

LUST

Leaking Underground Storage Tanks
CONTINUING EDUCATION
PROFESSIONAL DEVELOPMENT COURSE



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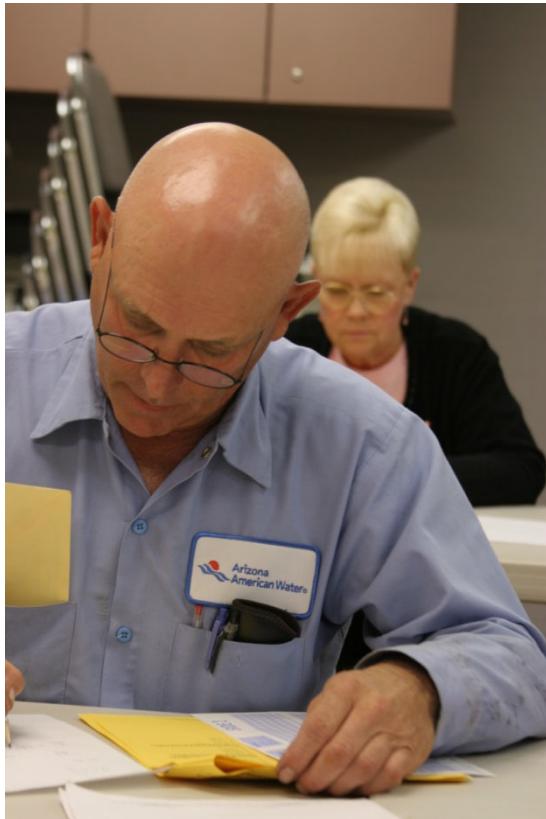
Professional Engineers; Most states will accept our courses for credit but we do not officially list the States or Agencies.

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Some States and many employers require the final exam to be proctored.

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Contributing Editors

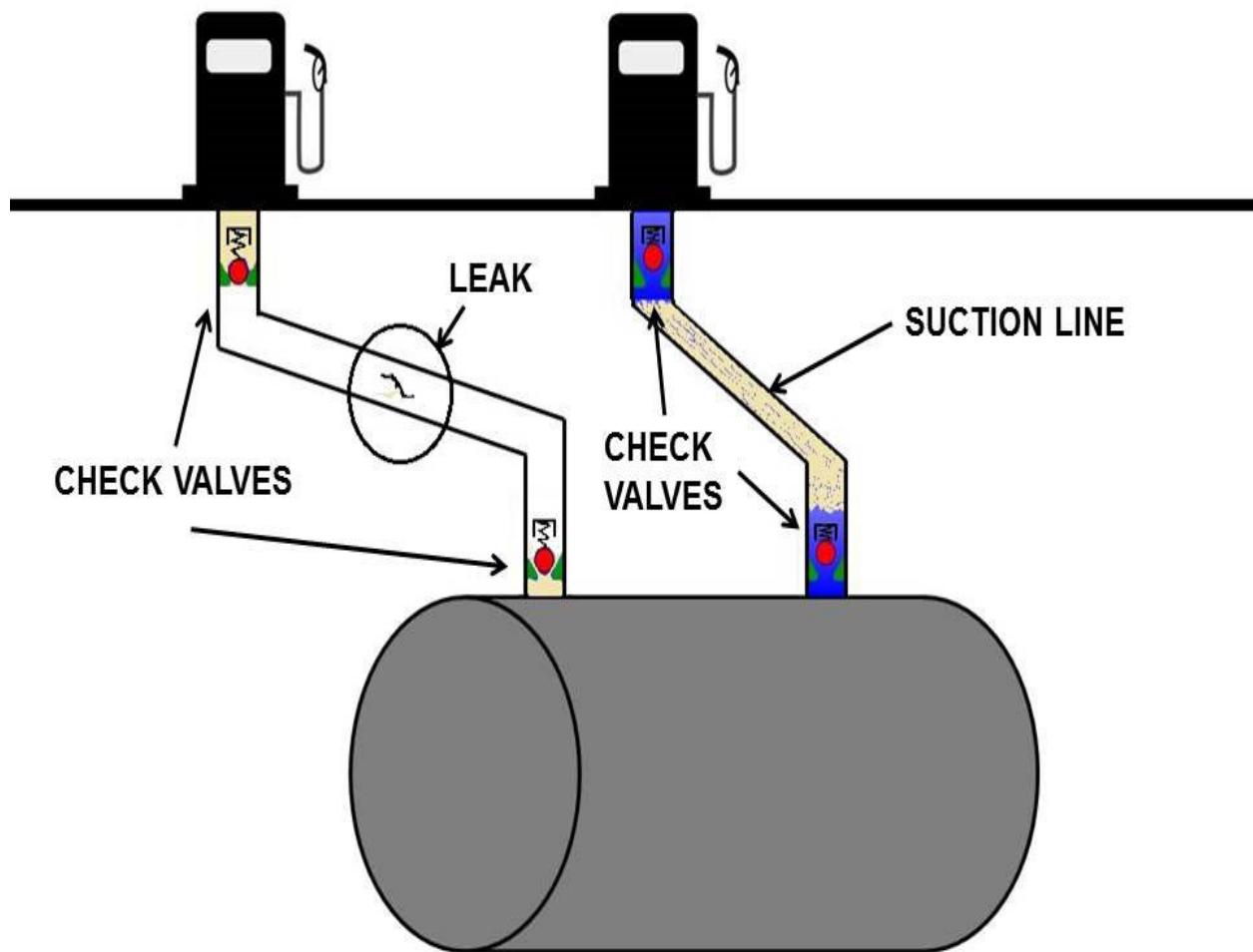
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SAFETY CHECK VALVE EXAMPLE

Technical Learning College's Scope and Function

Welcome to the Program,

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds several different governmental agency approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. TLC's distance based or independent study courses are offered in a print - based distance educational format. We will beat any other training competitor's price for the same CEU material or classroom training.

Our courses are designed to be flexible and for you to finish the material at your convenience. Students can also receive course materials through the mail. The CEU course or e-manual will contain all your lessons, activities and instruction to obtain the assignments. All of TLC's CEU courses allow students to submit assignments using e-mail or fax, or by postal mail. (See the course description for more information.)

Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling; i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored closed-book exams, depending upon your state or employer requirements.

Flexible Learning

At TLC, there are no scheduled online sessions or passwords you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus based student. You will work at your own pace, completing assignments in time frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

Course Structure

TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student-friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One

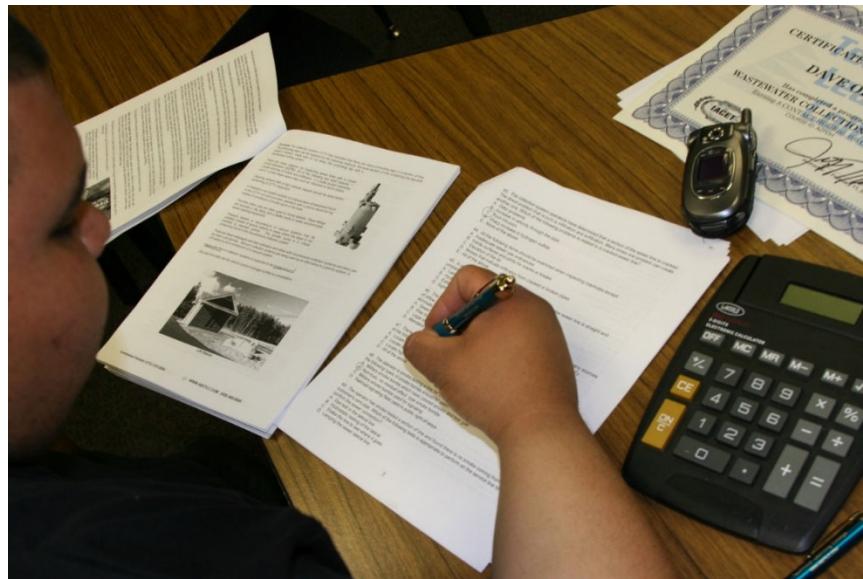
TLC offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members (S.M.E.) are assigned at the beginning of each course providing the academic support you need to successfully complete each course. Please call or email us for assistance.

No Data Mining Policy

Unlike most online training providers, we do not use passwords or will upload intrusive data mining software onto your computer. We do not use any type of artificial intelligence in our program. Nor will we sell you any other product or sell your data to others as with many of our competitors. Unlike our training competitors, we have a telephone and we humanly answer.

Satisfaction Guaranteed

We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 20,000 students.



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail. If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of \$50.

Contact Numbers
Fax (928) 468-0675
Email Info@tlch2o.com
Telephone (866) 557-1746

Course Description

LUST Leaking Underground Storage Tank

The goal of the Underground Storage Tank (UST) Leak Prevention Program is to protect human health and the environment from petroleum and hazardous substance releases from UST systems. The release of these regulated products into the environment threatens groundwater resources and can cause explosive vapors to seep into confined spaces and occupied dwellings.



The objectives of the UST Leak Prevention Program are to ensure that:

1. UST systems are properly constructed and designed using recognized industry standards;
2. installations, repairs and removals are conducted and inspected by qualified, trained and licensed individuals;
3. active USTs are properly operated and monitored for releases;
4. upon closure, USTs are properly decommissioned and sites assessed for environmental damages.



Why Are UST Systems Regulated?

As of March 31, 2002, 422,573 releases have been reported from UST systems. For state-by-state data (reported semi-annually) on the cumulative number of active USTs, confirmed releases, cleanups initiated, cleanups completed, and emergency responses.

These releases have been caused by leaks, spills, and overfills from UST systems. These releases can threaten human safety and health as well as the environment because UST systems contain hazardous and toxic chemicals.

Fumes and vapors can travel beneath the ground and collect in areas such as basements, utility vaults, and parking garages where they can pose a serious threat of explosion, fire, and asphyxiation or other adverse health effects. Too many people have been injured or have lost their lives as the result of these types of accidents.

Gasoline, leaking from service stations, is one of the most common sources of groundwater pollution. Because approximately one-half of the population of the United States relies on groundwater as their source of drinking water, groundwater pollution is a serious problem.

Many municipal and private wells have had to be shut down as the result of contamination caused by releases from UST systems.

Preventing and cleaning up releases are the two primary goals of the programs that regulate USTs. Cleaning up petroleum releases is difficult and usually expensive; it is easier and less costly to prevent releases before they happen. The old adage of "*an ounce of prevention being worth a pound of cure*" is particularly relevant to UST systems.



Course Learning Goals

I. Leaking Underground Storage Tank Familiarization

- A. Definitions
- B. Physical Description

II. Types of Detection Methods

- A. Application and Treatment Methods
- B. Excavation and Safety Methods
- C. Confine Space/Atmospheric Hazards

III. Environmental Protection Agency

- A. Definitions
- B. Rules and Regulations
- C. Reporting Standard

III. Program Review

- A. References
- B. Glossary
- C. EPA Rule

IV. Advanced remediation/treatment application and competency

Course Learning Objectives

1. Ability to explain the different chemical/petroleum contaminates and quality/physical characteristics.
2. Define LUST terminology.
3. Describe how LUST contaminates groundwater supplies.
4. Describe the US EPA's rules and regulations and how these rules affect LUSTs.
5. Define remediation, tank testing, and vapor testing and give examples.
6. List the key functions of the UST owner/operator.
7. Identify various state and federal UST programs and roles.
8. Understand 40 CFR and advanced competency.
9. Understand owner/operator's reporting responsibilities.

Prerequisites: None, you will not need any other materials for this course.

Course Procedures for Registration and Support:

All of Technical Learning College correspondence courses have complete registration and support services offered. Delivery of services will include, e-mail, web site, telephone, fax and mail support. TLC will attempt immediate and prompt service.

When a student registers for a distance or correspondence course, he/she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work. If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request.

All students will be tracked by a unique number assigned to the student.

Instructions for Written Assignments

The LUST distance learning course uses a Multiple Choice and a True/False style answer key.

You can write your answers in this manual or type out your own answer key. TLC would prefer that you type out and e-mail the examination to TLC, but it is not required.

Feedback Mechanism (Examination Procedures)

Each student will receive a feedback form as part of his or her study packet. You will be able to find this form in the front of the course or lesson(assignment).

Security and Integrity

All students are required to do their own work. All lesson sheets and final exams are not returned to the student to discourage sharing of answers. Any fraud or deceit and the student will forfeit all fees and the appropriate agency will be notified.

Grading Criteria

TLC will offer the student either pass/fail or a standard letter grading assignment. If TLC is not notified, you will only receive a pass/fail notice.

Required Texts

The course will not require any other materials. This course comes complete. No other materials are needed.

Environmental Terms, Abbreviations, and Acronyms

TLC provides a glossary that defines in non-technical language commonly used environmental terms appearing in publications and materials. It also explains abbreviations and acronyms used throughout EPA and other agencies. You can find the glossary this in the rear of the manual.

Recordkeeping and Reporting Practices

TLC will keep all student records for a minimum of seven years. It is your responsibility to give the completion certificate to the appropriate agencies.

ADA Compliance

TLC will make reasonable accommodations for persons with documented disabilities. Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of this particular group.

Continuing Education Units

You will have 90 days from receipt of this manual to complete in order to receive your Continuing Education Units (**CEUs**) or Professional Development Hours (**PDHs**). A score of 70 % is necessary to pass this course.

If you should need any assistance, please email all concerns and the final test to info@tlch2o.com.

There are 100 total points possible for the course: This course will be graded on a "P" (credit) or "Z" (no credit) basis. If you desire a letter grade for this course, you must inform the instructor prior to submitting any of the assignments.

The final grade options are as follows:

Letter grade (**A, B, C, D, F**) - These grades are awarded based on the course grading scale.

Withdrawn (**W or Y**) - Students who enroll but do not participate in the class may withdraw themselves by calling Admissions and Records, or their instructor may withdraw them. Either case will result in a grade of "**W**." Note that participation means the completion of a single homework assignment or an exam. Completion of the pretest and/or syllabus receipt does not imply course participation.

If you are a student in this class for any amount of time up to but not including the midway point of the course and then cease to participate, you may withdraw yourself from the course by calling Admissions and Records.

You may also request, in writing, that your instructor withdrew you. Either of these cases will result in a grade of "**W**."

If you participate up to the midway point of the course, and then cease to participate, your instructor will not automatically withdraw you. You must contact your instructor to initiate a withdrawal. This case will result either in a "**Y**" or a "**W**". The issuance of a "**Y**" or a "**W**" will be at the exclusive decision of your instructor. A "**Y**" grade is withdrawal failing and counts as an "**F**" toward your grade point average.

Credit/no credit option (P/Z) - None Available

Your assignments are due on time. Any assignment or mailed-in examination that is one to five days late will be marked down one letter grade. Any assignment or mailed-in examination that is turned in *later* than five days will not be accepted and will be recorded in my grade book as "non-participating" and you can be withdrawn from class. (See final grade options.)

Note to students: Keep a copy of everything that you submit. That way if your work is lost you can submit your copy for grading. If you do not receive your graded assignment or quiz results within two or three weeks after submitting it, please contact your instructor.

We expect every student to produce his/her original, independent work. Any student whose work indicates a violation of the Academic Misconduct Policy (cheating, plagiarism) can expect penalties as specified in the Student Handbook, which is available through Student Services; contact them at (928) 468-0665.

A student who registers for a Distance Learning course is assigned a "**start date**" and an "**end date**." It is the student's responsibility to note due dates for assignments and to keep up with the course work.

If a student falls behind, she/he must contact the instructor and request an extension of her/his **end date** in order to complete the course.

It is the prerogative of the instructor to decide whether to grant the request.

You will have 90 days from receipt of this manual to complete in order to receive your Continuing Education Units (**CEUs**) or Professional Development Hours (**PDHs**). A score of 70 % is necessary to pass this course.

If you should need any assistance, please email all concerns and the final test to info@tlch2o.com.

Course Objective: To understand and describe the dangers associated with leaking underground storage tanks, identification, remediation, removal, reporting treatment methods.

Educational Mission

The educational mission of TLC is:

To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,

To provide TLC students opportunities to apply and understand the theory and skills needed for operator certification,

To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

To provide a forum in which students can exchange experiences and ideas related to environmental education,

To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.



"Release detection" means determining whether a release of a regulated substance has occurred from the UST system into the environment or into the interstitial space between the UST system and its secondary barrier or secondary containment around it.



