gasoline). The influence of additives in fuels is not currently known. However, observations by owner/operators and firms that clean tanks (e.g., tank lining contractors) have indicated that a change-in-service from unoxygenated to oxygenated fuel (i.e., those with additives such as ethanol) can remobilize existing sludge and residues.

- Tank Type and Age - Steel tanks tend to contain more residues than fiberglass tanks, have been in use longer than fiberglass tanks, and tend to internally corrode at a higher rate. Fiberglass tanks may be subject to internal corrosion if sulfur is present in the residual aqueous phase.

- Proper Filling and Maintenance - Filling and maintenance procedures can affect the total amount of foreign material or sediment that may be introduced and the total water content in tank bottoms.

- System Through-Put/Dormancy - Tank systems that have low through-put and remain relatively dormant (i.e., those infrequently pumping fuel in and out) can allow time for residues to form, settle, and accumulate. Tank systems with higher through-put keep solid particles suspended and dispersed in the product and thus minimize settling and density segregation.

- Tank Location - Tank temperatures are generally lower for tanks located below the water table and may promote water condensation in the tank, oxidation of upper tank surfaces, as well as affecting microbial activity in the tank.

The effect of these variables on residue formation has not been systematically investigated and could provide valuable constraints that could be used to predict and reduce residue generation.

Cleaning Methods

A wide range of methods and techniques are used in cleaning residues from UST systems. The selection of a cleaning method apparently depends on the ultimate fate of the tank. For example, contractors that line tanks for reuse indicate that a tank is not "clean" (or ready for lining) until it has been sand blasted, while contractors preparing tanks for disposal have indicated that a simple, single rinse with low-pressure water is adequate.

At a minimum, state and local agencies require removal of combustible vapors in the tank before transport for safety reasons. Residues remaining in a tank for a period of a few hours after venting or purging may volatilize after a tank has been "emptied." Vapors from the volatilized contamination in the residue can make the tank hazardous for transport. Some contractors minimize the risk of later volatilization by rapidly completing the cleaning, transport, and disposal operation rather than initially removing more of the volatile residues in the tanks.

There is also no consensus for determining when a tank is clean. Tanks may be considered clean after a single rinse with low pressure water. Some jurisdictions require multiple rinsing with high pressure water. Rinseate which is no longer contaminated after multiple rinses is another criteria for measuring tank cleanliness. Visual inspection may be adequate to confirm cleanliness in some cases, while an analytical determination may be necessary in other cases. The remainder of this section will discuss the methods of cleaning tanks, including:

- Entry and physical removal;
- High pressure water;
- High pressure steam;
- Cleaning agents; and
- Fuel cleaning.

Inerting--

To inert a tank, vapors from an UST are purged and an inert gas (e.g., $CO_2$ and $N_2$) is introduced at low pressure through a single tank opening at a point near the bottom of the tank at the end opposite the vent. Introducing compressed gas into the tank may create a potential ignition hazard from the generation of static electricity. Explosions have resulted from discharging $CO_2$ fire extinguishers into tanks in the flammable range. Solid dry ice is the preferred form of $CO_2$.

Physical Removal of Residues

API publications 2015 and 2015A give general guidance on tank entry. API publications 2201 and 631, and NLPA 631 provide guidance for cutting manways in older tanks. Tanks are continually ventilated or purged during tank entry and physical removal of residual material.

During tank entry, sludge, scale, sediment and residual petroleum products may be physically removed by several techniques depending on tank design (e.g., number and size of openings, size of tank). Physical removal of residues is usually accomplished by:

- scraping of side scale to dislodge flakes;
- shoveling sludge, sediment, and scale into buckets and/or drums; or
- sandblasting.

Non-sparking scrapers and shovels are generally used (i.e., aluminum, brass, wood). Once the tank has been scraped and shoveled, it is usually rinsed with water. Other cleaning methods may include rinseates, such as detergents, solvents, high pressure water, or steam. Cleaning is complete once the tank has been washed or swept and the remaining moisture in the tank has been removed by squeegees, rags, or sawdust.

Sandblasting is commonly used to abrasively remove scale or resistant sludge deposits. The sandblasting process can produce a substantial amount of dust above ground from the manway. A simple system used to control the dust consists of placing alternating layers of perforated plastic sheet tubing across the manway. The tubing directs the dust out of the perforations and is dampened by an adjacent waterline. A sand slurry mixture is produced in this process and is usually allowed to runoff with the excess water.

Removal of Residues by Low Pressure Water

Cleaning USTs with low pressure water is sometimes used rather than tank entry and physical removal. Water is sprayed in from outside of the tank. The cleaning process consists of rinsing with spray from a garden hose at low line pressure. The rinseate and suspended residual material is then pumped out. The tank may or may not be inclined in a direction to facilitate the removal of rinseate water and residual material. There is no current objective information on the effectiveness of this method. Many contractors do not confirm tank cleanliness and simply rinse once and call the tank clean.

Removal of Residues by High Pressure Water

Cleaning with high pressure water can be used in lieu of physical removal methods. The water is sprayed from outside of the tank using a hand-held nozzle or agitating nozzle under enough pressure to physically dislodge resistant deposits of sludge and scale (approximately 25,000-40,000 psi). Agitation with high pressure water can generate static electricity which may act as a possible ignition source; thus most tanks are purged or inerted with nitrogen or carbon dioxide (dry ice) prior to cleaning. Water sprayed under high pressure (required to accomplish adequate cleaning) can also cause serious injury. In some cases, for single-wall steel tanks, high pressure water is used to dismantle the tank itself.

The volume of water that is required to clean the tank is generally less than that required for simple low pressure rinsing. Thus, the total amount of rinseate water that has to be disposed of is limited. Generally the volume of water generated is less than 1/3 of the total volume of the tank. In some jurisdictions tanks are rinsed three times (i.e., triple-rinsed). Each wash water rinse is monitored for total petroleum hydrocarbons (TPH) to determine if an acceptable level of cleanliness has been achieved. The tank may have TPH levels less than the rinseate, and while the rinseate may be considered unacceptable or contaminated (e.g., <80 ppm TPH), the tank will be considered clean. Monitoring of rinseate causes logistical problems and increases both the time and cost of cleaning tanks. Other methods for determining tank cleanliness involve visual inspection of rinse water as it is removed or visual inspection of the tank surface. The particular method used to determine tank cleanliness is dependent upon local or state regulatory requirements.

Removal of Residues by High Pressure Steam

Steam cleaning uses the abrasive action of pressure and combined with temperature to dislodge sludge and scale from tank walls and to dissolve residual hydrocarbon constituents that are soluble in water at elevated temperatures. High pressure steam is sprayed into the tank from the outside and is generally done at centralized facilities because of the need for specialized equipment and rinseate runoff collection.

During cleaning, a hose is inserted through an anchor on a tank opening, which discharges 200°C (400°F) steam at 300 psi. The hose agitates under pressure and scours the tank interior with high velocity steam. Excess rinse water condensate and dislodged sludge and scale are removed through tank openings. The rinse water may or may not be separated from the tank residues and is treated according to RCRA regulations. In some cases it is recycled or reused to clean other tanks.

Removal of Residues Using Special Cleaning Agents

Cleaning methods that involve the use of cleaning agents for dislodging and partially dissolving some of the residual deposits may be performed from outside of the tank. A solvent stream directed through open manways or rotating nozzles, agitators, and other similar devices, has been used to dislodge sludge and scale for pumping and removal. Two types of cleaning agents are commonly used:

- Caustic/acidic agents; and
- Biodegradable agents including solvents, degreasers, and emulsifiers.

Caustic and acidic agents such as trisodium phosphate (TSP) are used as a rinse (usually after the water rinses) to chemically leach lead from scale and rust adhering to the inside of the vessel walls. These agents lower the overall lead content of steel tanks to enable the steel to go to a scrap dealer without further cleaning. TSP is a strong cleaning agent and can be potentially hazardous. In some instances, it is used instead of sandblasting for preparing a tank for lining. In general, these agents are considered to be too harsh for tanks of marginal structural integrity.

Biodegradable solvent cleaners and degreasers are more common tank cleaning agents. Some biodegradable agents are water soluble cleaner-degreasers formulated with an organic nonpetroleum hydrocarbon solvent and multicomponent surfactant-emulsifier. Rinse solutions that have been put into above ground separation tanks or holding ponds after cleaning can undergo phase separation, allowing residual hydrocarbons to rise to the surface. Other biodegradable agents or emulsifiers containing no solvents. When applied with agitation, they break up oil residues and form a nonflammable emulsion that can be washed easily away. Some of these agents are combustible while others actually reduce the risk of combustion by lowering the flashpoint of the mixture. These biodegradable cleaners have been successfully used to clean tanks containing more viscous fuels, such as diesel fuels.

Removal of Residues by Fuel Cleaning

An *in situ* cleaning method involves recirculating fuel already in a tank through a filtering system which then returns the fuel as a pressurized stream via a mobile nozzle. The sprayed fuel hydraulically agitates tank sediments and cleans the tank. Tank residues (sludge, scale, etc.) are pumped out along with recirculated fuel. Thus, the end result is a clean tank containing clean fuel. The process is continuous and requires multiple cycling of the entire tank contents. Tanks that contain a large amount of sediment may require extended periods of recycling (e.g., as long as a week).

If a tank is tilted away from the fillpipe the fuel sprayer nozzle is not as effective in cleaning the downslope portion of the tank. This cleaning method has been observed to merely clean paths in tanks tilted away from the fillpipe and does not remove all of the residues.

High temperatures in the surrounding environment can adversely affect the development of the vacuum required to remove product and residues. The fuel heats up and can volatilize during the recycling/filtration process. For fuels that have a high vapor pressure, it is sometimes difficult to maintain the proper vacuum under these higher temperatures.

The amount of residues that are filtered from a particular fuel may vary considerably depending on a number of factors noted earlier. Estimates for the amount of residues removed from a tank containing gasoline during filtration are on the order of 50 gallons of sediment per 50,000 gallons of fuel. However, some residues are not cleaned out of the tank by this process. The quantity of material remaining in a tank is a function of the design specifications of the pressurized stream vacuum or pumpout line and the degree to which side scale, sludge and sediment are mobilized from the tank walls.

On-Site Versus Off-Site Cleaning

Certain states or municipalities require cleaning of underground storage tanks on-site prior to transport. Generally, the costs associated with off-site cleaning are lower than those for on-site cleaning. Cleaning methods generally used on-site include those used *in situ* prior to tank removal or used on tanks that have been already removed. The fuel-cleaning method is strictly used for tanks in place. Cleaning methods that are commonly used at off-site facilities include high pressure water, high pressure steam and caustic/acidic solutions such as TSP. These methods can also be conducted on-site if adequate runoff collection or pumping equipment is used.

## REFERENCED DOCUMENTS


1. American Petroleum Institute. 1987. Recommended Practice for Removal and Disposal of Used Underground Petroleum Storage Tanks. Publication 1604. Washington, D.C.

2. American Petroleum Institute. 1985. Cleaning Petroleum Storage Tanks. Publication 2015. Washington, D.C.

3. American Petroleum Institute. 1985. Procedures for Welding or Hot Tapping on Equipment Containing Flammables. Publication 2201. Washington, D.C.

4. American Petroleum Institute. 1983. Interior Lining of Underground Storage Tanks. Publication 1631. Washington, D.C.

5. American Petroleum Institute. 1982. A Guide for Controlling the Lead Hazard Associated with Tank Entry and Cleaning. Publication 2015A. Washington, D.C.

6. Camp Dresser & McKee Inc. 1988. Evaluation of the Technical Aspects of UST Closure. Boston, MA. Prepared for the U.S. Environmental Protection Agency.

# APPENDIX B

## TANK ISOLATION AND TANK SURFACE PREPARATION

### TANK ISOLATION

Before any work on the exterior or interior surfaces of tanks begins, tanks must be isolated. An inspection is required to determine how the tanks can be separated from other tanks and isolated from other fuel sources. If a tank is equipped with a vent manifold, fill lines or syphon assembly, necessary measures must be taken to isolate each tank. The vent for the tank being inspected must be isolated from vents for other tanks which may still be in service. This separation may require a temporary separate vent for the subject tank. All electrical switches supplying current to submerge pumps and/or other equipment connected to the tank should be disconnected and locked. Tank isolation prior to venting and entry is very important.

The following are procedures for tank isolation and preparation before tank lining or repair of existing lining:

- Remove stored product from the tank to point less than one inch on the tank bottom.
- Completely isolate and plug the product line at the pump to prevent product from leaking into surrounding soils.
- If tanks are manifolded, the vent lines must be removed and plugged, the ball check valve should be removed.
- Disconnect electricity to the pump. Lock-out the power supply. Remove the pump.
- Remove the manway cover. If there is no manway, excavate an opening to the tank dome. Shore the excavation to prevent any collapsing of the excavation walls (cave-ins).
- Locate and open as many fittings in the tank as possible.
- Remove the drop and any siphon tubes.

- Install the venting apparatus. The fumes must be vented at least 2 meters (6 feet) above grade.

- Before starting the venting process, take an initial tank reading (oxygen and fumes) to establish a reference point.

- Vent the tank and monitor air quality within the tank every 15 minutes.

## TANK SURFACE PREPARATION

Tank walls must undergo surface preparation prior to any inspection activity. This surface preparation consists of grinding away scale or loose glass fibers using approved abrasive blasting materials and equipment. Safety precautions described in Appendix A and API Publication 2077 (Ignition Hazards Involved in Abrasive Blasting of Tanks in Service) should be followed during tank surface preparation.

Before and during abrasive blasting, the tank must be checked with a combustible gas indicator to ensure that no flammable vapors have developed in the tank. Abrasive blast operators should wear approved helmets connected to sources of clean air. Bonding is recommended by FPTPI before internal inspection.

Personal safety and clothing requirements must comply with safety requirements for sandblasting in a confined space. Separators and traps should be used to remove oil and water from compressed air. Following completion of the abrasive blasting operation, the surface shall be brushed with a clean hair, bristle or fiber brush, and blown with compressed air.