"Petroleum UST system" means an underground storage tank system that contains petroleum or a mixture of petroleum with *de minimis* quantities of other regulated substances. Such systems include those containing motor fuels, jet fuels, distillate fuel oils, residual fuel oils, lubricants, petroleum solvents, and used oils.

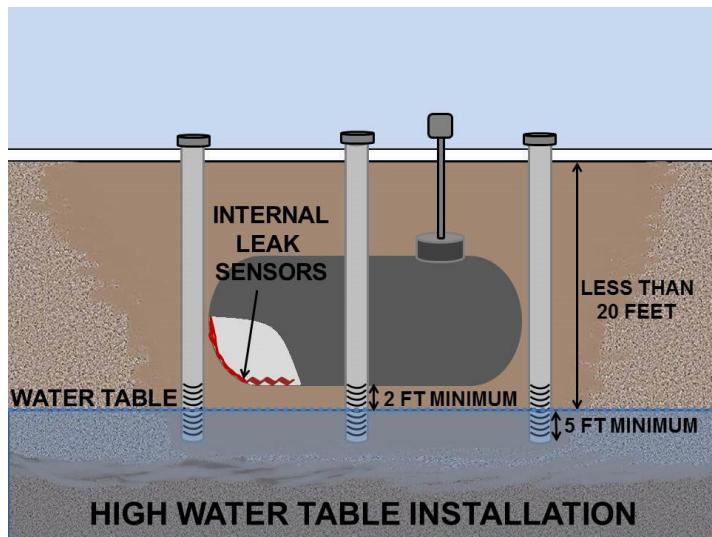


Waste oil collection tank

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Important Information about this Manual



This manual has been prepared to educate and operators in general safety awareness of dealing with the often-complex and various underground/aboveground storage tanks, testing devices, methods, and applications.

This manual will cover general laws, regulations, required procedures and accepted policies relating to leaking underground storage tanks. It should be noted, however, that the regulation of leaking underground storage tanks and hazardous materials is an ongoing process and subject to change over time. For this reason, a list of resources is provided to assist in obtaining the most up-to-date information on various subjects.

This manual is not a guidance document for owners or operators who are involved with leaking underground storage tanks. It is not designed to meet the requirements of the United States Environmental Protection Agency or your local State environmental protection agency or health department.

This course manual will provide general leaking underground storage tanks awareness and should not be used as a basis for leaking underground storage tanks removal, testing, and treatment method/device guidance. This document is not a detailed leaking underground storage tanks or a source or remedy for leaking underground storage tanks.

Technical Learning College or Technical Learning Consultants, Inc. make no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information. It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for educational purposes only and is not considered a legal document.

Individuals who are responsible for leaking underground storage tanks should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with EPA and other appropriate federal, state and local agencies.

Key Words

Anti-siphon: Sometimes called a "solenoid valve;" a valve installed at the highest point in the piping to prevent liquid from accidentally siphoning or leaking out of the tank in the event of a piping leak or rupture. An anti-siphon valve is needed when the liquid level in the tank is higher than the elevation of the dispenser or any product piping.

AST: Aboveground storage tank. Any vessel that stores a hazardous substance and is located above ground level. Note that this definition includes both federal and state regulated and non-regulated ASTs.

Brackish water: Water with a salinity level between that of freshwater and seawater.

Connected/disconnected (manually): To deal with fluctuating water levels, some facilities may be equipped with sections of piping that may be added and removed manually, as necessary.

Double-walled: Piping or tank that provides secondary product containment. If "secondary containment" is not capable of containing product in the event of a release from the primary containment, it is NOT considered secondary containment. (e.g., Many systems use PVC piping as structural support for primary piping. PVC is not an approved piping material, and is not considered secondary containment.)

Electronic monitoring: An *electrical* device installed to monitor tanks and/or piping for leaks. Examples include electronic line leak detectors, and sump or interstitial liquid sensors. Typically electronic monitoring uses an audible and visual alarm system.

Emergency Shut-off (ESO): An emergency, electrical shut-off. Tripping it (or pushing the button) shuts off power to the system in the event of an emergency. This switch is usually well marked and is usually found on the dock so that anyone can shut off the system. *Do not confuse this with regular shut-off valves along the piping run.*

Excess flexible piping not on hose reel: Some marinas may use flexible piping and extend it or retract it as needed, but instead of storing the piping on a hose reel, the owner or operator may store the excess piping on the ground, the dock, or in or on the water.

Facility ID #: Your agency's unique identifying facility tracking number.

Frequency: Continuous, hourly, daily, monthly, annually, etc.

Gravity: The movement of liquid from the tank to the dispenser is caused by gravity. There is no pumping unit.

Hose reel: A reel upon which flexible piping is rolled while not extended to its full length. Because most marinas must contend with fluctuating water levels, they may have excessive lengths of flexible piping that they extend as necessary. When not fully extended, some owners/operators may store the excess piping on a hose reel. It is the same concept as the reel where a garden hose is stored when not in use, or when not fully stretched out.

Line tightness test: A test, conducted by an individual that determines the physical integrity of primary piping.

Marina Fueling Facility: Any land-based fueling facility that dispenses product over a waterway. This includes storage tanks located over water that are integral with a floating pier (dock), as long as the pier/dock is permanently attached to land. In some cases, both the tank and the dispenser may be on land, but the dispensing nozzle is located over water. This, too, is considered a marina fueling facility for our purposes. (Note that this inspection form does not include fuel transfers at marine oil terminals, where a facility transfers oil to or from tankers or barges.)

Mechanical monitoring: A *mechanical* device installed to monitor tanks and/or piping for leaks. Examples include mechanical line leak detectors and mechanical float mechanisms found in some types of under-dispenser containment.

Metallic: Steel, copper, iron, or other metallic materials.

Non-metallic: Includes any non-metallic materials such as fiberglass reinforced plastic. For the purposes of this inspection form, "*non-metallic*" does not include rubber hose.

On-shore fueling: Dispensing product on land.

Pressurized: A pumping unit *located at the tank* that pushes product from the tank, through the piping, to the dispenser.

Rubber Hose: A flexible tube, made of rubber or synthetic materials, used for conveying liquids. It looks like the rubber hose attached to the dispenser at a typical automobile gas station. This flexible rubber hose can come in various colors.

Single-walled: Piping or tank that provides only primary product containment.

Shut-off valve: There are numerous types of valves associated with piping. For the purposes of this inspection form, a shutoff valve is any valve, such as a faucet handle or lever that an operator *manually* turns to stop product flow from the valve to the end of the piping run/dispenser.

SPCC Plan: Spill Prevention, Control and Countermeasures Plan. A written document signed by a Professional Engineer which outlines in detail the steps that have to be taken to prevent spills. The plan also outlines the procedures to be followed in the event of a spill. Required for most AST sites and some UST sites.

Suction: A pumping unit *located in the dispenser* that pulls product from the tank, through the piping, to the dispenser.

SW (single wall) tank with other secondary containment: Secondary containment, not integral to the primary containment that can hold the entire contents of the primary containment, e.g., a concrete basin surrounding an AST or a bladder installed inside a UST.

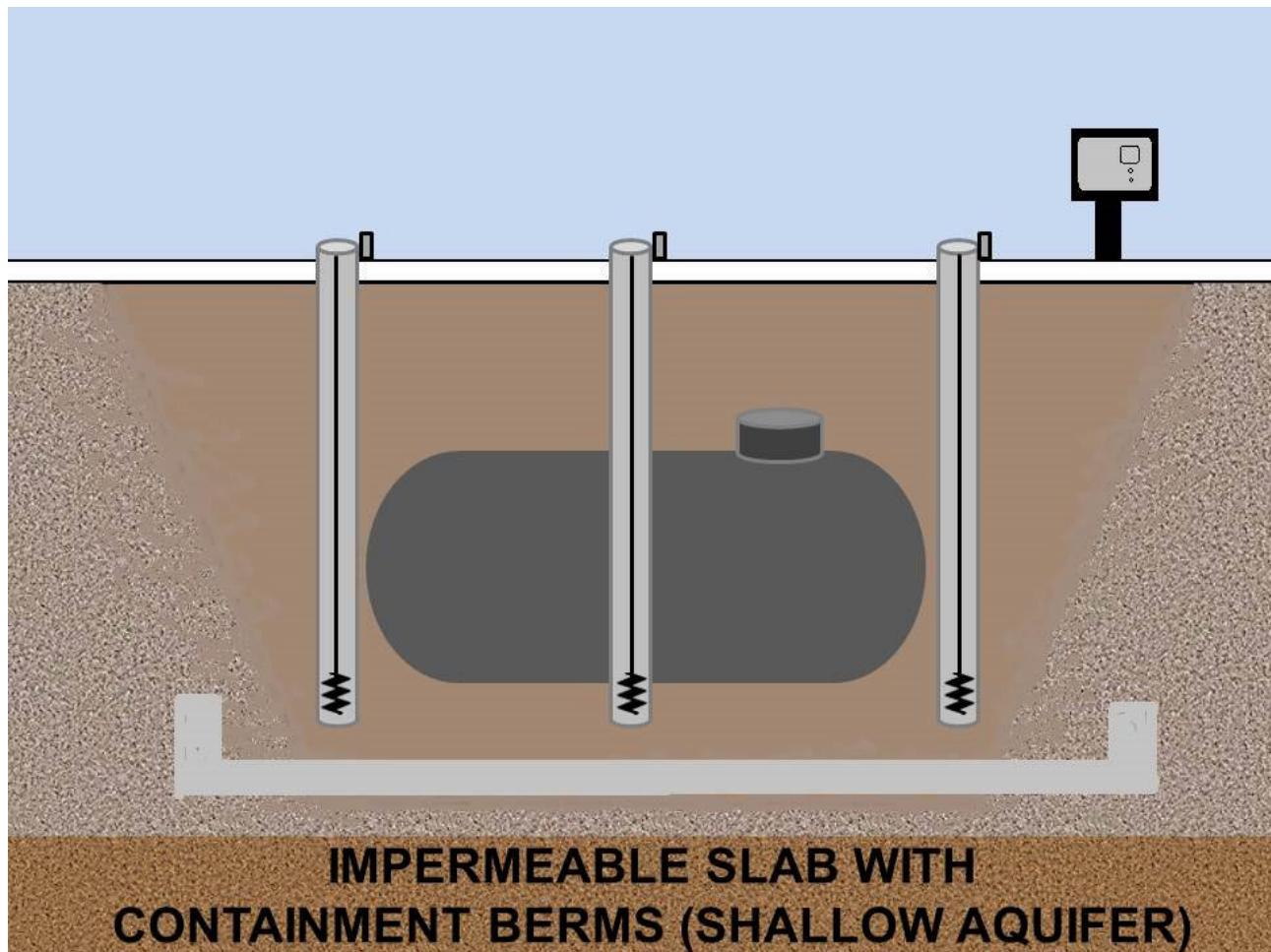
Throughput: The number of gallons pumped from the tank (dispensed) annually.

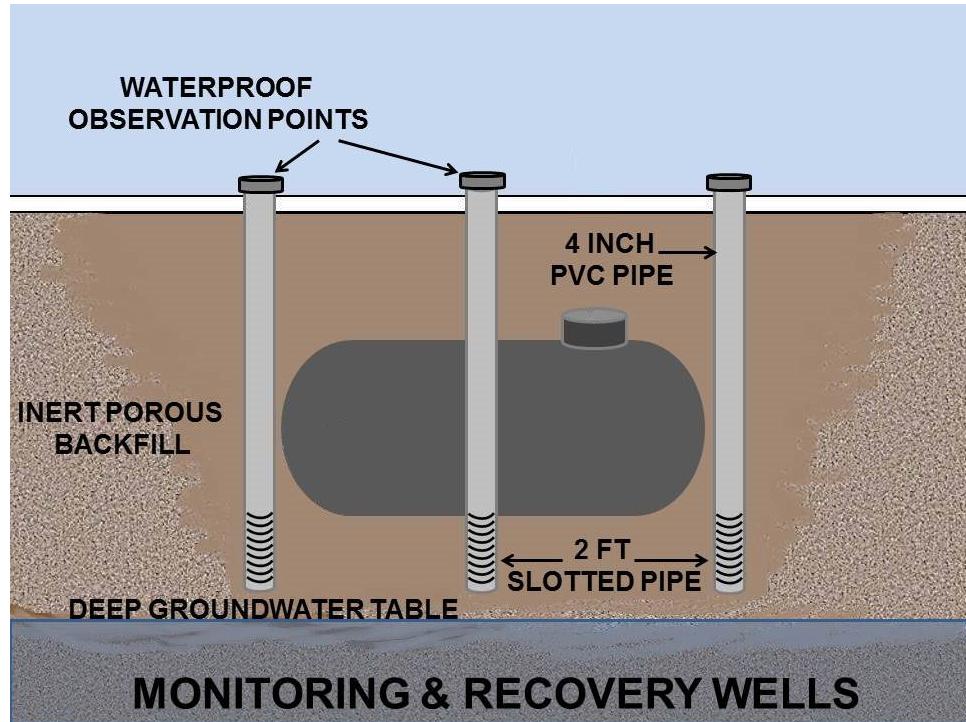
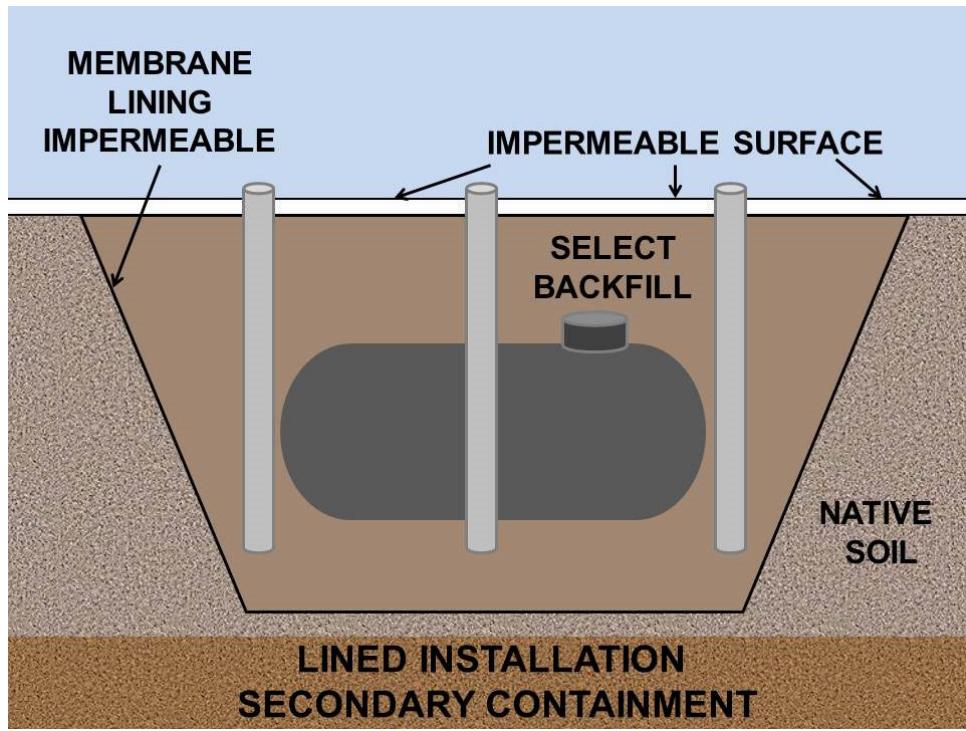
Transition point: The interface where two different types of piping come together. This consists of a coupling such as a fitting, valve or cam lock. Short lengths of flexible piping are *not* transitions; they are considered separate types of piping.

Under-dispenser containment: Also called "*dispenser pans*" or "*dispenser sumps*". Containment devices positioned directly beneath dispensers. These containment pans are designed to catch and retain motor fuel that may leak from the piping and valves that connect dispensers to the piping system.

UST: Underground storage tank. Tank, including piping connected thereto, which is used for the storage of hazardous substances and which is substantially or totally beneath the surface of the ground.

Visual monitoring: Visually inspecting the exterior of the tank and/or piping system for leaks.





CATEGORIES OF ACTIVITIES THAT IMPACT GROUNDWATER AND SOURCES OF DRINKING WATER

RUNOFF

Water washes away many substances which later seep into the ground and mixes with groundwater.

Examples of runoff including stormwater include:

AGRICULTURAL

- Animal Wastes
- Fertilizers
- Pesticides
- Sediments

URBAN

- Chemicals
- Grease and Oils
- Solvents

LANDFILL

- Garbage
- Leachate

CONSTRUCTION

- Contaminated Soil
- Stormwater Runoff
- Waste and Trash

LEAKING STORAGE TANKS (ULST)

Fuels and chemicals stored in underground or above ground tanks can leak into groundwater.

Examples of substances that are expensive and difficult to remove are:

- Chemicals
- Diesel Fuel
- Fertilizers
- Gasoline
- Heating Oil
- Pesticides
- Solvents



HOLDING PONDS

Surface ponds serve a number of purposes in rural or industrial areas but also threaten groundwater quality.



Some examples are:

ANIMAL WASTES

- Microbial Contaminants
- Toxic levels of Nitrogen and Phosphorus

MINE WASTES

- Acid Waters
- Heavy Metals, Arsenic, Lead, etc.
- Sediments

WASTEWATER LAGOONS

- Microbial Contaminants
- Toxic Levels of Nitrogen and Phosphorus

WASTES FROM HUMAN AND ANIMALS

Waste by-products from humans and animals can seep into the ground and stay in a concentrated form. Groundwater containing harmful waste by-products cannot be used as drinking water.

Some examples of possible pollutant sources are:

- Animal Feeding Operations including Aqua-Culture
- Animal Waste Ponds
- Leaking Wastewater Lines
- Manure Spreading
- Septic Systems

WELLS

Wells are drilled into the ground for drinking water, irrigation water, to recharge (injection) the aquifer, and to dispose of low-concentrated wastes. Any of these wells can allow pollutants to reach groundwater. Wells not in use must be properly capped and sealed to prevent contamination to the groundwater.

COMMON SOURCES OF WELL POLLUTANTS

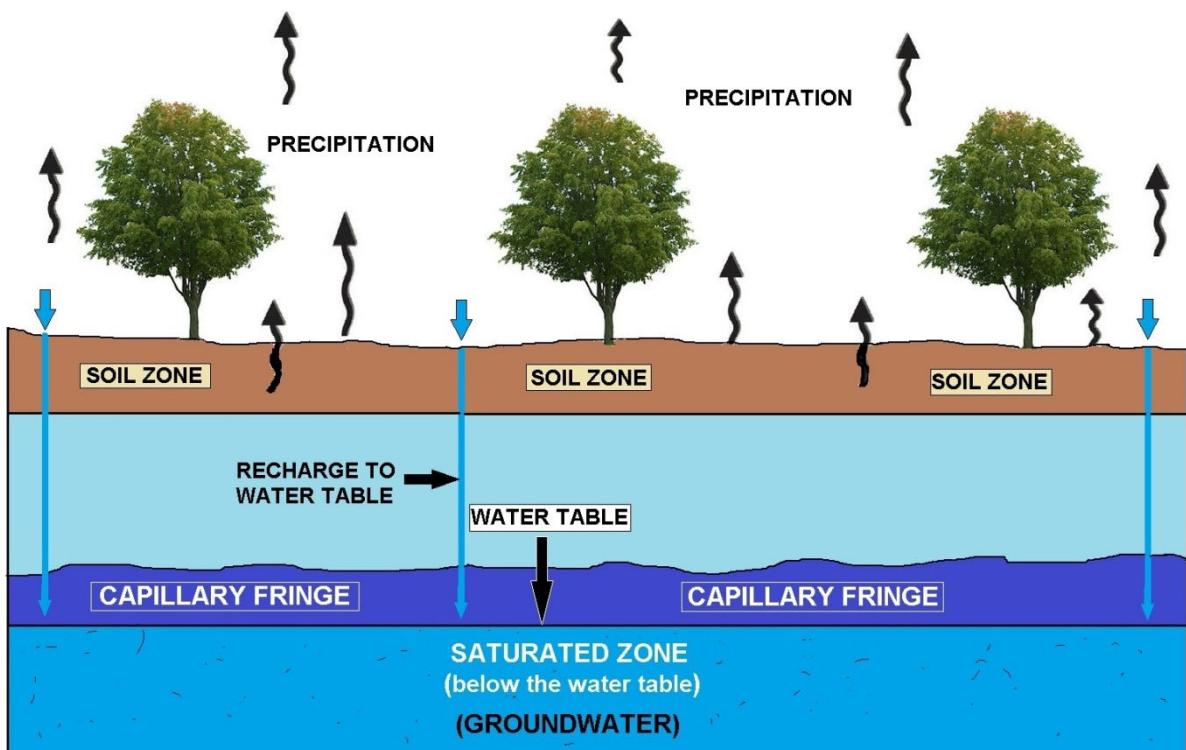
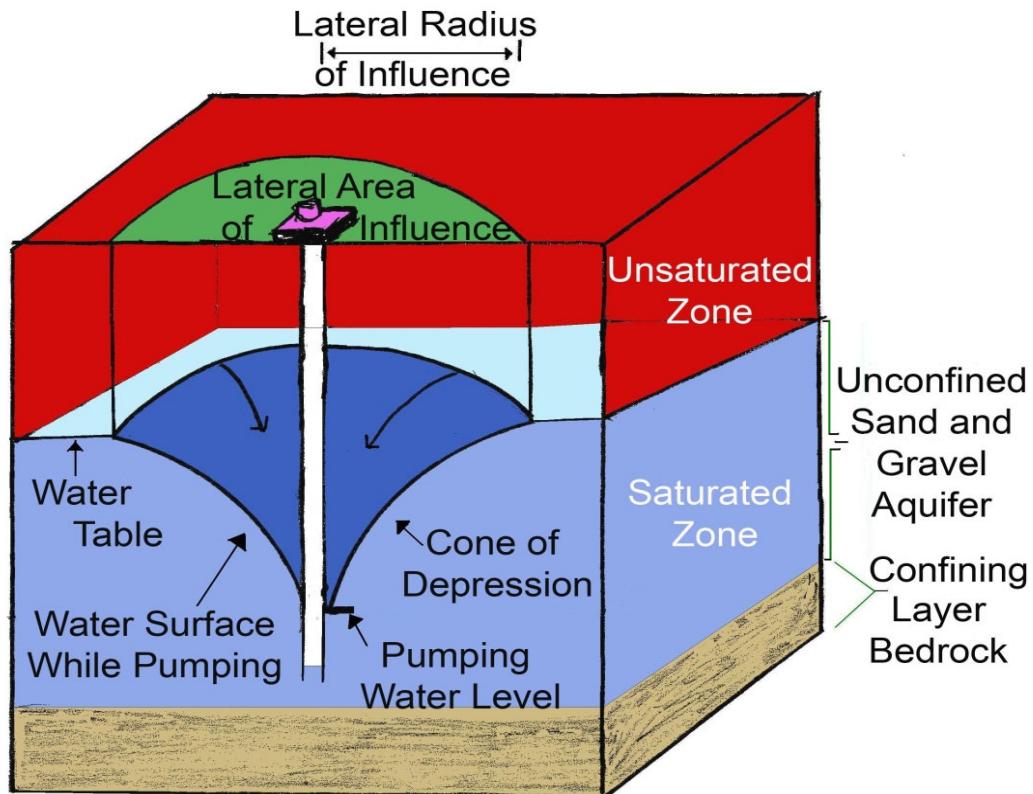
- Abandoned or improperly closed wells
- Injection wells
- Irrigation wells left uncapped when not in use

DRINKING WATER WELLS ARE SUSCEPTIBLE TO POLLUTANTS WHEN THE WELL

- Has an improperly cased/grouted pipe
- Is too shallow
- Is located within 50 feet to septic or leach fields
- Is too close to chemical or biological contaminants

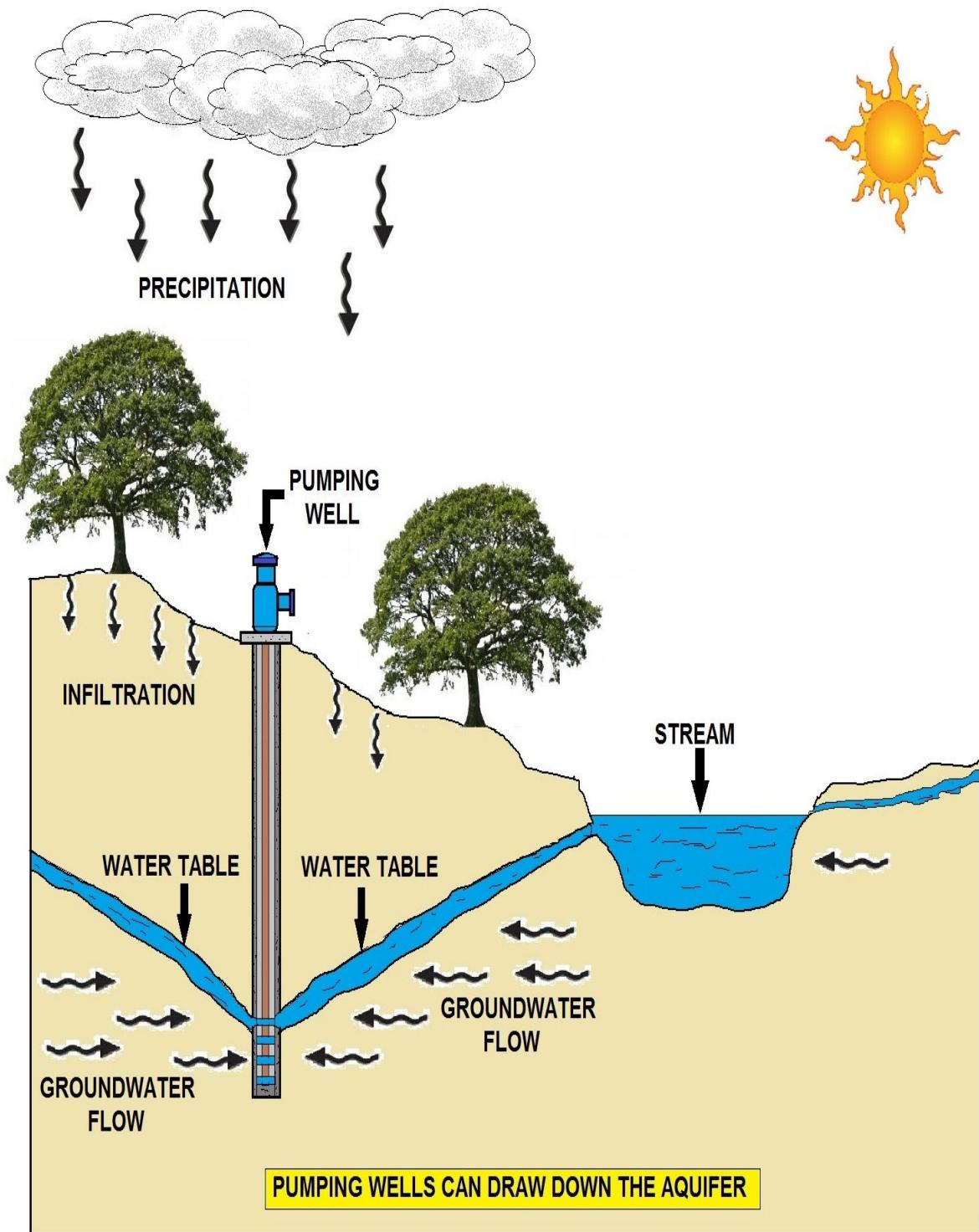


3 Compartment Interceptor



CAPILLARY FRINGE

(Material above water table that may contain water by capillary pressure in small voids)



UST Section

What Is An Underground Storage Tank (UST) System?

An underground storage tank (UST) system is a tank (or a combination of tanks) and connected piping having at least 10 percent of their combined volume underground. The tank system includes the tank, underground connected piping, underground ancillary equipment, and any containment system. The federal UST regulations apply only to underground tanks and piping storing either petroleum or certain hazardous substances.

The following types of tanks do not have to meet federal UST regulations:

- Farm and residential tanks of 1,100 gallons or less capacity holding motor fuel used for noncommercial purposes;
- Tanks storing heating oil used on the premises where it is stored;
- Tanks on or above the floor of underground areas, such as basements or tunnels;
- Septic tanks and systems for collecting storm water and wastewater;
- Flow-through process tanks;
- Tanks of 110 gallons or less capacity; and
- Emergency spill and overfill tanks.

Some state/local regulatory authorities, however, may include these tank types in their UST regulations—be sure you check with these authorities if you have questions about the requirements for your tank type.

Also, some tank types only need to meet the federal UST requirements for cleaning up a release (these tank types have been deferred from needing to meet most other federal UST requirements). Some examples of these tank types are field-constructed tanks, UST systems containing radioactive material, USTs that are part of an emergency generator system at nuclear power generation facilities, and airport hydrant fuel distribution systems.



Other storage sites, such as surface impoundments, are not covered by the federal requirements. For more detailed information on the applicability of federal UST requirements for different types of USTs, please refer to Subpart A of Part 280 of the Code of Federal Regulations (CFR). This Rule is provided for you in the rear of this manual.

Who Regulates UST Systems?

In 1984, Congress directed the U.S. EPA to develop regulations for underground storage tank (**USTs**) systems. The Office of Underground Storage Tanks (**OUST**) was created to carry out this mandate. The federal regulations went into effect in December 1988. These regulations delegate UST regulatory authority to approved state programs. States with approved programs operate in lieu of the federal regulations. Currently 29 states (plus the District of Columbia and Puerto Rico) have approved UST programs.

How Did The Federal UST Program Begin?

Except in a few instances, federal regulations prior to 1984 did not address underground storage tanks (**UST**) systems. The Resource Conservation and Recovery Act (**RCRA**) of 1976 regulated only tanks containing hazardous wastes, not tanks storing petroleum or hazardous products.

The Clean Water Act (**CWA**) of 1972 required owners of large underground tanks (greater than 42,000 gallons) to take certain measures to prevent corrosion and to test tanks periodically. These requirements, however, applied only to those tanks that were potentially direct sources of pollution into navigable waters. Because releases from USTs generally contaminated only groundwater, and usually affect surface water only indirectly, the CWA could not be used as a general basis for regulating most USTs.

The Comprehensive Environmental Response, Compensation, and Liability Act (**CERCLA**) of 1980, commonly known as Superfund, authorized EPA to respond whenever a hazardous substance is released into the environment. Superfund, however, cannot be used to respond to releases from UST systems because petroleum is specifically excluded from the list of hazardous substances defined under CERCLA.