The tank should be sandblasted to at least a near white (SSPC-SP10) metal, removing all residues from plugged holes and sludge from all pits. Debris from the sandblasting operations can be vacuum pumped. Cleaning should continue until the tank interior is free of all visible oil, grease, dirt, dust, mill scale, rust and paint.

## REFERENCED DOCUMENTS

1. Midwest Research Institute and PEI Associates, Inc. "Background Report on Underground Storage Tank Closure: Current Practices." Prepared for the U.S. Environmental Protection Agency, Office of Underground Storage Tanks, Washington, D.C. Draft 1988.

## APPENDIX C

## STANDARDS INVESTIGATED

| | |
|---|---|
| ACT-100 | Specifications for the Fabrication of FRP Clad Underground Storage Tanks (Association for Composite Tanks) |
| API 510 | Pressure Vessel Inspection Code -- Maintenance Inspection, Rating, Repair, and Alteration (American Petroleum Institute) |
| API 1631 | Interior Lining of Underground Storage Tanks |
| API 2200 | Repairing Crude Oil, Liquified Petroleum Gas, and Product Pipelines |
| ASTM D 2563-70 | Recommended Practice for Classifying Visual Defects in Glass-Reinforced Plastic Laminate Parts (American Society for Testing and Materials) |
| ASTM D 2583-87 | Test Method for Indentation Hardness of Rigid Plastics by means of a Barcol Impressor |
| ASTM E 214-68 | Recommended Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves |
| ASTM E 268-84a | Definitions of Terms Relating to Electromagnetic Testing |
| ASTM E 269-84a | Definitions of Terms Relating to Magnetic Particle Examination |
| ASTM E 500-85 | Terminology Relating to Ultrasonic Testing |
| ASTM E 610-82 | Definitions of Terms Relating to Acoustic Emission |
| ASTM E 797 | Practice for Measuring Thickness by Manual Ultrasonic |
| ASTM D 2563-70 | Recommended Practice for Classifying Visual Defects in Glass-Reinforced Laminates and Parts Made Therefrom |

| | |
|---|---|
| ASTM E165-80 | Practice for Liquid Penetrant Inspection Method |
| ASTM E 270-84 | Definition of Terms Relating to Liquid Penetrant Inspection |
| NACE RP0184-84 | Repair of Lining Systems (National Association of Corrosion Engineers) |
| NACE RP0188-88 | Discontinuity (Holiday) Testing of Protective Coatings |
| NACE RP0274-74 | High Voltage Electrical Inspection of Pipeline Coatings Prior to Installation |
| NACE RP0287-87 | Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape |
| NACE RP0288-88 | Inspection of Linings on Steel and Concrete |
| NFPA 30 | Flammable and Combustible Liquids Code (National Fire Protection Association) |
| NLPA 631 | Spill Prevention, Minimum 10-year Life Extension of Existing Steel Underground Storage Tanks by Lining Without the Addition of Cathodic Protection (National Leak Prevention Association) |
| NLPA 632 | Internal Inspection of Steel Tanks for Upgrading with Cathodic Protection without Internal Lining |
| SSPC-SP 10 | Surface Preparation Specification No. 10 -- Near-White Blast Cleaning (Steel Structures Painting Council) |
| sti-$P_3$® | Specification for Sti-$P_3$® System of External Corrosion Protection of Underground Storage Tanks (Steel Tank Institute) |
| UL 58 | Steel Underground Tanks for Flammable and Combustible Liquids (Underwriters Laboratories Inc.) |
| UL 1316 | Glass-Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products |

# APPENDIX D

## INTERNAL INSPECTIONS DURING TANK REMANUFACTURE

A relatively recent development in tank overhauling is the practice of "remanufacturing" tanks for reuse. The term "remanufacturing" specifically refers to those activities designed to upgrade previously used tanks in accordance with Federal regulations which prescribe performance standards. Some tank manufacturers view remanufacturing as field service activities such as repairs or lining applications. These activities "recondition" the tank to prolong its life span and involve similar procedures as those done in tank manufacturing. However, the term "remanufacturing" as viewed in this report is not reconditioning tanks on-site for continued use and regulatory compliance, but rather reconditioning tanks that have been removed and would otherwise be sent for disposal in a junkyard, scrapyard, or regulated landfill or recycled.

Tank remanufacturing is primarily performed on steel tanks. In this process, the interior and exterior surfaces of the steel tank are sandblasted and inspected. After the internal and external inspection, the tank interior and exterior surfaces are laminated or "cladded" using FRP material. The FRP application is performed within 12 hours of the sandblasting process.

Table 11 provides a list of the inspections performed during the remanufacturing process.

## TABLE 11. REMANUFACTURING STEEL/FRP COMPOSITE TANKS

Wall Thickness Determination
- a. Ultrasonic Test, or
- b. Hammer Testing

Tank Discontinuity Inspection
- a. Visual Examination, or
- b. Liquid Dye Penetrant, or
- c. Magnetic Particle

Structural Integrity Inspection
- a. Pressure Test

Tank Lining Integrity
- a. Dry Film Thickness, and
- b. Holiday Test

Structural Integrity
- a. Bubble Test

The Association for Composite Tanks (ACT) is primarily responsible for the standards and specifications of tank remanufacturing for reuse. The organization has developed a standard (ACT 100) for inspections and qualifications for remanufacturing tanks and is currently lobbying with Underwriters Laboratories (UL) for a new label for remanufacturing tanks that meet UL58 standards. ACT is developing a standard for tank remanufacturing (ACT 200) that addresses inspection requirements, remanufacturing procedures, and quality assurance. This standard is essentially a revision of ACT 100, but it also incorporates the UL labelling procedure and ACT tank certification.

At this writing, tank remanufacturing is a rapidly evolving business area, preceding a comprehensive research effort in this study. Market growth is attributed to the decreasing numbers of junkyards, scrap dealers and regulated landfills willing to accept tanks for disposal. The disposal of tanks that do not meet current Federal performance standards is costly to the owner/operator and poses a potential environmental liability. Tank remanufacturing provides a cheaper alternative. Rather than risk the liability of becoming an PRP at an improperly managed landfill or junkyard, the owner/operator may have his tank remanufactured and experience the following advantages:

1. A tank that is compatible with petroleum products, additives and alcohol blends such as M-85,

2. No complicated backfill procedures,

3. A tank with the structural strength of steel and the exterior corrosion resistance of FRP, and

4. No post-installation requirements such as monitoring.

For further information on remanufacturing activities, contact:

Mr. Bob Holland
Executive Vice President
Association For Composite Tanks
Baltimore, MD 21211
301/235-6000

## APPENDIX E

## SAFETY PRECAUTIONS

In this appendix, EPA and its contractors (CDM, CDM FPC, and PEI) are not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, or to fulfill their obligations under local, state or Federal laws.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the applicable material safety data sheet. In addition, the tank inspector needs to consult publications by API, NFPA, NIOSH, and OSHA as well as Federal, state, or local regulations regarding flammable and combustible liquids. Any safety and testing equipment used during internal inspection should be operated by qualified people who understand how to use and maintain the equipment.