In 1984, Congress prepared amendments to RCRA that would address the problems of leaking UST systems. In October 1984, Congress passed a final version of the Hazardous and Solid Waste Amendments (HSWA) to RCRA. In November 1984, President Reagan signed the amendments into law. Title IV of the Amendments added Subtitle I (sections 9001 through 9010) which specifically provided for regulation of UST systems. Subtitle I includes requirements for tank notification, interim prohibition, new tank standards, reporting and recordkeeping requirements for existing tanks, corrective action, financial responsibility, compliance monitoring and enforcement, and approval of State programs. The law also requires EPA to develop a comprehensive program for the regulation of UST systems "*as may be necessary to protect human health and the environment.*"

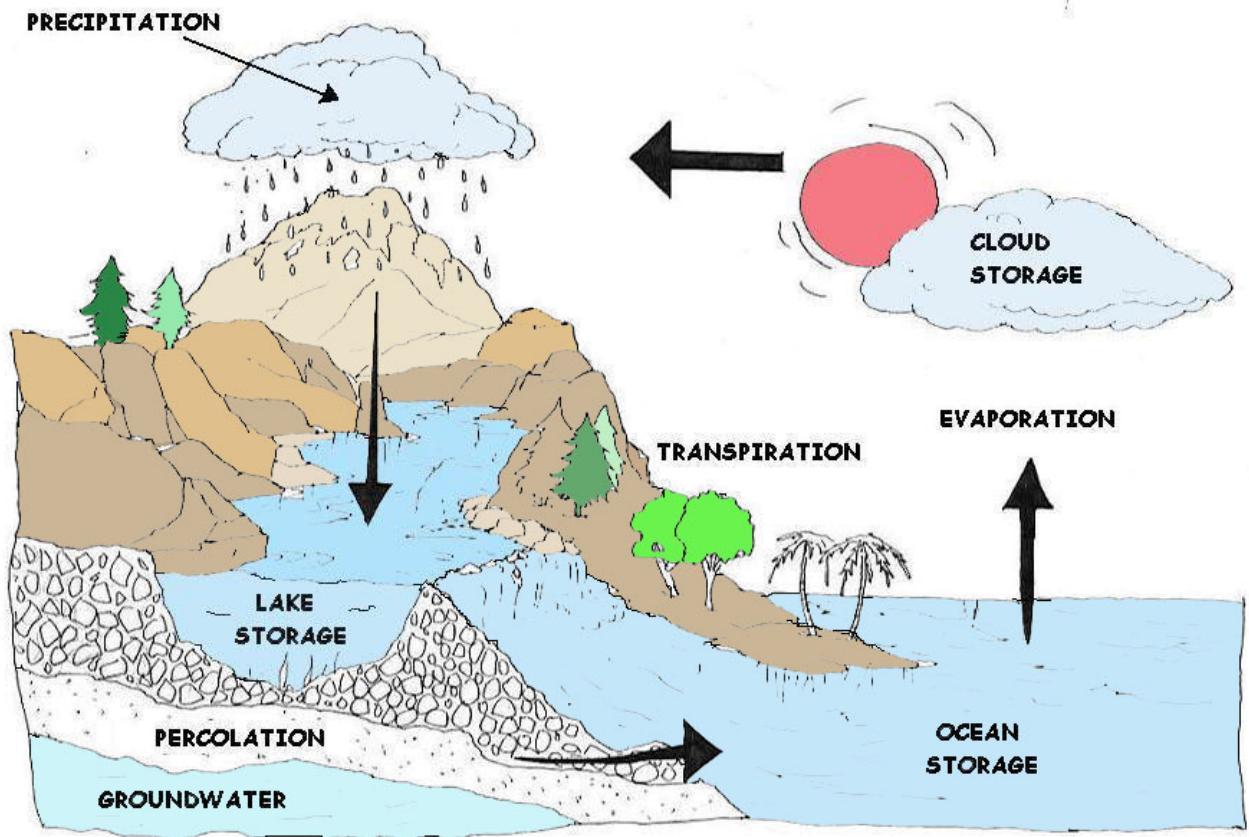
The Office of Underground Storage Tanks (**OUST**) was created in 1985 as part of EPA's Office of Solid Waste and Emergency Response (**OSWER**) to carry out the Congressional mandate to develop and implement a new regulatory program for UST systems. OUST has two divisions: The Policy and Standards Division and the Implementation Division. OUST is charged with developing regulations for UST systems in the areas of technical standards for tanks, financial responsibility, and state program approval.

In 1986, Congress passed the Superfund Amendments Reauthorization Act (**SARA**) which amended Subtitle I to provide Federal funds for corrective actions on petroleum releases from UST systems. This amendment established the Leaking Underground Storage Tank (**LUST**) Trust Fund, commonly known as the "**LUST Trust Fund**".

On September 23, 1988, EPA published the final technical regulations for tanks. On October 26, 1988, EPA published the financial responsibility regulations, indicating the minimum levels of insurance UST owners and operators need to ensure that they can take "*corrective action*" in response to any leaks that occur from their UST systems and compensate anyone who is harmed by a release. Corrective action includes assessing the release and the extent of damage or danger to human health and the environment, determining what action is needed to repair any damage and remove contaminants, and taking the necessary remedial action (e.g., free product recovery, bioventing).

CHAPTER I. Introduction

Many people have never heard of groundwater. That's not really so surprising since it isn't readily visible -- groundwater can be considered one of our "**hidden**" resources.



What Is Groundwater, and Where Does It Come From?

Actually, groundwater occurs as part of what can be called the oldest recycling program - the hydrologic cycle. The hydrologic cycle involves the continual movement of water between the earth and the atmosphere through evaporation and precipitation. As rain and snow fall to the earth, some of the water runs off the surface into lakes, rivers, streams, and the oceans; some evaporates; and some is absorbed by plant roots.

The rest of the water soaks through the ground's surface and moves downward through the unsaturated zone, where the open spaces in rocks and soil are filled with a mixture of air and water, until it reaches the water table. The water table is the top of the saturated zone, or the area in which all interconnected spaces in rocks and soil are filled with water. The water in the saturated zone is called groundwater. In areas where the water table occurs at the ground's surface, the groundwater discharges into marshes, lakes, springs, or streams and evaporates into the atmosphere to form clouds, eventually falling back to earth again as rain or snow - thus beginning the cycle all over again.

Where Is Groundwater Stored?

Groundwater is stored under many types of geologic conditions. Areas where groundwater exists in sufficient quantities to supply wells or springs are called aquifers, a term that literally means "water bearer." Aquifers store water in the spaces between particles of sand, gravel, soil, and rock as well as cracks, pores, and channels in relatively solid rocks. An aquifer's storage capacity is controlled largely by its porosity, or the relative amount of open space present to hold water. Its ability to transmit water, or permeability, is based in part on the size of these spaces and the extent to which they are connected.

Basically, there are two kinds of aquifers: confined and unconfined. If the aquifer is sandwiched between layers of relatively impermeable materials (e.g., clay), it is called a confined aquifer. Confined aquifers are frequently found at greater depths than unconfined aquifers. In contrast, unconfined aquifers are not sandwiched between these layers of relatively impermeable materials, and their upper boundaries are generally closer to the surface of the land.

Does Groundwater Move?

Groundwater can move sideways as well as up or down. This movement is in response to gravity, differences in elevation, and differences in pressure. The movement is usually quite slow, frequently as little as a few feet per year, although it can move as much as several feet per day in more permeable zones. Groundwater can move even more rapidly in karst aquifers, which are areas in water soluble limestone and similar rocks where fractures or cracks have been widened by the action of the groundwater to form sinkholes, tunnels, or even caves.

How Is Groundwater Used?

According to the U.S. Geological Survey, groundwater use increased from about 35 billion gallons a day in 1950 to about 87 billion gallons a day in 1980. Approximately one-half of all fresh water used in the nation comes from groundwater. Whether it arrives via a public water supply system or directly from a private well, groundwater ultimately provides approximately 35 percent of the drinking water supply for urban areas and 95 percent of the supply for rural areas, quenching the thirst and meeting other household needs of more than 117 million people in this nation.

Overall, more than one-third of the water used for agricultural purposes is drawn from groundwater; Arkansas, Nebraska, Colorado, and Kansas use more than 90 percent of their groundwater withdrawals for agricultural activities. In addition, approximately 30 percent of all groundwater is used for industrial purposes.

Groundwater use varies among the states, with some states, such as Hawaii, Mississippi, Florida, Idaho, and New Mexico, relying on groundwater to supply considerably more than three-fourths of their household water needs and other states, such as Colorado and Rhode Island, supplying less than one-quarter of their water needs with groundwater.



CHAPTER II. Groundwater Quality

Until the 1970s, groundwater was believed to be naturally protected from contamination. The layers of soil and particles of sand, gravel, crushed rocks, and larger rocks were thought to act as filters, trapping contaminants before they could reach the groundwater. Since then, however, every state in the nation has reported cases of contaminated groundwater, with some instances receiving widespread publicity. We now know that some contaminants can pass through all of these filtering layers into the saturated zone to contaminate groundwater.

Between 1971 and 1985, 245 groundwater related disease outbreaks, with 52,181 associated illnesses, were reported. Most of these diseases were short-term digestive disorders. About 10 percent of all groundwater public water supply systems are in violation of drinking water standards for biological contamination. In addition, approximately 74 pesticides, a number of which are known carcinogens, have been detected in the groundwater of 38 states. Although various estimates have been made about the extent of groundwater contamination, these estimates are difficult to verify given the nature of the resource and the difficulty of monitoring its quality.

How Does Groundwater Become Contaminated?

Groundwater contamination can originate on the surface of the ground, in the ground above the water table, or in the ground below the water table. Table I shows the types of activities that can cause groundwater contamination at each level. Where a contaminant originates is a factor that can affect its actual impact on groundwater quality. For example, if a contaminant is spilled on the surface of the ground or injected into the ground above the water table, it may have to move through numerous layers of soil and other underlying materials before it reaches the groundwater.

As the contaminant moves through these layers, a number of processes are in operation (e.g., filtration, dilution, oxidation, biological decay) that can lessen the eventual impact of the substance once it finally reaches the groundwater. The effectiveness of these processes also is affected by both the distance between the groundwater and where the contaminant is introduced and the amount of time it takes the substance to reach the groundwater. If the contaminant is introduced directly into the area below the water table, the primary process that can affect the impact of the contaminant is dilution by the surrounding groundwater.

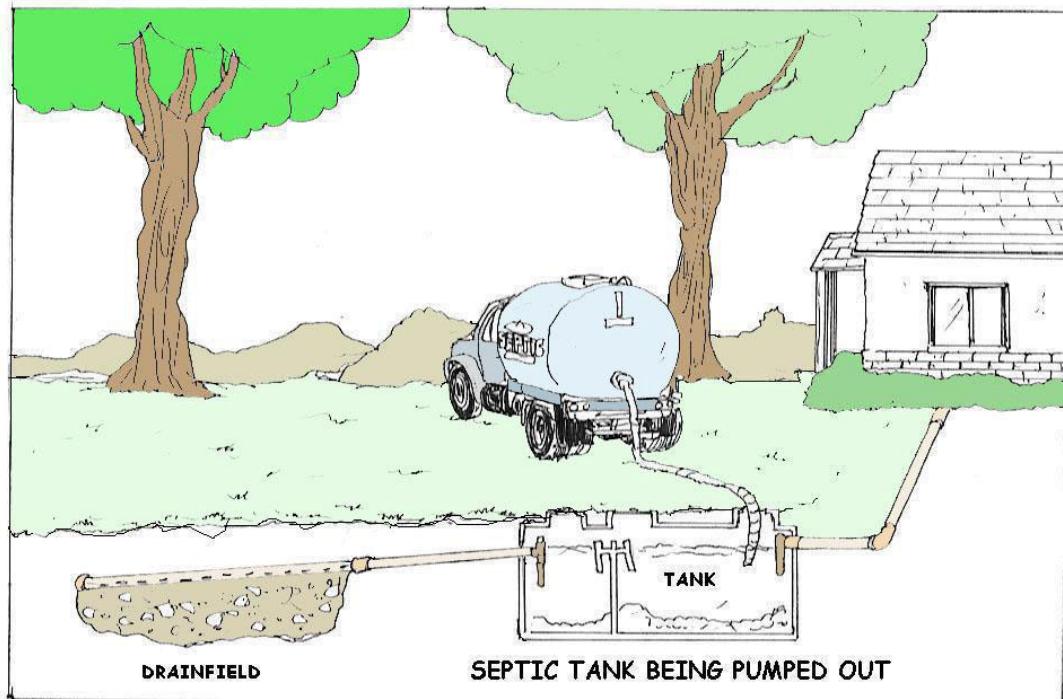
GROUND SURFACE	Infiltration of polluted surface water Land disposal of wastes Stockpiles Dumps Sewage sludge disposal	De-icing salt use & storage Animal feedlots Fertilizers & pesticides Accidental spills Airborne source particulates
ABOVE WATER TABLE	Septic tanks, cesspools, & privies Holding ponds & lagoons Sanitary landfills Waste disposal in excavations Underground storage tank leaks	Underground pipeline leaks Artificial recharge Sumps and dry wells Graveyards
BELOW WATER TABLE	Waste disposal in wells Drainage wells and canals Underground storage Mines	Exploratory wells Abandoned wells Water-supply wells Groundwater withdrawal

TABLE 1. Activities That Can Cause Groundwater Contamination

In comparison with rivers or streams, groundwater tends to move very slowly and with very little turbulence. Therefore, once the contaminant reaches the groundwater, little dilution or dispersion normally occurs. Instead, the contaminant forms a concentrated plume that can flow along the same path as the groundwater. Among the factors that determine the size, form, and rate of movement of the contaminant plume are the amount and type of contaminant and the speed of groundwater movement. Because groundwater is hidden from view, contamination can go undetected for years until the supply is tapped for use.

What Kinds of Substances Can Contaminate Groundwater, and Where Do They Come From?

Substances that can contaminate groundwater can be divided into two basic categories: substances that occur naturally and substances produced or introduced by man's activities. Substances that occur naturally include minerals such as iron, calcium, and selenium. Substances resulting from man's activities include synthetic organic chemicals and hydrocarbons (e.g., solvents, pesticides, petroleum products); landfill **leachates** (liquids that have dripped through the landfill and carry dissolved substances from the waste materials), containing such substances as heavy metals and organic decomposition products; salt; bacteria; and viruses. A significant number of today's groundwater contamination problems stem from man's activities and can be introduced into groundwater from a variety of sources.



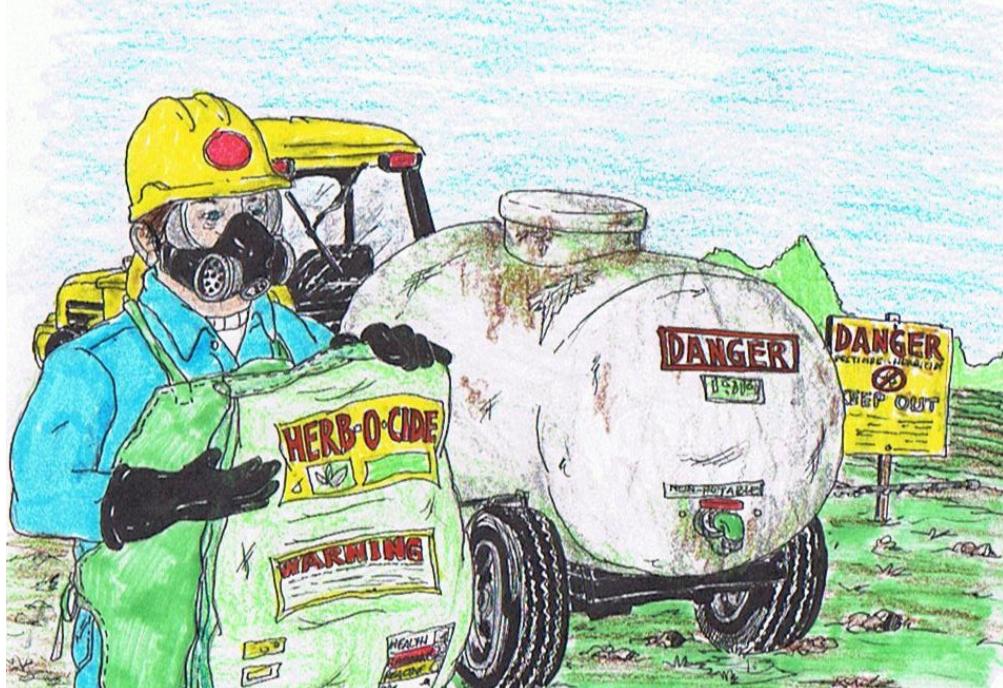
Septic Tanks, Cesspools, and Privies

A major cause of groundwater contamination in many areas of the United States is effluent, or outflow, from septic tanks, cesspools, and privies. Approximately one fourth of all homes in the United States rely on septic systems to dispose of their human wastes. If these systems are improperly sited, designed, constructed, or maintained, they can allow contamination of the groundwater by bacteria, nitrates, viruses, synthetic detergents, household chemicals, and chlorides.

Although each system can make an insignificant contribution to groundwater contamination, the sheer number of such systems and their widespread use in every area that does not have a public sewage treatment system makes them serious contamination sources.

Surface Impoundments

Another potentially significant source of groundwater contamination is the more than 180,000 surface impoundments (e.g., ponds, lagoons) used by municipalities, industries, and businesses to store, treat, and dispose of a variety of liquid wastes and wastewater. Although these impoundments are supposed to be sealed with compacted clay soils or plastic liners, leaks can and do develop.



Agricultural Activities

Agricultural activities also can make significant contributions to groundwater contamination with the millions of tons of fertilizers and pesticides spread on the ground and from the storage and disposal of livestock wastes. Homeowners, too, can contribute to this type of groundwater pollution with the chemicals they apply to their lawns, rosebushes, tomato plants, and other garden plants.

Landfills

There are approximately 500 hazardous waste land disposal facilities and more than 16,000 municipal and other landfills nationwide. To protect groundwater, these facilities are now required to be constructed with clay or synthetic liners and leachate collection systems. Unfortunately, these requirements are comparatively recent, and thousands of landfills were built, operated, and abandoned in the past without such safeguards. A number of these sites have caused serious groundwater contamination problems and are now being cleaned up by their owners, operators, or users; state governments; or the federal government under the Superfund program. In addition, a lack of information about the location of many of these sites makes it difficult, if not impossible, to determine how many others may now be contaminating groundwater.