### HAZARDOUS ASSESSMENT

A variety of safety hazards exist when internally inspecting USTs. All personnel working within the established exclusion zones should be familiar with the hazards associated with chemical exposure, physical safety, an explosive atmosphere and an oxygen-deficient atmosphere. This section outlines the chemical and physical hazards, and the associated procedures and protective and monitoring equipment that can reduce these hazards.

#### Chemical Hazards

Information concerning safety and health risks and proper precautions for particular materials and conditions should be obtained from the employer, the manufacturer or the supplier of that material, and the material safety data sheet. Government agencies are additional sources of information. Toxicity considerations for substances likely to be found in underground petroleum storage tanks are described below.

> Benzene - High occupational exposure to benzene has been associated with various human blood disorders, including an increased risk of leukemia. Very high levels have also been known to affect the central nervous system. Benzene administered by mouth has induced cancer in

laboratory animals in long-term tests. Benzene is rapidly absorbed through the skin. The American Conference of Government industrial hygienists (ACGIH) recommends a Threshold Limit Value (TLV) for benzene at 10 parts per million time-weighted average, with a short-term exposure limit of 25 parts per million. The Occupational Safety and Health Administration (OSHA) stipulates an 8-hour time-weighted average for benzene of 10 parts per million with an acceptable ceiling concentration of 25 parts per million and an acceptable peak of 50 parts per million for 10 minutes (29 CFR 1910.1000, Table Z-2). OSHA's Occupations Safety and Health Regulations should be checked for the current TLV.

- Tetraethyl Lead - Exposure to tetraethyl lead can cause diseases of the central and peripheral nervous systems, the kidney, and the blood. Skin absorption of this compound is a major route of entry into the body. The ACGIH recommended time-weighted average is 0.1 milligrams per cubic meter for general room air. Biological monitoring is essential for personnel safety. The OSHA standard is 0.075 milligrams per cubic meter.

- Epoxy Compounds - The most commonly encountered toxic effects associated with use of epoxy compounds are dermatitis, eye irritation, and pulmonary irritation. Systemic effects in man are uncommon. Some of these compounds have produced tumors in laboratory animals, generally by dermal application.

Inhalation of Vapors, Accidental Ingestion, Dermal Absorption of Liquids and Solids

- Symptoms
  - Intoxication-like behavior
  - Dizziness
  - Excitement
  - Unconsciousness
- Treatment
  - Remove individual to fresh air
  - Give oxygen, if necessary
  - Give respiratory assistance if breathing has stopped
  - Seek prompt medical attention

Health Precautions

When working with petroleum substances:

1. Avoid skin contact.
2. Avoid inhaling vapors.
3. Keep petroleum liquids away from eyes, skin, and mouth; they can be harmful or fatal if inhaled, absorbed through the skin, or ingested.
4. Use soap and water to remove any petroleum product that contacts skin.
5. Do not use gasoline or similar solvents to remove oil and grease from skin.

6. Promptly wash petroleum-soaked clothes.
7. Properly dispose of rags.
8. Keep work areas clean and well ventilated.
9. Clean up spills promptly.

## Physical Hazards

Physical hazards likely to occur during operations include the following:

- Fire Hazard
- Oxygen-Deficiency (Confined Space entry)
- Heat Stress

These physical hazards are described below along with safety precautions.

Fire Hazard--

Most UST removals will involve flammable vapors from products stored in the tank and from accumulated residues left in the tank even after it has been pumped dry. Be aware of the basic fire triangle: fuel, oxygen, ignition source. All three points of the triangle are necessary to support combustion. These three elements need to be recognized, evaluated, and controlled to make a safe work place and to avoid disaster. Safe working operations require continuous attention to these potential hazards to eliminate or reduce the risk of explosion.

Fire Prevention--

To reduce or eliminate fire hazards, one of the three elements must be removed or controlled. Control methods are summarized for ignition sources, fuel, and oxygen.

If operations require the use of equipment that may become ignition sources (e.g., abrasive blasting), the tank must be ventilated in order to reduce the flammable (or combustible) vapors (the fuel in the fire triangle) below the lower flammable or explosive limit or (L.F.L. or L.E.L.). Ventilation equipment, such as venting eductors, can be used to reduce the flammable (or combustible) vapors. In cases where tank entry is not necessary, fire hazards can also be controlled by reducing the amount of oxygen in the tank (e.g., flooding the tank with inert gases such as nitrogen).

Eliminate Sources of Ignition--

1. Flammable (or combustible) vapors are likely to be present in the work area. The concentration of vapors in or around the tank may reach the flammable (or explosive) range before venting is completed and a safe atmosphere is reached. Precautions should be taken to:

   a. eliminate all potential sources of ignition from the area.

      - remove all smoking materials

- remove nonexplosive-proof electrical and internal combustion equipment and internal combustion equipment.

- isolate tank from contaminated soils.

b. prevent the discharge of static electricity during venting of flammable vapors.

c. prevent the accumulation of vapors at ground level

2. The process of introducing the compressed gases into the tank may create a potential ignition hazard due to the development of static electrical charges. The discharging device must therefore be grounded. Explosions have resulted from the discharging of carbon dioxide fire extinguishers into tanks containing a flammable vapor-air mixture.

3. Tanks or containers that have held high flash point liquids may become hazardous during cutting or welding operations or when heated.

Ventilate--

1. Flammable (or combustible) vapors can be purged with an inert (non-reactive) gas such as carbon dioxide or nitrogen. This method displaces flammable (or combustible) vapors and reduces the oxygen levels. It, therefore, should not be used if the tank is to be entered for any reason unless an external oxygen supply is provided.

2. The vapors in the tank may be displaced by adding solid carbon dioxide (dry ice) to the tank.

   - Caution: Skin contact with dry ice may produce burns.
   - Air pressure in the tank should not exceed 5 pounds per square inch.

3. Vapors can also be purged using explosion-proof eductors or other ventilation equipment.

Notify Proper Authority--

1. Anyone who becomes aware of a hazardous condition should notify the proper authority. However, every reasonable effort should be made first to determine the degree of the problem.

Oxygen-Deficiency (Confined Space Entry)--

Hazards associated with reduced oxygen environments are mainly from entering confined spaces. The following discussion summarizes the hazards associated with confined-space entry as defined in 29 CFR 1910.146. In addition, measures taken to supply oxygen to the tank inspector are summarized below.

"Confined space" means any space not intended for continuous employee occupancy, having a limited means of egress, and which is also subject to either the accumulation of an actual or potentially hazardous atmosphere as defined in this subsection or has a potential for engulfment as defined in this subsection. Open spaces greater than 4 feet in depth, such as pits, tubs, vaults and vessels, may also be categorized as confined spaces if the three criteria above are met.

All confined spaces shall be emptied, flushed, or otherwise purged of flammable, injurious, or incapacitating substances to the extent feasible. To the extent feasible, initial cleaning should be done from outside the confined space.

Where the existence of a hazardous atmosphere is demonstrated by tests performed by a qualified person, the confined space shall be mechanically ventilated until the concentration of the hazardous substance(s) is reduced to a safe level, and ventilation shall be continued as long as the recurrence of the hazard(s) is possible. In addition, appropriate personal protective equipment should be used. Confined space entry must be performed by at least two people (i.e., the buddy system) and comply with local, state and Federal codes. Figure E-1 gives an example of a confined space entry checklist that is used in several states for permitting confined-space entry.

The following guidelines have been drafted by FPTPI for classifying confined space entry conditions and appropriate procedures:

- No Entry - Absolutely NO ENTRY is allowed if the oxygen levels are below 16% and/or the flammable (or explosion) levels are above 20% L.F.L. (or L.E.L.) regardless of the use an external air supply. Absolutely NO ENTRY is allowed until the atmosphere inside the tank is improved using venting procedures.

- Restricted Entry - The technician may enter the tank if the oxygen levels in the tank are between 16.1% and 19.4% and flammable (or explosion) levels are 10 to 20% L.F.L. (or L.E.L.). The technician can enter the tank only if equipped with the proper breathing and safety gear. A stand-by must be provided.

  In this case, the proper safety equipment is either a self contained breathing apparatus (SCBA) or a supplied air source.

## FIGURE E-1. CONFINED SPACE ENTRY PERMIT-- OPERATING TANKS

PRE-ENTRY (Check if Yes)

______ 1. Has tank been emptied?

______ 2. Has the air mover been installed, properly grounded and is it effectively exhausting air from the tank?

______ 3. Have all internal openings into the tank been blanked, capped, removed or disconnected?

______ 4. Has the entry hole been adequately barricaded?

______ 5. Has the stand-by been instructed on the use of safety harness and self-contained breaking apparatus (SCBA)?

______ 6. Has the stand-by been instructed as to his responsibilities?

Technician signature: ______________________
Does he fully understand: ______________________
Stand-by signature: ______________________

______ 7. Emergency Procedure reviewed?

Rescue/Life Squad Phone Number: ______________
Police Phone Number: ______________
Fire Department Phone Number: ______________

______ 8. Pre-entry readings:
Oxygen level: ______________
Flammable Vapor level: ______________

______ 9. Air-supplied mask and air capsule in good working order?

______ 10. Safety harness and lifelines secure?

______ 11. Only air tools in the tank?

______ 12. This entry checklist is posted near the entry hole?

POST-ENTRY

______ 13. Have all tools, safety equipment and materials been moved?

Technician signature: ______________________
Date completed: ______________________

- Special Entry - For tanks that have stored flammable or combustible liquids that are temporarily above ground during remanufacturing/recertification.

  This tank may have oxygen levels between 19.5% and 21.4% and flammable (or explosive) vapor levels of 3 to 10% L.F.L. (or L.E.L.)

  With Special Entry tanks the technician must still wear a safety harness with a rope, but can enter the tank wearing an approved organic cartridge respirator. Several types of respirators are available for this purpose. A stand-by must be provided.

- General Entry - The oxygen levels in this tank are between 19.5% and 21.4% and flammable (or explosive) vapor levels are below 3% L.F.L. (or L.E.L.) This tank is safe to enter, but, as always, a safety harness must be worn. This level of tank must be maintained by continuous venting during the remanufacturing or inspection process. A stand-by must be provided.

Thermal Stress--

One or more of the following control measures can be used to help control heat stress:

- Provision of adequate liquids to replace lost body fluids. Employees must replace water and electrolytes lost from sweating. Employees must be encouraged to drink more than the amount required to satisfy thirst. Salt tablets should be available. Thirst satisfaction is not an accurate indicator of adequate salt and fluid replacement. Replacement fluids can be a 0.1 percent salt water solution, commercial mixes such as Gatorade® or Quick Kick®, or a combination of these with fresh water.

- Establishment of a work regimen that will provide adequate rest periods for cooling down. This may require additional shifts or workers. All breaks are to be taken in a cool rest area (77°F) is best.

- Cooling devices, such as vortex tubes or cooling vests, can be worn beneath protective garments.

- Inform all employees of the importance of adequate rest, acclimation, and proper diet in the prevention of heat stress.

During periods of intense activity, the site Health & Safety representative will continually observe the workers for symptoms of heat stress, especially in areas where protective clothing is being worn. If the body's physiological processes to maintain a normal body temperature fail or are overburdened due to excessive heat exposure, a number of physical reactions can occur such as fatigue, irritability, anxiety, and decreases in mental concentration. Heat-related problems are presented below:

- Heat Rash - This is caused by continual exposure to heat and humid air, and aggravated by chaffing clothes. Heat rash decreases a person's ability to tolerate heat as well as becoming an irritating nuisance.

- Heat Cramps - This is caused by profuse perspiration with inadequate water intake and chemical electrolyte imbalance. This results in muscle spasm and pain in the extremities and abdomen.

- Heat Exhaustion - Increased stress on various organs to meet increasing demands to cool the body will result in signs and symptoms including shallow breathing; pale, cool, moist skin; profuse sweating; dizziness and lassitude.

- Heat Stroke - This is the most severe form of heat stress which must be treated immediately by cooling the body or death may result. Signs and symptoms include red, hot, dry skin; lack of perspiration; nausea; dizziness and confusion; strong, rapid pulse; and coma.

The symptoms of heat stress may also include: fatigue; irritability; headache; faintness; weak, rapid pulse; shallow breathing; cold, clammy skin; profuse perspiration.

Treatment--

1. Instruct victim to lie down in a cool, shaded area or air-conditioned room. Elevate feet.

2. Massage affected muscles.

3. Give cold salt water (1/2 teaspoon to 1/2 glass of water) or cool, sweetened drink, especially iced tea and coffee, every 15 minutes until victim recovers.

4. DO NOT let victim sit up, even after feeling recovered.

5. Call for medical aid.

Protective Equipment

Specific levels of protection are used to safeguard employees on the job from potential hazards. Three distinct levels of protection (i.e., levels B, C, or D) may be required. The final determination of any required level of protection will be based upon the hazards and current conditions of the work site. The only person who may make this determination is the Health and Safety Representative. The situations requiring specific levels of protection are described in the following sections.

Level B Protection--

This level of personal protection will be utilized by individuals when: 1) the toxic nature of the material or anticipated airborne concentration of known contaminants may be greater than two times the OSHA permissible exposure limits (PELs), 2) when the total hydrocarbon reading on the HNu is greater than 10 ppm above background, or 3) when the oxygen level on the MSA combustible gas indicator sustains a reading of less than 19.5%.

The following equipment will be used for Level B Protection:

- Full-face self-contained breathing apparatus or supplied air respirator which is NIOSH/MSHA approved.
- Hooded, chemical-resistant Saranex-coated Tyvek® (Outer)
- Unhooded, chemical-resistant white Tyvek® (Inner)
- Gloves - chemical-resistant nitrile or polyvinyl chloride (PVC) (Outer)
- Gloves - latex surgical or PVC (Inner)
- Boots - chemical-resistant neoprene with steel toes and shank (Outer). Steel sole inserts will be used where materials could puncture boots. Disposable PVC booties over steel-toed shoes for equipment operators.
- Hard hat
- Hearing protection (if necessary)

Level C Protection--

Level C protection will be required when the toxic nature of the material and airborne concentration of contaminants are known to be at or above the TLV or the PEL, or when the total hydrocarbon reading on the HNu is above background.