Underground Storage Tanks

Between five and six million underground storage tanks are used to store a variety of materials, including gasoline, fuel oil, and numerous chemicals. The average life span of these tanks is 18 years, and over time, exposure to the elements causes them to corrode. Now, hundreds of thousands of these tanks are estimated to be leaking, and many are contaminating groundwater. Replacement costs for these tanks are estimated at \$2 per gallon of storage capacity; a cleanup operation can cost considerably more.

Abandoned Wells

Wells can be another source of groundwater contamination. In the years before there were community water supply systems, most people relied on wells to provide their drinking water. In rural areas this can still be the case. If a well is abandoned without being properly sealed, however, it can act as a direct channel for contaminants to reach groundwater.



Accidents and Illegal Dumping

Accidents also can result in groundwater contamination. A large volume of toxic materials is transported throughout the country by truck, train, and airplane. Every day accidental chemical or petroleum product spills occur that, if not handled properly, can result in groundwater contamination. Frequently, the automatic reaction of the first people at the scene of an accident involving a spill will be to flush the area with water to dilute the chemical. This just washes the chemical into the soil around the accident site, allowing it to work its way down to the groundwater. In addition, there are numerous instances of groundwater contamination caused by the illegal dumping of hazardous or other potentially harmful wastes.

Highway De-icing

A similar flushing mechanism also applies to the salt that is used to de-ice roads and highways throughout the country every winter. More than 11 million tons of salt are applied to roads in the United States annually. As ice and snow melt or rain subsequently falls, the salt is washed into the surrounding soil where it can work its way down to the groundwater. Salt also can find its way into groundwater from improperly protected storage stockpiles.

What Can Be Done After Contamination Has Occurred?

Unlike rivers, lakes, and streams that are readily visible and whose contamination frequently can be seen with the naked eye, groundwater itself is hidden from view. Its contamination occurs gradually and generally is not detected until the problem has already become extensive. This makes cleaning up contamination a complicated, costly, and sometimes impossible process.

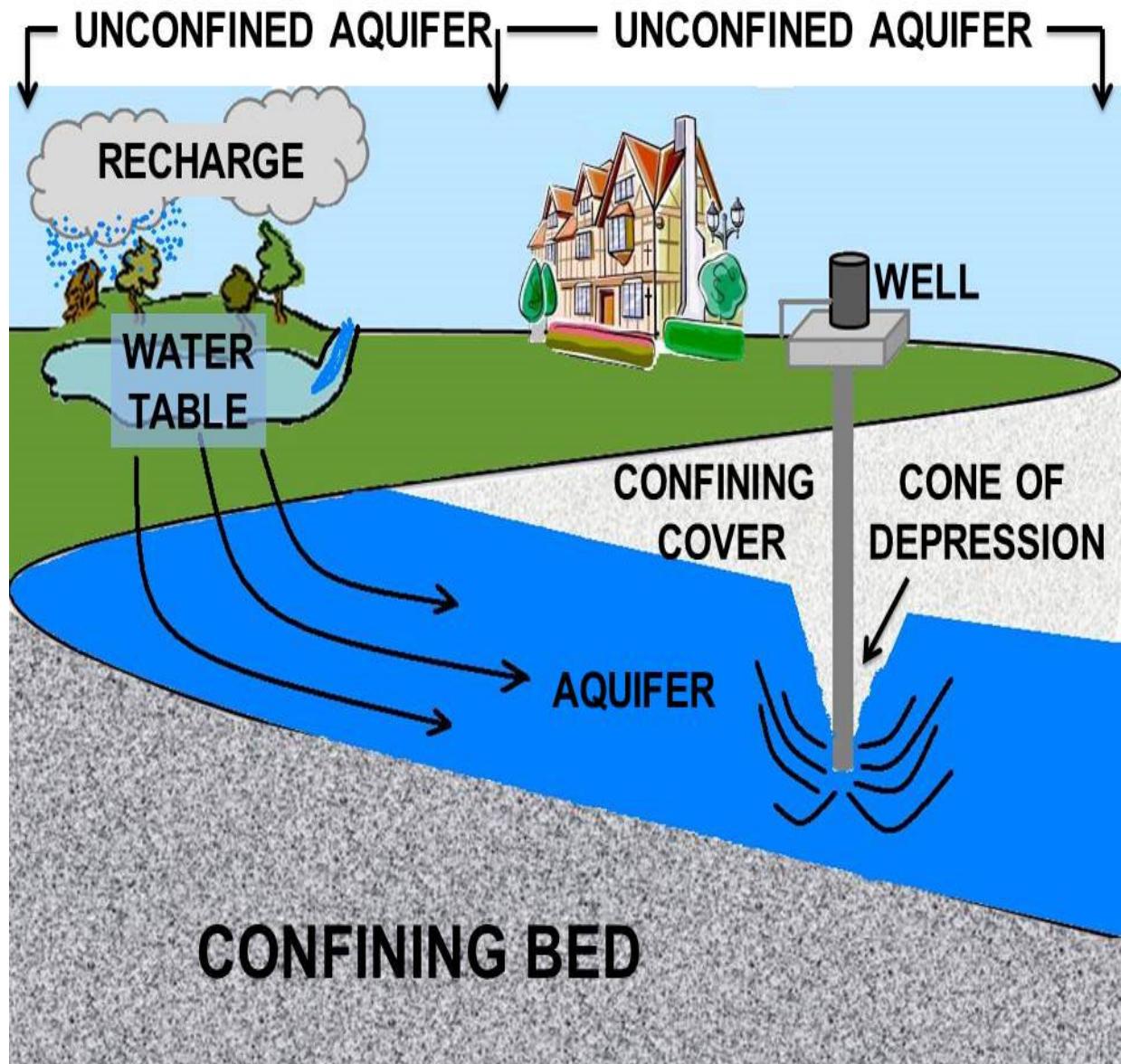
In general, a community whose groundwater supply has been contaminated has five options:

- Contain the contaminants to prevent their migration from their source.
- Withdraw the pollutants from the aquifer.
- Treat the groundwater where it is withdrawn or at its point of use.
- Rehabilitate the aquifer by either immobilizing or detoxifying the contaminants while they are still in the aquifer.
- Abandon the use of the aquifer and find alternative sources of water

Which option is chosen by the community is determined by a number of factors, including the nature and extensiveness of the contamination, whether specific actions are required by statute, the geologic conditions, and the funds available for the purpose. All of these options are costly. For example, a community in Massachusetts chose a treatment option when the wells supplying its public water system were contaminated by more than 2,000 gallons of gasoline that had leaked into the ground from an underground storage tank less than 600 feet from one of the wells.

The town temporarily provided alternative water supplies for its residents and then began a cleanup process that included pumping out and treating the contaminated water and then recharging the aquifer with the treated water. The cleanup effort alone cost more than \$3 million.

Because of the high costs and technical difficulties involved in the various containment and treatment methods, many communities will choose to abandon the use of the aquifer when facing contamination of their groundwater supplies. This requires the community to either find other water supplies, drill new wells farther away from the contaminated area of the aquifer, deepen existing wells, or drill new wells in another aquifer if one is located nearby. As Atlantic City, New Jersey, found, these options also can be very costly for a community. The wells supplying that city's public water system were contaminated by leachate from a landfill. The city estimated that development of a new wellfield would cost approximately \$2 million.



CHAPTER III. Government Groundwater Protection Activities

Given the importance of groundwater as a source of drinking water for so many communities and individuals and the cost and difficulty of cleaning it up, common sense tells us that the best way to guarantee continued supplies of clean groundwater is to prevent contamination.

Are There Federal Laws or Programs to Protect Groundwater?

The U.S. Environmental Protection Agency (EPA) is responsible for federal activities relating to the quality of groundwater. EPA's groundwater protection activities are authorized by a number of laws, including:

- The Safe Drinking Water Act, which authorizes EPA to set standards for maximum levels of contaminants in drinking water, regulate the underground disposal of wastes in deep wells, designate areas that rely on a single aquifer for their water supply, and establish a nationwide program to encourage the states to develop programs to protect public water supply wells (i.e., wellhead protection programs).
- The Resource Conservation and Recovery Act, which regulates the storage, transportation, treatment, and disposal of solid and hazardous wastes to prevent contaminants from leaching into groundwater from municipal landfills, underground storage tanks, surface impoundments, and hazardous waste disposal facilities.
- The Comprehensive Environmental Response, Compensation, and Liability Act (Superfund), which authorizes the government to clean up contamination caused by chemical spills or hazardous waste sites that could (or already do) pose threats to the environment, and whose 1986 amendments include provisions authorizing citizens to sue violators of the law and establishing "community right-to-know" programs (Title III).
- The Federal Insecticide, Fungicide, and Rodenticide Act, which authorizes EPA to control the availability of pesticides that have the ability to leach into groundwater.
- The Toxic Substances Control Act which authorizes EPA to control the manufacture, use, storage, distribution, or disposal of toxic chemicals that have the potential to leach into groundwater.
- The Clean Water Act, which authorizes EPA to make grants to the states for the development of groundwater protection strategies and authorizes a number of programs to prevent water pollution from a variety of potential sources.

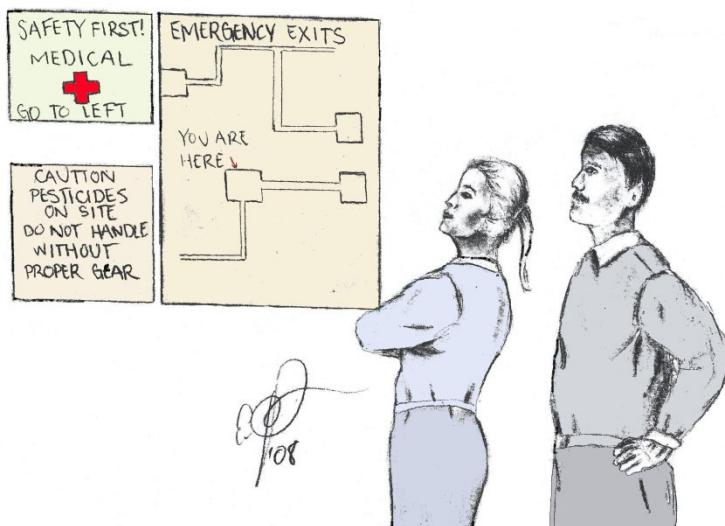
The federal laws tend to focus on controlling potential sources of groundwater contamination on a national basis. Where federal laws have provided for general groundwater protection activities such as wellhead protection programs or development of state groundwater protection strategies, the actual implementation of these programs must be by the states in cooperation with local governments.

A major reason for this emphasis on local action is that protection of groundwater generally involves making very specific decisions about how land is used. Local governments frequently exercise a variety of land-use controls under state laws.

Do the States Have Laws or Programs to Protect Groundwater?

According to a study conducted for EPA in 1988, most of the states have passed some type of groundwater protection legislation and developed some kind of groundwater policies. State groundwater legislation can be divided into the following subject categories:

- Statewide strategies - Requiring the development of a comprehensive plan to protect the state's groundwater resources from contamination.
- Groundwater classification - Identifying and categorizing groundwater sources by how they are used to determine how much protection is needed to continue that type of use.
- Standard setting - Identifying levels at which an aquifer is considered to be contaminated.
- Land-use management - Developing planning and regulatory mechanisms to control activities on the land that could contaminate an aquifer.
- Groundwater funds - Establishing specific financial accounts for use in the protection of groundwater quality and the provision of compensation for damages to underground drinking water supplies (e.g., reimbursement for groundwater cleanup, provision of alternative drinking water supplies).
- Agricultural chemicals - Regulating the use, sale, labeling, and disposal of pesticides, herbicides, and fertilizers.
- Underground storage tanks - Establishing criteria for the registration, construction, installation, monitoring, repair, closure, and financial responsibility associated with tanks used to store hazardous wastes or materials.
- Water-use management - Including groundwater quality protection in the criteria used to justify more stringent water allocation measures where excessive groundwater withdrawal could cause groundwater contamination.



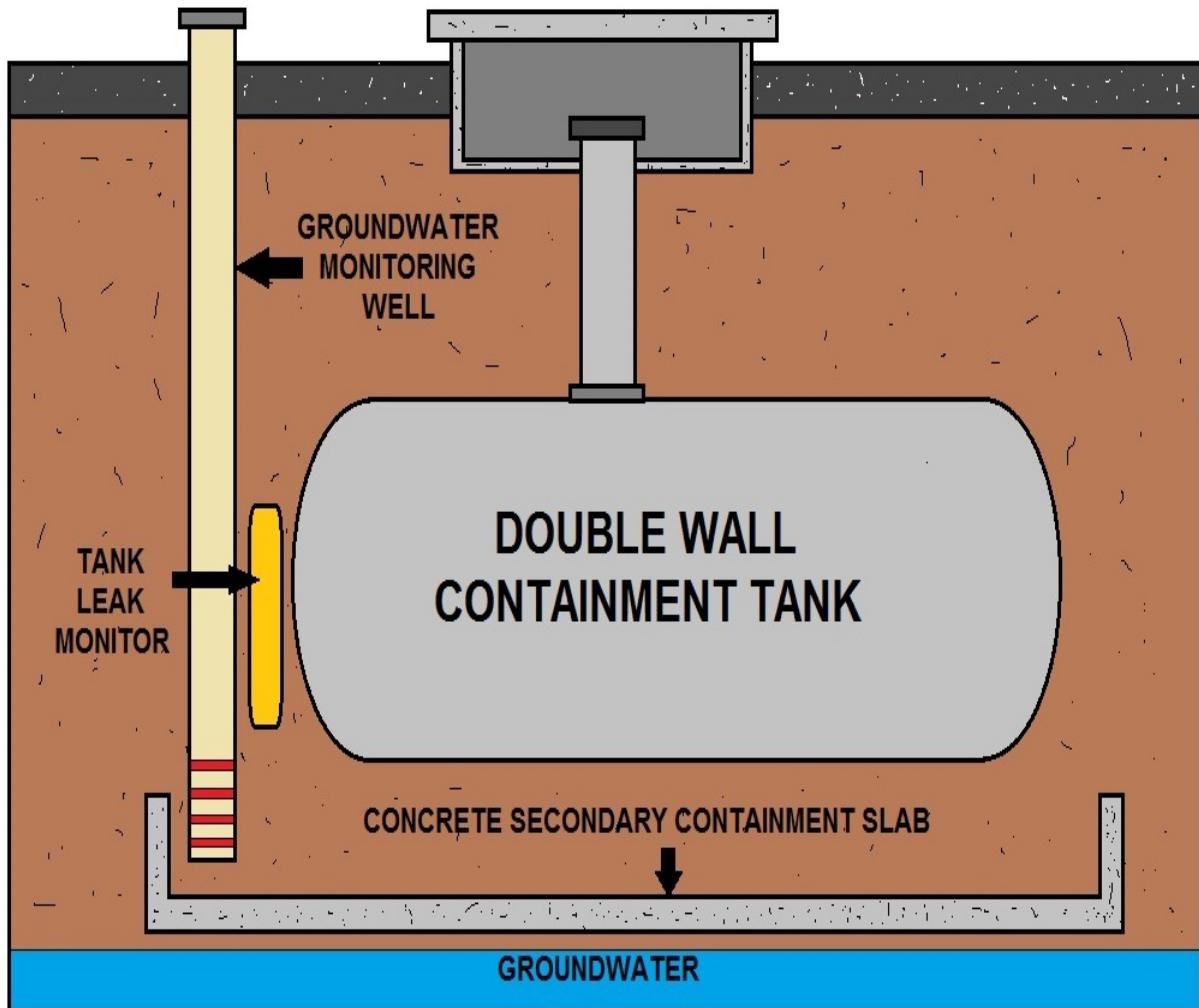
Appendix 1 presents a matrix showing the types of groundwater protection legislation enacted by the states. In addition to groundwater protection programs states may have developed under their own laws, one state groundwater protection program is required by federal law. The 1986 amendments to the Safe Drinking Water Act established the wellhead protection program and require each state to develop comprehensive programs to protect public water supply wells from contaminants that could be harmful to human health. Wellhead protection is simply protection of all or part of the area surrounding a well from which the well's groundwater is drawn. This is called a wellhead protection area (WHPA). The size of the WHPA will vary from site to site depending on a number of factors, including the goals of the state's program and the geologic features of the area.