The following equipment will be used for Level C protection:

- Full-face, air purifying respirators with organic vapors which are NIOSH/MSHA approved. Half-face respirators will be utilized if accompanied by chemical splash goggles and specified by the Regional Health and Safety Representative.
- Hooded, chemical-resistant white Tyvek®
- Gloves - chemical-resistant nitrile or PVC (Outer)

- Gloves - latex surgical gloves (Inner)

- Boots - chemical-resistant neoprene with steel toes and steel-toed shoes (Outer)

- Hard hat

- Hearing protection (if necessary)

Level D Protection--

The minimal level of protection that may be required of personnel at a site is Level D. The following equipment is characteristic of Level D protection:

- Coveralls or Tyvek®

- Boots/Shoes - Safety shoes with steel toes

- Safety glasses or goggles

- Hard hat

- Chemical-resistant nitrile or PVC protective gloves with surgical latex undergloves.

The levels of chemicals or oxygen that trigger the upgrade from Level D to Level C or from Level C to Level B are determined by the Health and Safety Representative.

Fire and Other Safety Equipment--

The following equipment will also be used on site:

- An approved light source designed for an explosive atmosphere

- Fire extinguisher

- Safety harness

- An air-operated venting or tank de-fuming apparatus

- An extra compressed air cylinder or other air purifying system with appropriate respirator and organic vapor cartridges

- Approved safety goggles, safety glasses or face shield, ear plugs, rubber gloves and rubber boots

- An appropriate first aid kit and fire blankets

Monitoring Equipment

In most tank work, two types of air monitoring equipment are generally employed to warn workers of potential hazards (e.g.,hazardous vapor concentrations, flammable vapor levels, oxygen levels):

- Combustible Gas Indicator (CGI) - monitors the explosive levels of flammable vapors and oxygen

- Organic vapor monitoring instrument (e.g., PID, FID, GC/MS, colorimetric tubes) - monitors total organic vapor concentrations or individual constituent levels in air around workers.

GENERAL WORK PRACTICES

All work being performed during the remedial action should be done using the "buddy" system. Before beginning work each day, buddies should be assigned. These team members will keep in visual contact with each other at all times. These team members will be aware of: any slip or trip; all lifting hazards; any potential exposure to chemical substances; all potential for heat or cold stress; and any general hazards within the work areas. All information regarding work to be performed, emergency procedures, and health and safety hazards will be reviewed before the work begins during a daily tailgate safety meeting. No work will be performed without completing these procedures. In addition, while work is being performed inside the tank, a safety technician should monitor continuously the oxygen levels, flammable vapors, and organic vapor levels inside the tank.

Transportation by any other means than those prescribed for movement of personnel will be strictly prohibited. When trucks or other heavy equipment enter the site, flagmen will direct traffic.

Several fire extinguishers will be on site. In the event of an emergency, these extinguishers will be ready for the worker's safety and protection. Any deviation from this site safety program must be discussed in advance with the Health and Safety Representative. Smoking will not be permitted on the premises.

No unapproved electrical equipment for hazardous atmospheres will be permitted in areas where a flammable or combustible vapor atmosphere exists. All static ignition sources will be identified and eliminated by the use of standard bonding and grounding techniques.

## REFERENCES

The names of references and organizations that may be of value to those responding to hazardous materials incidents are provided below. These names are not all-inclusive, and can be expanded based on personal preferences and requirements. References are listed according to title, author, publisher, and place of publication. The year of publication is not always given because many of these references are revised annually. The user should attempt to obtain the most recent edition.

Sources of these references as well as other information that might be useful are also listed. Usually, these agencies and associations will provide a catalogue on request. Where available, phone numbers are also listed.


1. NIOSH/OSHA Pocket Guide to Chemical Hazards, DHHS No. 85-114, NIOSH, Department of Health and Human Services, Cincinnati, OH.

2. Registry of Toxic Effects of Chemical Substances, DHHS No. 83-107, National Institute for Occupational Safety and Health, Rockville, MD.

3. Respiratory Protective Devices Manual, American Industrial Hygiene Association, Akron, OH.

4. TLVs Threshold Limit Values and Biological Exposure Indices (Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment), American Conference of Governmental Industrial Hygienists, Cincinnati, OH.

5. Fire Protection Handbook, National Fire Protection Association, Quincy, MA.

6. Flammable Hazardous Substances Emergency Response Handbook: Control and Safety Procedures, Prepared for U.S.EPA under Contract No. 68-03-3014.

7. Guidelines for the Selection of Chemical Protective Clothing, Volume 1: Field Guide, A.D. Schwope, P.P. Costas, J.O. Jackson, D.J. Weitzman, Arthur D. Little, Inc., Cambridge, MA (March 1983).

8. Guidelines for the Selection of Chemical Protective Clothing, Volume 2: Technical and Reference Manual, A.D. Schwope, P.P. Costas, J.O. Jackson, D.J. Weitzman, Arthur D. Little, Inc., Cambridge, MA (March 1983).

9. Hazardous Materials Injuries, A Handbook for Pre-Hospital Care, Douglas R. Stutz, Robert C. Ricks, Michael F. Olsen, Bradford Communications Corp., Greenbelt, MD.

10. National Safety Council Safety Sheets, National Safety Council, Chicago, IL.

11. NIOSH Certified Equipment Lists, U.S. Dept. of Health and Human Services, Washington, D.C.

12. Personal Protective Equipment for Hazardous Materials Incidents: A Selection Guide, NIOSH, U.S. Department of Health and Human Services, Washington, D.C.

13. SCBA - A Fire Service Guide to the Selection, Use, Care, and Maintenance of Self-Contained Breathing Apparatus, National Fire Protection Association, Batterymarch Park, Quincy, MA.

14. Standard First Aid and Personal Safety, American Red Cross.

15. Underwriters Laboratories Testing for Public Safety, Annual Directory, Underwriters Laboratories, Inc., Northbrook, IL.

Agencies and Associations

Agency for Toxic Substances Disease Registry
Shamlee 28 S., Room 9
Centers for Disease Control
Atlanta, GA 30333
404/452-4100

American Conference of Governmental Industrial Hygienists
6500 Glenway Avenue - Building D-5
Cincinnati, OH 45211
513/661-7881

American Industrial Hygiene Association
475 Wolf Ledges Parkway
Akron, OH 44311-1087

American National Standards Institute, Inc.
1430 Broadway
New York, NY 10018
212/354-3300

American Petroleum Institute (API)
1220 L. St., NW, 9th Floor
Washington, DC 20005
202/639-2100

Chemical Manufacturers Association
2501 M St., N.W.
Washington, DC 20037
202/887-1100

Compressed Gas Association
1235 Jefferson Davis Highway
Arlington, VA 22202
703/979-0900

CRC Press, Inc.
2000 Corporate Blvd. N.W.
Boca Raton, FL 33431
305/994-0555, Ext. 330

National Fire Protection Association
Batterymarch Park
Quincy, MA 02269
617/328-9290

U.S. Department of Transportation
Materials Transportation Bureau
Office of Hazardous Materials Operations
400 7th St. S.W.
Washington, DC 20590
202/336-4555

U.S. EPA, Office of Solid Waste (WH-562)
Superfund Hotline
401 M St, S.W.
Washington, DC 20460
800/424-9346

Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402
202/783-3238

U.S. Mine Safety and Health Administration
Department of Labor
4015 Wilson Blvd. Room 600
Arlington, VA 22203
703/235-1452

U.S. National Oceanic and Atmospheric Administration
Hazardous Materials Response Branch
N/OMS 34
7600 Sand Point Way NE
Seattle, WA 98115
206/527-6317

# APPENDIX F

# CLASSIFICATION OF SURFACE AND SUBSURFACE DISCONTINUITIES FOR TRANSLUCENT VISUAL EXAMINATION OF FRP TANKS ASME SD-2563

# CLASSIFICATION OF DISCONTINUITIES FOR TRANSLUCENT VISUAL EXAMINATION ASME SD-2563

| Name | Definition | Level I | Level II | Level III |
|---|---|---|---|---|
| Chip | a small piece broken off an edge or surface | none | maximum dimension of break, 3.0 mm (1/8 in.) | maximum dimension of break, 6.5 mm (1/4 in.) |
| Crack | an actual separation of the laminate, visible on opposite surfaces, and extending through the thickness | none | none | none |
| Crack, surface | crack existing only on the surface of the laminate | none | maximum length, 3.0 mm (1/8 in.) | maximum length 6.5 mm (1/4 in.) |
| Crazing | fine cracks at or under the surface of a laminate | none | maximum dimension of crazing, 13 mm (1/2 in.) frequency and location | maximum dimension of crazing, 25 mm (1 in.) to be determined by customer |
| Delamination, edge | separation of the layers of material at the edge of a laminate | none | maximum dimension, 3.0 mm (1/8 in.) | maximum dimension, 6.5 mm (1.4 in.) |
| Delamination, internal | separation of the layers of material in a laminate | none | none | none |
| Dry-spot | area of incomplete surface film where the reinforcement has not been wetted with resin | none | maximum diameter, 9.5 mm (3.8 in) | maximum diameter, 14 mm (9/16 in.) |
| Foreign inclusion (metallic) | metallic particles included in a laminate which are foreign to its composition | none | none, if for electrical use; maximum dimension, 0.8 mm (1/32 in), 1/0.09 $m^2$ (1 $ft^2$), if for mechanical use | none, if for electrical use; maximum dimension, 1.5 mm (1/16 in.), 1/0.09 $m^2$ (1 $ft^2$), if for mechanical use |
| Foreign inclusion (nonmetallic) | nonmetallic particles of substance included in a laminate which seem foreign to its composition | none | maximum dimension, 0.8 mm (1/32 in.) 1/0.09 $m^2$ (1 $ft^2$) | maximum dimension, 1.5 mm (1/16 in.); 1/0.09 $m^2$ (1 $ft^2$) |
| Fracture | rupture of laminate surface without complete penetration | none | maximum dimension, 21 mm (13/16 in.) | maximum dimension, 29 mm (1-1/8 in.) |
| Air bubble (void) | air entrapment within and between the plies of reinforcement, usually spherical in shape | none | maximum diameter, 1.5 mm (1/16 in.); 2/in.$^2$ | maximum diameter, 3.0 mm (1/8 in); 4/ in.$^2$ |
| Blister | rounded elevation of the surface of a laminate, with boundaries that may be more or less sharply defined, somewhat resembling in shape a blister on the human skin | none | maximum diameter, 3.0 mm (1.8 in.); height from surface not to be outside drawing tolerance | maximum diameter, 6.5 mm (1/4 in.); height from surface not to be outside drawing tolerance |

## CLASSIFICATION OF DISCONTINUITIES FOR TRANSLUCENT VISUAL EXAMINATION ASME SD-2563 (cont'd)

| Name | Definition | Level I | Level II | Level III |
|---|---|---|---|---|
| Burned | showing evidence of thermal decomposition through some discoloration, distortion, no destruction of the surface of the laminate | none | none | none |
| Fish-eye | small globular mass which has not blended completely into the surrounding material and is particularly evident in a transparent of translucent material | none | maximum diameter, 9.5 mm (3/8 in.) | maximum diameter, 13 mm (1/2 in.) |
| Lack of fillout | an area, occurring usually at the edge of a laminated plastic, where the reinforcement has not been wetted with resin | none | maximum diameter, 6.5 mm (1/4 in.) | maximum diameter, 9.5 mm (3/8 in.) |
| Orange-peel | uneven surface somewhat resembling an orange peel | none | maximum diameter, 14 mm (9/16 in.) | maximum diameter, 29 mm (1-1/8 in.) |
| Pimple | small, sharp, or conical elevation on the surface of a laminate | none | none | maximum diameter, 3.0 mm (1/8 in.) |
| Pit (pinhole) | small crater in the surface of a laminate, with its width approximately of the same order of magnitude as its depth | none | maximum diameter, 0.4 mm (1/64 in.); depth less than 1 percent of wall thickness frequency and location | maximum diameter, 0.8 mm (1/32 in.); depth less than 20 percent of wall thickness to be determined by customer |
| Resin-rich edge | insufficient reinforcing material at the edge of molded laminate | none | maximum, 0.4 mm (1/64 in.) from the edge | maximum, 0.8 mm (1/32 in.) from the edge |
| Shrink-mark (sink) | depression in the surface of a molded laminate where it has retracted from the mold | none | maximum diameter, 9.5 mm (3/8 in.); depth not greater than 25 percent of wall thickness | maximum diameter, 14 mm (9/16 in.); depth not greater than 25 percent of wall thickness |
| Wash | area where the reinforcement of molded plastic has moved inadvertently during closure of the mold resulting in resin-rich areas | none | maximum dimension 21 mm (13/16 in.) | maximum dimension 29 mm (1-1/8 in.) |
| Wormhole | elongated air entrapment which is either in or near the surface of a laminate and may be covered by a thin film of cured resin | none | maximum diameter, 3.0 mm (1/8 in.) | maximum diameter, 6.5 mm (1/4 in.) |

## CLASSIFICATION OF DISCONTINUITIES FOR TRANSLUCENT VISUAL EXAMINATION ASME SD-2563 (cont'd)

| Name | Definition | Level I | Level II | Level III |
|---|---|---|---|---|
| Wrinkle | in a laminate, an imperfection that has the appearance of a wave molded into one or more plies of fabric or other reinforcement material | none | maximum length surface side, 13 mm (1/2 in.); maximum length opposite side, 13 mm (1/2 in); depth less than 10 percent of wall thickness | maximum length surface side, 25 mm (1 in.); maximum length opposite side, 25 mm (1 in.); depth less than 15 percent of wall thickness |
| Scratch | shallow mark, groove, furrow, or channel caused by improper handling or storage | none | maximum length, 25 mm (1.0 in.); maximum depth, 0.255 (o.010 in.) | maximum length, 25 mm (1.0); maximum depth, 0.255 (0.010 in.) |
| Short | in a laminate, an incompletely filled out condition<br>NOTE--this may be evident either through an absence of surface film in some areas, or as lighter unfused particles of material showing through a covering surface film, possibly accompanied by thin-skinned blisters | none | none | none |

## APPENDIX G

## QUALIFICATION PROCEDURE FOR NON-STANDARD TEMPERATURES FOR LIQUID DYE PENETRANT TESTS

Approach --

This procedure is performed when the operating conditions of the liquid dye penetrant test exceeds 125°F or are less than 60°F. Temperatures outside the recommended range are referred to as "Non-Standard Temperatures," while temperatures within the range are classified as "Standard Temperatures." Non-standard test conditions require qualification by ASME standards. A quenched aluminum block will be created in accordance to ASME specifications and be designated as the liquid penetrant comparator block.