The law specifies certain minimum components for the wellhead protection programs:

- The roles and duties of state and local governments and public water suppliers in the management of wellhead protection programs must be established.
- The WHPA for each wellhead must be delineated (i.e., outlined or defined).
- Contamination sources within each WHPA must be identified.
- Approaches for protecting the water supply within the WHPAs from the contamination sources (e.g., use of source controls, education, training) must be developed.
- Contingency plans must be developed for use if public water supplies become contaminated.
- Provisions must be established for proper siting of new wells to produce maximum water yield and reduce the potential for contamination as much as possible.
- Provisions must be included to ensure public participation in the process.

For a program to be successful, all levels of government must participate in the wellhead protection program. The federal government is responsible for approving state wellhead protection programs and for providing technical support to state and local governments. State governments must develop and implement wellhead protection programs that meet the requirements of the Safe Drinking Water Act. Although the responsibilities of local governments depend on the specific requirements of their state's program, these governments often are in the best position (and have the greatest incentive) to ensure proper protection of wellhead areas. They have the most to lose if their groundwater becomes contaminated.

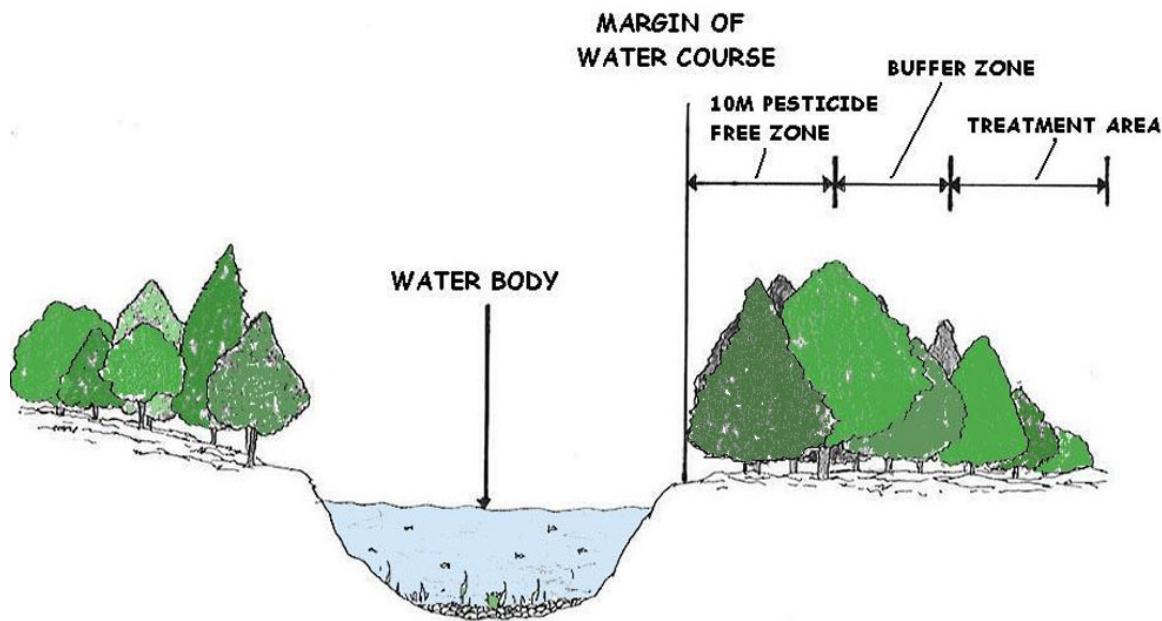
Although the Clean Water Act does not require states to develop groundwater protection strategies, the legislation does authorize states to take this action. As of 1989, all 50 states have at least begun to develop groundwater protection strategies, and some of these are in advanced stages. Proceeding at varying paces, the states are tailoring their efforts to fit their own perceived needs and budgets.



GROUNDWATER PROTECTION FIRST LINE OF DEFENSE

CHAPTER IV. Citizen and Community Roles

In the first three chapters of this guide, you learned how dependent our nation is on groundwater to provide water for drinking and other household uses, agriculture, and industry. You also learned a little about the many substances that can contaminate our groundwater supplies, where they can come from, and how difficult and costly it is to try to clean up groundwater once it has been contaminated. Finally, you were given some information about current national and state programs to protect groundwater. This chapter will focus on what actions you and your community can take to protect your groundwater supplies.



What Information Do You and Your Community Need?

Because no two communities are exactly alike in terms of hydrogeologic conditions, resources, or problems, groundwater protection efforts should be tailored specifically to meet the needs of each community. Thus, before you can begin to help your community develop an effective program to manage its groundwater resources; you will need the answers to some very specific questions.

What Has Your State Done to Protect Groundwater?

As you saw in Chapter III, the Safe Drinking Water Act requires all states to develop programs to protect public water supply wells from contaminants that could be harmful to human health. Information on your state's wellhead protection program should be available from the agency in your state that is managing this program. (Appendix 2 contains a list of the state agencies managing wellhead protection programs.)

Chapter III also mentioned that all 50 states are in the process of developing comprehensive groundwater protection strategies. Such a strategy can provide you with information on who has what groundwater responsibility in the state and on how any existing state programs fit together. A copy of your state's groundwater protection strategy should be available from the agency in your state that is managing this effort. (Appendix 2 also contains a list of these state agencies.)

Does Your Community's Drinking Water Come from Groundwater, and What Information Is Available About Your Community's Wells?

If your community's drinking water comes from groundwater, you will need some basic information about your community's hydrogeologic setting, including the types of soil conditions and geologic formations and the type, location, and depth of the aquifer that stores the groundwater. In addition, information on the community's wells will be needed, including whether they are public or private, shallow or deep; their locations; and how they are constructed. It also could be important to know if sites have been identified for future wells.

Potential sources for this information include your local library, your local water supply agency, your state geological survey, a local office of the U.S. Geological Survey (**USGS**), a county agricultural extension agent, or even the geology or engineering department of a local university or college.

What Is the Current Quality of Your Groundwater Supply, and What Actual or Potential Sources of Contamination Are Present in Your Community?

You will need to know if your water is currently free from bacterial and chemical pollution and what kinds of procedures are in place to test or monitor groundwater quality. Initial information on the quality of your community's groundwater should be available from your local water supply agency or your local health department.

Closely related to the issue of groundwater quality is determining whether there are activities in the community that produce or use toxic or hazardous substances and where underground storage tanks are located. Information on activities using or producing toxic or hazardous materials may be more difficult to obtain, but the community right-to-know provisions in the 1986 Superfund amendments may give you a starting point. These provisions require the establishment of state planning commissions, emergency planning districts, and local emergency planning committees. They also require companies that use certain toxic or hazardous substances to report to these committees.

Companies also are required to report serious environmental releases immediately. All of this information is required to be available to the public.

Another source of information on environmental releases is available in a data base developed by EPA called the Toxic Chemical Release Inventory that is publicly accessible through the National Library of Medicine. The data include the names, addresses, and public contacts of plants manufacturing, processing, or using the reported chemicals; the maximum amount stored onsite; the estimated quantity emitted into the air, discharged into bodies of water, injected underground, or released to land; methods used in waste treatment and their efficiency; and information on the transfer of chemicals offsite for treatment and disposal.

(To obtain additional information on this data base, see Appendix 2.) On a local level, your community's fire department also may be helpful in providing information on both companies using toxic or hazardous materials and the location of underground storage tanks.

What Can Your Community Do to Protect Its Groundwater?

If your community relies on groundwater for its water supplies, it has a strong incentive to protect that groundwater. Before a plan or program can be developed to protect groundwater, it is important to identify existing or potential threats to the groundwater.

This will generally mean conducting an inventory to learn the location of facilities using, manufacturing, or storing materials that have the potential to pollute groundwater. How your community conducts this inventory will depend largely on the resources available, particularly

the number of people available to do the work and funds. A number of communities, however, have had great success in using groups of volunteers to conduct their inventories. For example, the city of El Paso, Texas, has mobilized its senior citizens with the help of the federally funded Retired Senior Volunteer Program (RSVP) and the Texas Water Commission.

The inventory of existing or potential threats to the community's groundwater may be quite long, and it is unlikely that your community will have the resources to address all of these threats. How do community officials decide which threats are the most serious or set priorities? One way is to assess these threats on the basis of their relative risks to the community's groundwater. This requires determining which of the specific pollutants are most likely to be released and reach the groundwater in concentrations high enough to pose health risks.

In addition to having an incentive to protect its groundwater, your community has a number of powers that can be used for that purpose. These include implementing zoning decisions; developing land-use plans; overseeing building and fire codes; implementing health requirements; supplying water, sewer, and waste disposal services; and using their police powers to enforce regulations and ordinances. A few communities have begun developing their own groundwater protection programs using a variety of management tools based on these powers.

These management tools include:

- **Zoning Ordinances** - To divide a municipality into land-use districts and separate incompatible land uses such as residential, commercial, and industrial; zoning also defines the type of activity that can occur within a district and specifies appropriate regulations that can be used prevent activities that could be harmful to the community's groundwater.
- **Subdivision Ordinances** - Applied when a piece of land is actually being divided into lots for sale or development to ensure that growth does not outpace available local facilities such as roads, schools, and fire protection; subdivision ordinances also can be used to set density standards, require open space set asides, and regulate the timing of development, all of which can have significant impacts on groundwater quality.
- **Site Plan Review** - To determine if a proposed development project is compatible with existing land uses in the surrounding area and if existing community facilities will be able to support the planned development; this review also can be used to determine compatibility of the proposed project with any groundwater protection goals.
- **Design Standards** - To regulate the design, construction, and ongoing operation of various land-use activities by imposing specific physical requirements, such as the use of double-walled tanks to store chemicals underground.
- **Operating Standards** - To ensure the safety of workers, other parties, and the environment by specifying how an activity is to be conducted; these can take the form of best management practices (BMPs) that define a set of standard operating procedures for use in a particular activity to limit the threat to the environment (e.g., limits on pesticide applications or animal feedlot operations).
- **Source Prohibitions** - To prohibit the storage or use of dangerous materials in a defined area; these can take the form of prohibitions of certain activities or of restrictions on the use of certain materials.

- **Purchase of Property or Development Rights** - To guarantee community control over the activities on lands that feed water into an aquifer, this may involve outright purchase of the land or of a more limited interest, such as surface-use rights.
- **Public Education** - To build community support for regulatory programs, such as controls on pollution sources in special zoning districts, and to motivate voluntary groundwater protection efforts, such as water conservation or household hazardous waste management.
- **Groundwater Monitoring** - To assess the quality of local aquifers by sampling public and private wells for selected contaminants.
- **Household Hazardous Waste Collection** - To alleviate the threat to groundwater from the disposal in regular trash pickups, sewers, or septic systems of household products that contain hazardous substances or other materials that can be harmful to groundwater, such as paints, solvents, or pesticides.
- **Water Conservation** - To reduce the total quantity of water withdrawn from groundwater aquifers and to protect against contamination by reducing the rate at which contaminants can spread in the aquifer (e.g., excessive withdrawals from an aquifer located near the ocean can draw salt water into the aquifer and contaminate wells).

How Can You Clean Up Your Own Act?

So far, the emphasis has been on how you can help your community to protect its groundwater through the development of community-wide policies and programs. But groundwater protection also begins at home. How do your personal habits affect your community's groundwater quality? What can you, as an individual, do to protect your community's groundwater?

How Do You Dispose of the Polluting Materials Used in Your Home?

You may be surprised to learn that the way you dispose of products you use at home can contribute to the contamination of your community's groundwater. You may be even more surprised to learn that a number of the products you use at home contain hazardous or toxic substances.



The truth is, however, that products like motor oil, pesticides, left-over paints or paint cans, mothballs, flea collars, weedkillers, household cleaners, and even a number of medicines contain materials that can be harmful to groundwater and to the environment in general. (See Appendix 1 for a list of the types of products commonly found around homes and their potentially harmful components.) The average American disposes of approximately one pound of this type of waste each year. So, although the amount of any of these substances that you pour down your drain, put in your trash, or dump on the ground may seem insignificant to you, try multiplying it by the number of people in your community. That amount may not seem so insignificant.

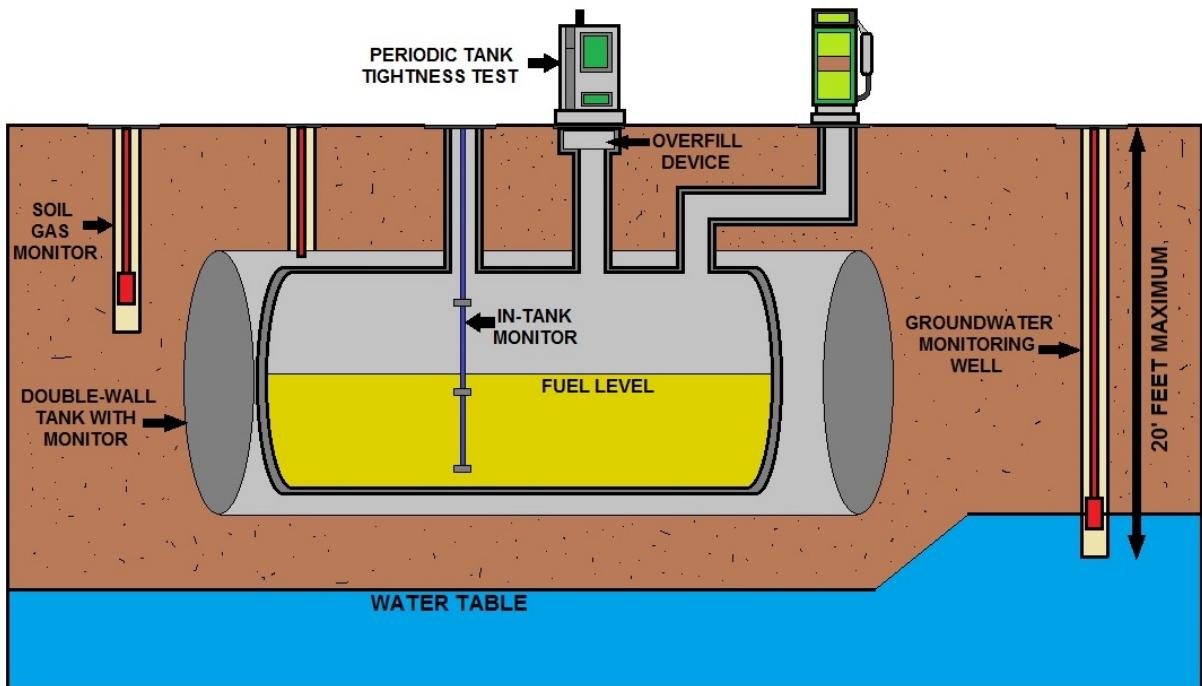
Don't Pour It Down the Drain! Anything you pour down your drain or flush down your toilet will enter your septic system or your community's sewer system. Using this method to dispose of products that contain harmful substances can affect your septic system's ability to treat human wastes. Once in the ground, these harmful substances can eventually contaminate the groundwater. In addition, most community wastewater treatment plants are not designed to treat many of these substances. Thus, they can eventually be discharged into bodies of surface water and cause contamination.

Don't Put It in the Trash! Community landfills also generally are not equipped to handle hazardous materials. As rain and snow pass through the landfill, the water can become contaminated by these products and eventually carry them into the groundwater and surface water.