Liquid Penetrant Comparator --

The following parameters are required for Liquid Penetrants:

| | |
|---|---|
| Material: | ASTM B 209, Type 2024 or SB-211, Type 2024 |
| Dimensions: | 2 in. x 3 in. x 3/8 in. |
| Labeling: | Center of each face shall be marked with a 950°F indicator crayon. |
| Production: | The aluminum block shall be heated to 950°F and then immediately quenched in cold water. The aluminum block is then dried by heating to 300°F. This process generates fine cracks on both faces of the block. After drying, the block is allowed to cool and is cut into two equally sized blocks. These blocks will be labelled block "A" and block "B". |

Qualification --

When using visible dye penetrants whose flaw detection is based on color contrast, a single comparator block may be used for the standard and non-standard temperatures. The block shall be thoroughly cleaned between the two processing steps. Photographs are taken after testing at the non-standard temperature, and again after testing at the standard temperature. The flaw indications of the block at the two temperatures are compared on the photographs. If the flaw indications of the comparator block at the non-standard temperature are essentially the same as the flaws at the standard temperature, the penetrant procedure is then "qualified." If the non-standard temperature is below 60°F and the procedure is "qualified," the penetrant procedure is qualified from that specific non-standard temperature up to 60°F.

# APPENDIX H

## CONTROL TESTS RECOMMENDED BY ASME SE-709 FOR MAGNETIC PARTICLE TESTS

Ammeter Accuracy Check --

The equipment meter readings should be compared to a control test meter reading, incorporating a shunt or current transformer to monitor the output current. Comparative readings shall be taken at a minimum of three output levels encompassing the usable range. The equipment meter reading shall not deviate by more than +/- 10% of full scale, relative to the actual current values as shown by the test meter. When measuring half-wave current, the direct current test meter reading is doubled.

Timer Control Check --

The timer should be checked and verified using a precision timer at routine intervals or suspected malfunctions on equipment utilizing a timer to control the duration of the current flow.

Magnetic Field Quick Break Check --

On equipment with magnetic field quick breaks, a test may be performed using a suitable oscilloscope or a simple test device usually available from the manufacturer.

Equipment Current Output Check --

To assure the continued accuracy of the equipment, ammeter readings at each transformer tap should be made with a calibrated ammeter-shunt combination. This accessory is placed in series with the contacts. The equipment shunt should not be used to check the machine of which it is an uncalibrated part. Variations exceeding +/- 10% from the equipment ammeter readings indicate the equipment needs service or repair.

Internal Short Circuit Check --

Magnetic particle equipment should be checked periodically for internal short-circuiting. With the equipment set for maximum amperage output, any deflection of the ammeter when the current is activated with no conductor between the contacts is an indication of an internal short circuit.

Electromagnetic Lifting Force --

The magnetizing force of a yoke can be tested by determining its lifting power on a steel plate. The lifting force relates to the electromagnetic strength of the yoke. Alternating current electromagnetic yokes should have a lifting force of at least 10 lb, and direct current yokes of 40 lb, at the maximum pole spacing.

# APPENDIX I

## TANK INTEGRITY TEST METHOD SUMMARY

# TANK INTEGRITY TEST METHOD SUMMARY

| Reference | Tank Type | Tank Specification | Test Type | Test Pressure | Test Period | Failure Criteria |
|---|---|---|---|---|---|---|
| UL 1316 | Fiberglass | 10 ft. diameter or less | Bubble | 5 psig | 5 min. (soak) | Continuous formation of bubbles |
| | | | Pressure | 25 psig | 1 min. | Rupture |
| | | Greater than 10 ft. diameter | Bubble | 3 psig | 5 min. (soak) | Continuous formation of bubbles |
| | | | Pressure | 15 psig | 1 min. | Rupture |
| | | Double Wall Annulus | Pressure | (a) | 1 min. | Rupture |
| | | Double Wall Annulus | Vacuum | (b) | 1 min. | Rupture |
| | | NS | Vacuum | (c) | NS | Rupture |
| ASTM D4021-81 | Fiberglass | 10 ft. diameter or less | Bubble | 5 psig | (d) | Continuous formation of bubbles |
| | | | Pressure | 25 psig | 1 min. | Rupture |
| | | Greater than 10 ft. diameter | Bubble | 3 psig | (d) | Continuous formation of bubbles |
| | | | Pressure | 15 psig | 1 min. | Rupture |
| | | NS | Vacuum | -2.5 psig | (e) | Rupture |
| UL 58 | Steel | NS | Bubble | 5-7 psig | NS | Continuous formation of bubbles |
| NFPA 30 | Steel Fiberglass | NS | Pressure | 3-5 psig | NS | NS |
| NLPA 631 | Steel Fiberglass | NS | Vacuum | (c) | 1 min. | Rupture |
| | | | Bubble | 3-5 psig | NS | Continuous formation of bubbles |

continued

## TANK INTEGRITY TEST METHOD SUMMARY (cont'd)

| Standard or Recommended Practice | Tank Type | Tank Specification | Test Type | Test Pressure | Test Period | Failure Criteria |
|---|---|---|---|---|---|---|
| FPTPI Draft Recommended Practice T-89-1 | Fiberglass | less than 12 ft. diameter | Bubble | 5 psig | NS | Continuous formation of bubbles |
| | | 12 ft. diameter | Bubble | 3 psig | NS | Continuous formation of bubbles |

Footnotes
NS - None Specified

(a) 2 times rated maximum annulus pressure.

(b) Rated maximum annulus vacuum plus 5.3 in. Hg vacuum.

(c) V = (1/2 D + h) x 0.88 inches Hg/ft
in which V is the vacuum in inches Hg,
D is the tank diameter in feet, and
h is the maximum recommended burial depth in feet, but not less than 3 feet.

(d) Test begins when pressure has stabilized (variable soak period) and continues until exposed surface is tested.

(e) Test pressure only has to be attained without rupture to pass test (no holding period).



☆U.S. GOVERNMENT PRINTING OFFICE:1991 -548 -187/20528

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

BULK RATE
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

Official Business
Penalty for Private Use, $300

Please make all necessary changes on the above label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE ☐; detach, or copy this cover, and return to the address in the upper left-hand corner.

EPA/600/2-90/061