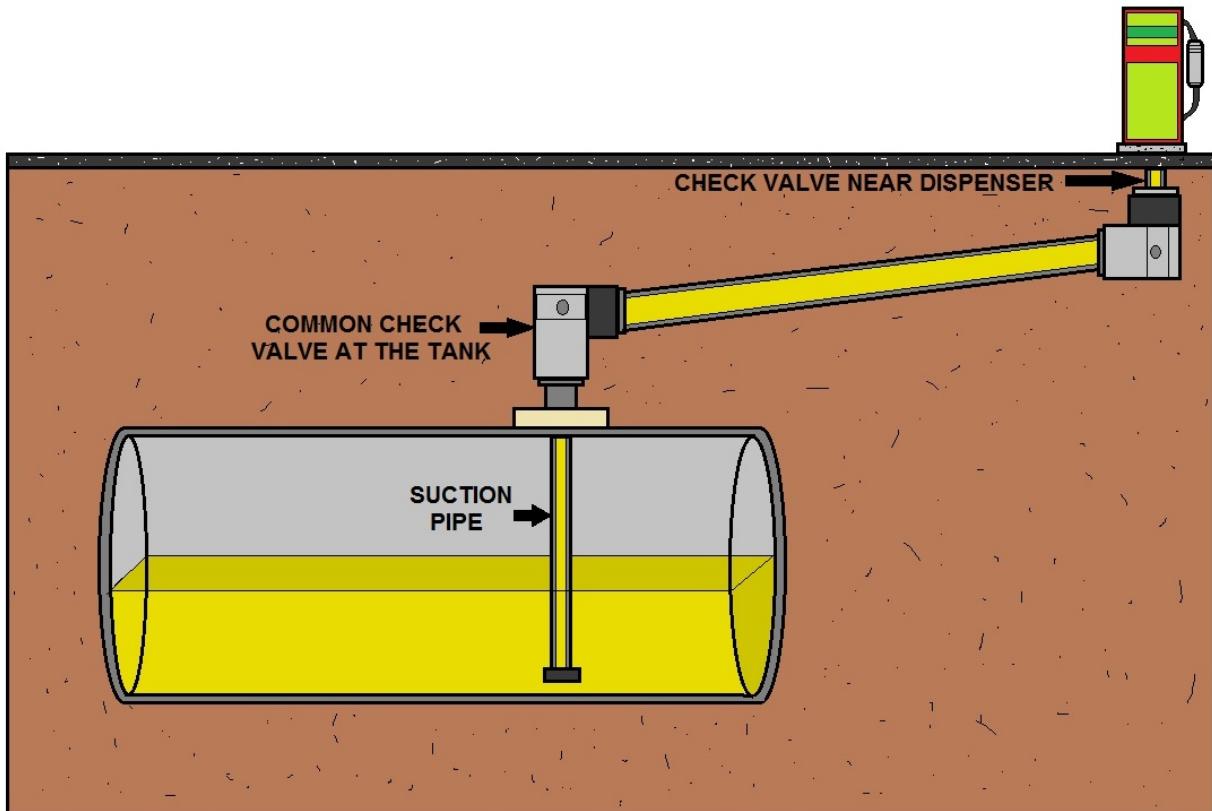
Don't Dump It on the Ground! Hazardous wastes that are dumped on or buried in the ground can contaminate the soil and either leach down into the groundwater or be carried into a nearby body of surface water by runoff during rainstorms.



Do Use and Dispose of Harmful Materials Properly! There are very few options for disposing of hazardous products used in your home, so the first step may be to limit your use of such products. Whenever possible, substitute a nonhazardous product. When that is not possible, buy only as much as you need.



LEAK DETECTION ALTERNATIVES



SUCTION PIPING FOR UNDERGROUND STORAGE TANK

How Have The UST Requirements Helped Protect The Environment?

Since the federal regulations for underground storage tanks (**USTs**) became effective in December 1988, states and federal authorities have worked together with the regulated industry to reduce significantly the number and extent of problems caused by leaking USTs:

- More than 1.5 million substandard USTs have been closed and (when closed properly) no longer pose a threat to the environment.
- About 698,000 USTs are currently active, located at more than 260,000 sites nationwide. Many of these USTs meet operational requirements for spill, overfill, and corrosion protection, as well as operational requirements for leak detection. ("Operational compliance" means that equipment is installed, operated, and maintained as set forth in the UST requirements.) Regulatory authorities and industry continue working to help UST owners and operators reach higher levels of operational compliance with all requirements as soon as reasonably possible.
- Cleanups have been initiated at more than 427,000 sites, of which over 284,000 sites have been closed. For state-by-state data (reported semi-annually) on the cumulative number of active USTs, closed USTs, confirmed releases, cleanups initiated, cleanups completed, and emergency responses go to the Corrective Action Measures Archive. <http://www.epa.gov/OUST/cat/camarchv.htm>
- Over the last few years, fewer releases are being reported annually, in part as a result of old substandard USTs being closed or upgraded to meet the 1998 deadline.
- More than 40 states have state funds that raise over \$1 billion a year for cleanups (for more information on each state's UST program and potential state funds, see the "State and Territorial UST Program Directory" for state-specific information).
- A federal Trust Fund has provided nearly \$1 billion to states to help them fund oversight and enforcement of cleanups and to do cleanup work. More information is available on the Leaking Underground Storage Tank (**LUST**) Trust Fund.
- EPA has intensified cleanup efforts at abandoned gas stations by allocating \$1 Million for 10 pilot projects under the USTfields Initiative. Another 40 USTfields pilots are in the process of being awarded in 2002. More information is available on the USTfields Initiative. <http://www.epa.gov/OUST/ustfield/index.htm>

How Much Work Remains To Be Done?

State and federal regulatory agencies, working with the regulated industry, still have a significant amount of work to do to make underground storage tank (**UST**) sites as safe as possible. EPA's Office of Underground Storage Tanks has four program initiatives addressing the following challenges:

- Raise operational compliance levels at UST sites. Too many USTs do not have or do not use properly the protective equipment that could help eliminate new releases.
- Continue evaluating the efficacy of the UST requirements. We need to be sure the UST requirements identify equipment and methods that work.
- Increase the pace of cleanups. Releases from UST systems continue to occur faster than they can be cleaned up and there is a significant backlog of cleanups still to be completed.
- Use the USTfields Initiative to increase cleanups. UST releases may have occurred at nearly 200,000 Brownfields sites; these may be candidates for cleanup and redevelopment.

Are Aboveground Storage Tanks (ASTs) A Way To Avoid Regulation?

No. But, some underground storage tank (**UST**) owners or operators mistakenly think they can avoid environmental and safety requirements by changing to aboveground storage tanks (**ASTs**). However, ASTs are subject to both Federal regulations and State/local regulations. Before choosing an AST option, UST owners and operators should keep the following in mind:



- Replacing an existing UST with an AST still requires closing the existing UST properly—proper closure includes notifying your regulatory authority at least 30 days before you close your UST, conducting any necessary site assessment and remedial action, having the tank emptied and cleaned safely, and either removing the tank or leaving it buried but filled with an inactive solid, such as sand.
- Most ASTs need to meet U.S. EPA's Spill, Prevention, Control, and Countermeasure (**SPCC**) requirements (40 CFR, Part 112). SPCC applies to facilities with a single AST with a storage capacity greater than 660 gallons, or multiple tanks with a combined capacity greater than 1,320 gallons. SPCC requires procedural and contingency plans, as well as various technical requirements, such as corrosion protection. For more information on SPCC requirements call EPA's Hotline at 800-424-9346, or contact EPA's Hugo Fleischman by telephone at 703-603-8769 or by email at fleischman.hugo@epa.gov.
- ASTs can increase the risk of fire and hazards resulting from damage caused by vehicles or vandals. AST owners should install AST systems that have adequate safeguards against fire, overfills, and damage.
- At a minimum, most ASTs need to meet state and local fire codes, which usually have some mix of construction, installation, operation and maintenance requirements that are intended to prevent fires and other hazards that can come

- from mismanaged or substandard ASTs. For more information, check with your local authority having jurisdiction, such as your local fire marshal.
- Some ASTs may need to meet additional state or local regulatory requirements that safeguard human health and the environment from potential threats posed by ASTs. You should check with your state agency in charge of oil pollution control activities for information on state and local requirements.

Are Heating Oil Tanks Regulated?

Tanks used for the storage of heating oil for consumptive use on the premises where stored are excluded from federal UST regulations. However, state or territorial regulatory agencies may regulate these tanks.

You can view a map showing which states regulate these tanks but note that this data is from the Petroleum Equipment Institute Web site and may not be up-to-date. You should contact your local regulatory agency for more information.

"**Heating oil**" includes several grades of petroleum fuel oils: No. 1, No. 2, No. 4-light, No. 4-heavy, No. 5-light, No.5-heavy, No.6, Navy Special Fuel Oil, and Bunker C, plus No.2 diesel fuel and kerosene when used for heating purposes only.

A flow chart is available to aid you in determining whether your UST qualifies for the heating oil tank exclusion.

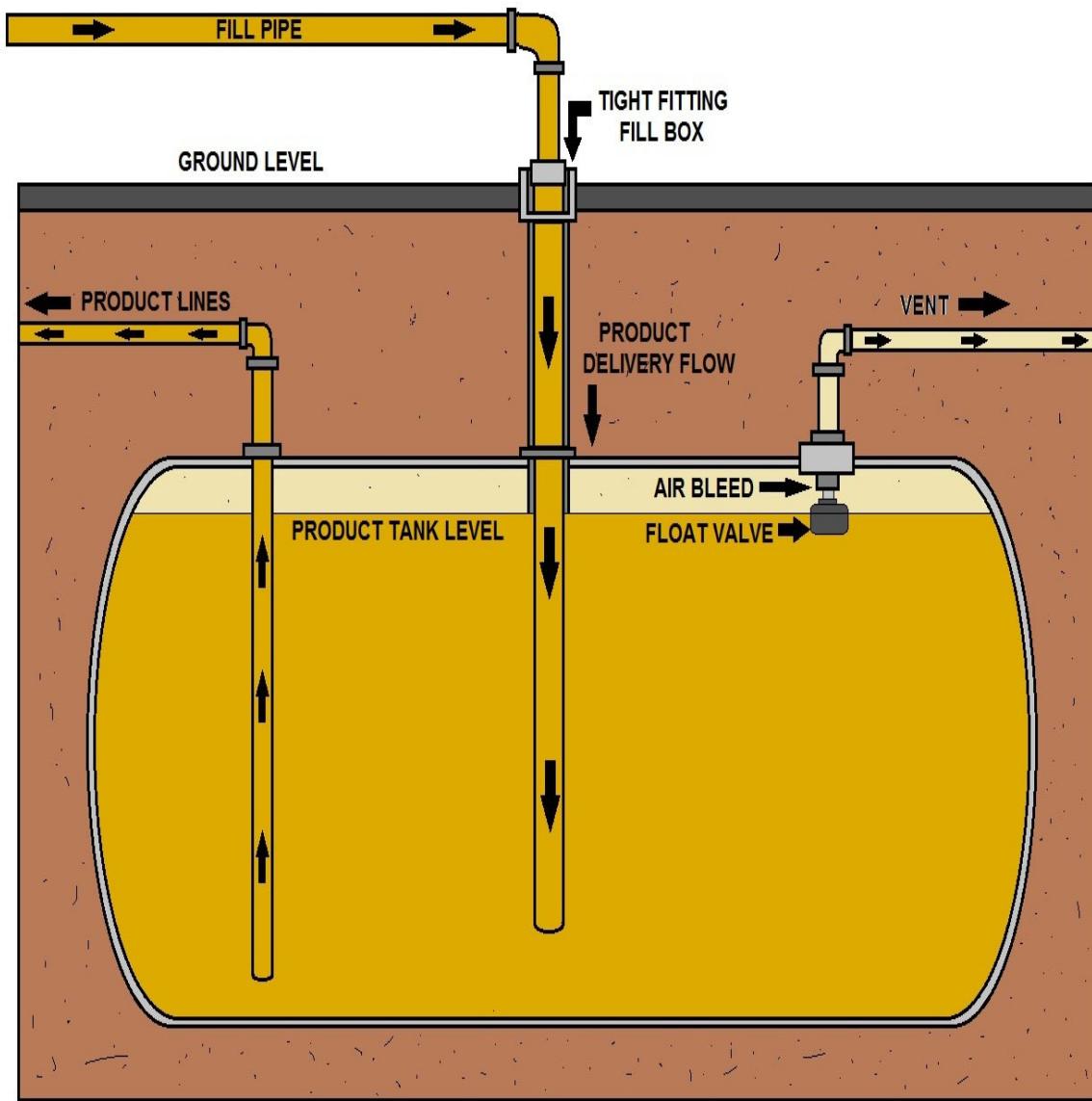
The flow chart is in PDF format (requires the Adobe Acrobat reader--which is free from Adobe and is entitled "**Does my tank qualify for the heating oil tank exemption?**".

"**Consumptive use**" is not intended to be limited to heating purposes only: the definition extends to any on-site use including heating, generating emergency power, and generating steam, process heat, or electricity.

The exclusion does not apply to tanks storing heating oil for resale.

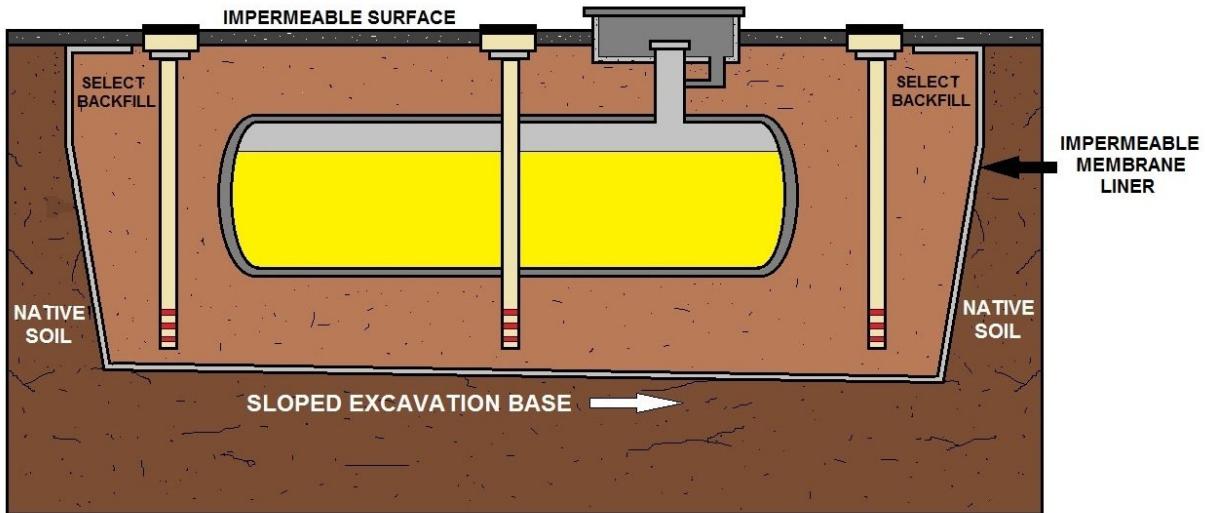
The "**premises**" is not limited to the building where the heating oil is stored; it includes anywhere on the same property. Thus, centralized heating units using heating oil that serve more than one building on the same property would qualify for exclusion.



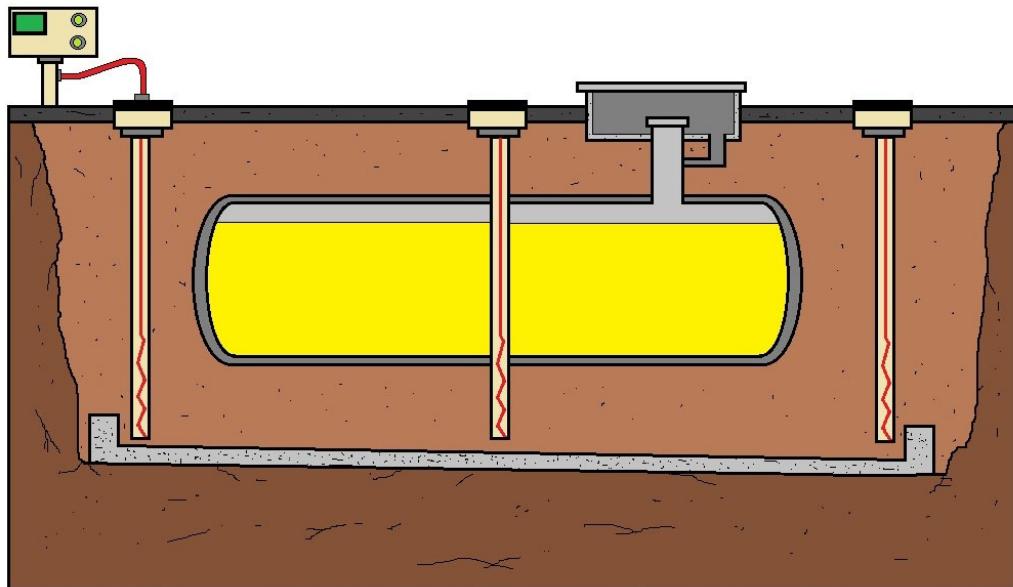


OVERFILL PROTECTION OF STORAGE TANK

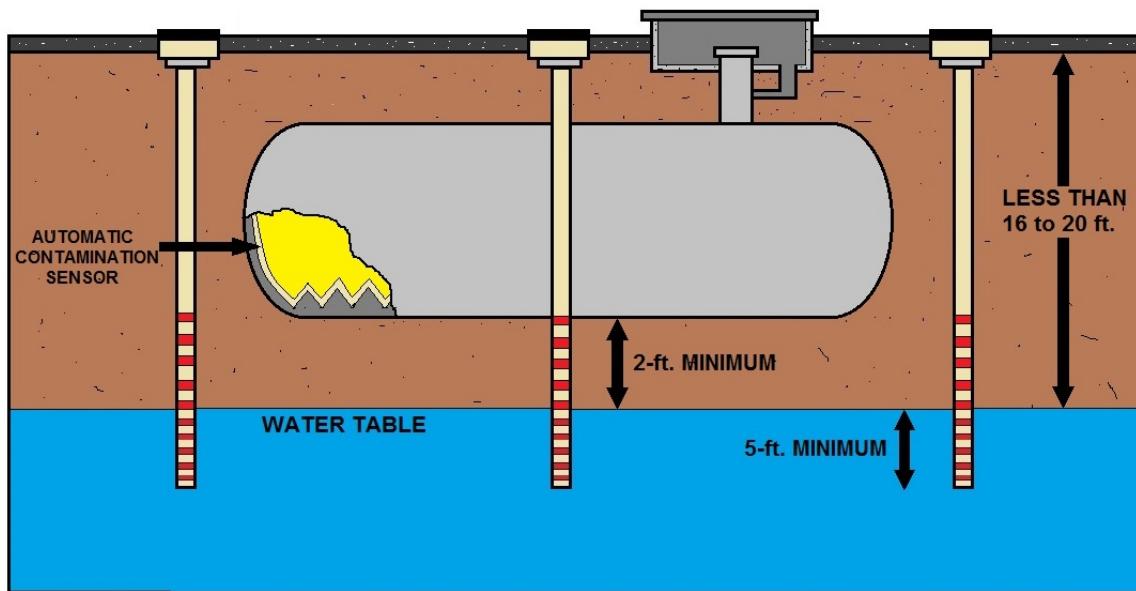
Diagrams of UST Systems



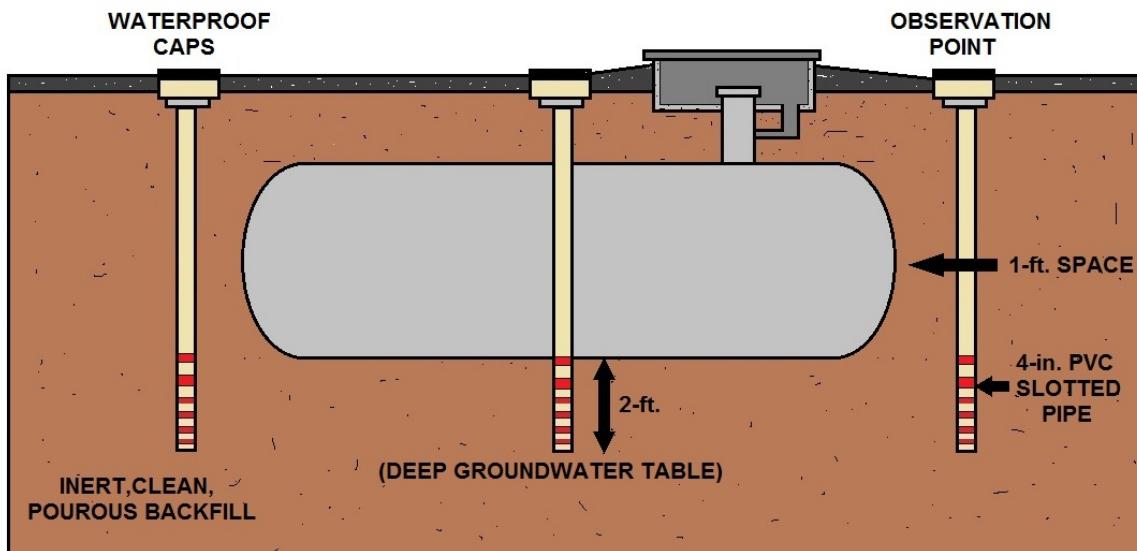
**INSTALLATION OF UNDERGROUND STORAGE TANK
(LINED DURING EXCAVATION FOR SECONDARY CONTAINMENT)**



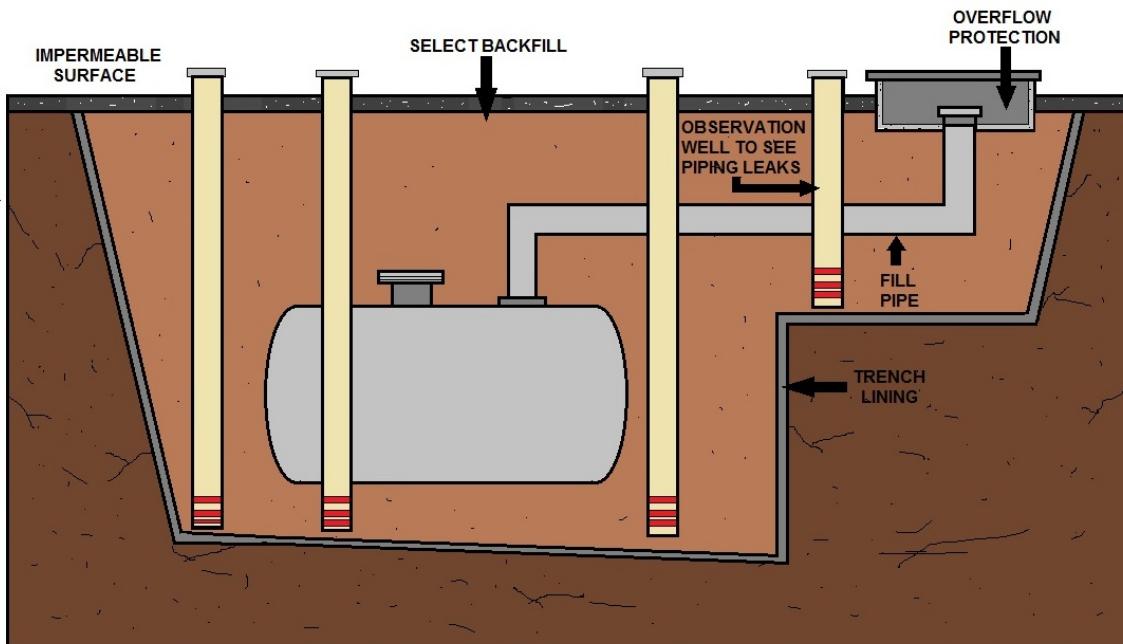
**INSTALLATION OF UNDERGROUND STORAGE TANK
IMPERMEABLE CONCRETE SLAB, WITH CONTAINMENT BERMS
(FOR LOW GROUNDWATER TABLE)**



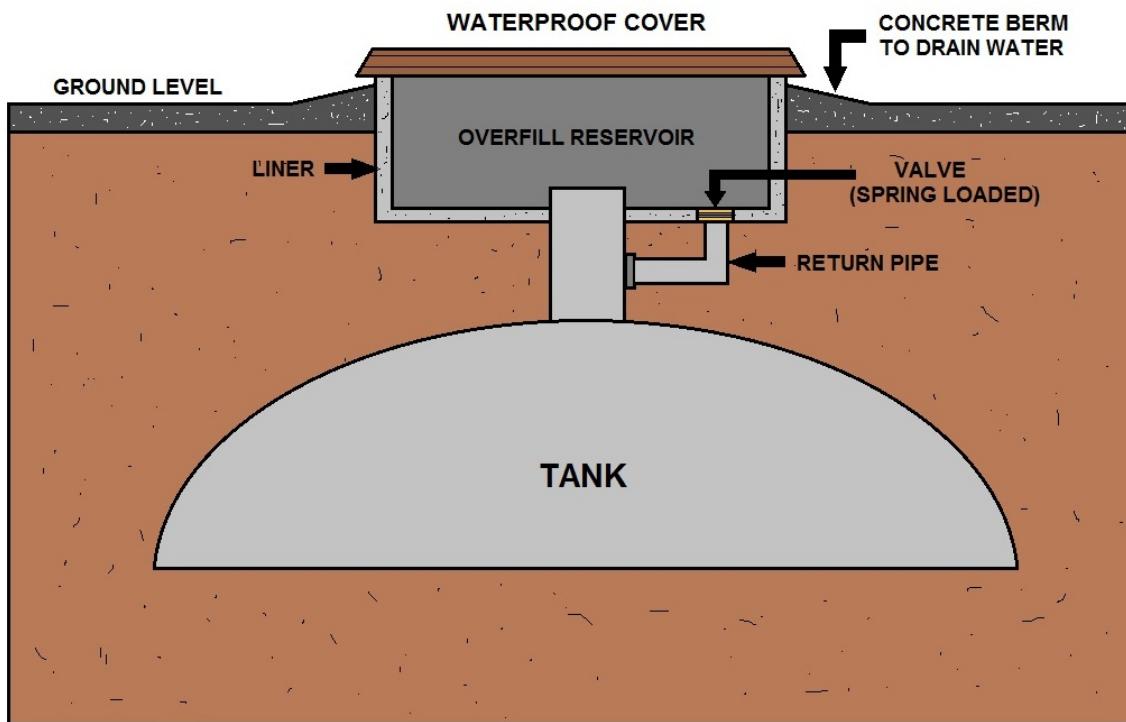
**INSTALLATION OF UNDERGROUND STORAGE TANK
(HIGH WATER TABLE CONDITIONS)**



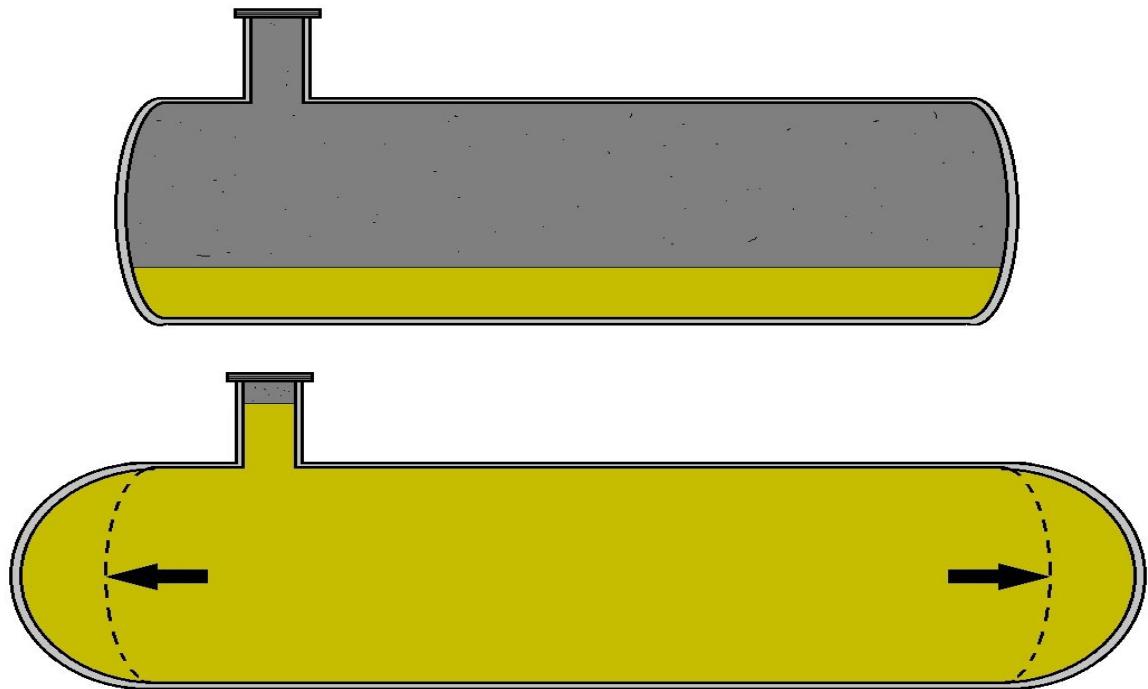
**INSTALLATION OF UNDERGROUND STORAGE TANK
(OBSERVATION / MONITORING / RECOVERY WELLS)**



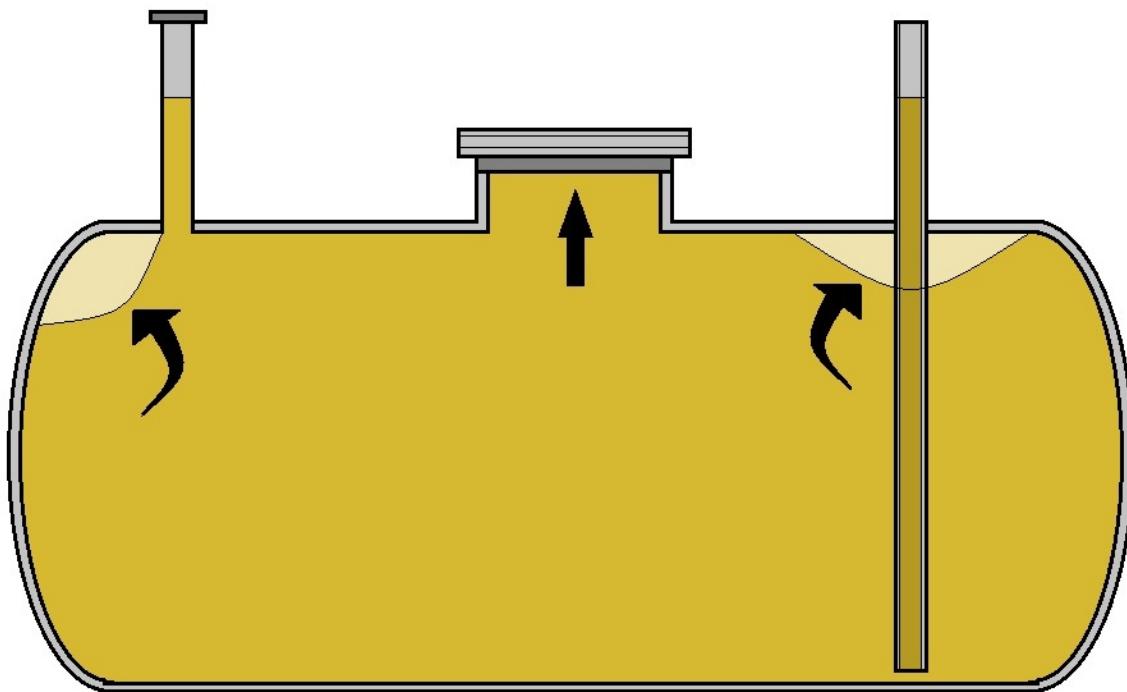
INSTALLATION OF PIPING PROTECTION



PROTECTING FROM OVERFILL



TANK END DEFLECTION



VAPOR POCKETS IN A STORAGE TANK

Can Leaking Tanks Be Repaired?

You can repair a leaking tank if the person who does the repair carefully follows standard industry codes that establish the correct way to conduct repairs.

Within 30 days of the repair, you must prove that the tank repair has worked by doing one of the following:

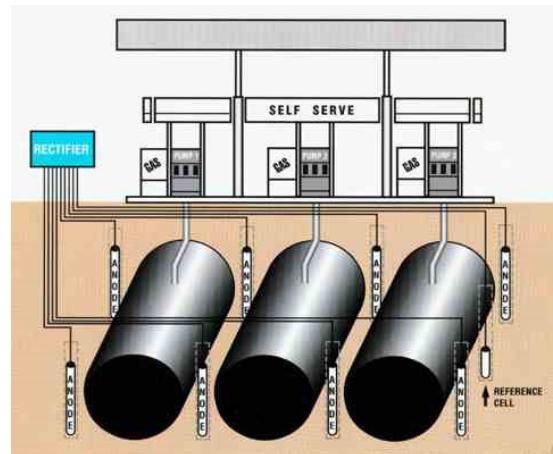
- Have the tank inspected internally or tightness tested following standard industry codes; or
- Use one of the monthly leak detection monitoring methods; or
- Use other methods approved by the regulatory authority.

Within 6 months of repair, USTs with Cathodic protection must be tested to show that the Cathodic protection is working properly.

You must keep records for each repair as long as you keep the UST in service.

Cathodic protection. A tank may be upgraded by Cathodic protection if the Cathodic protection system meets the requirements of § 280.20 (a) (2) (ii), (iii), and (iv) and the integrity of the tank is ensured using one of the following methods:

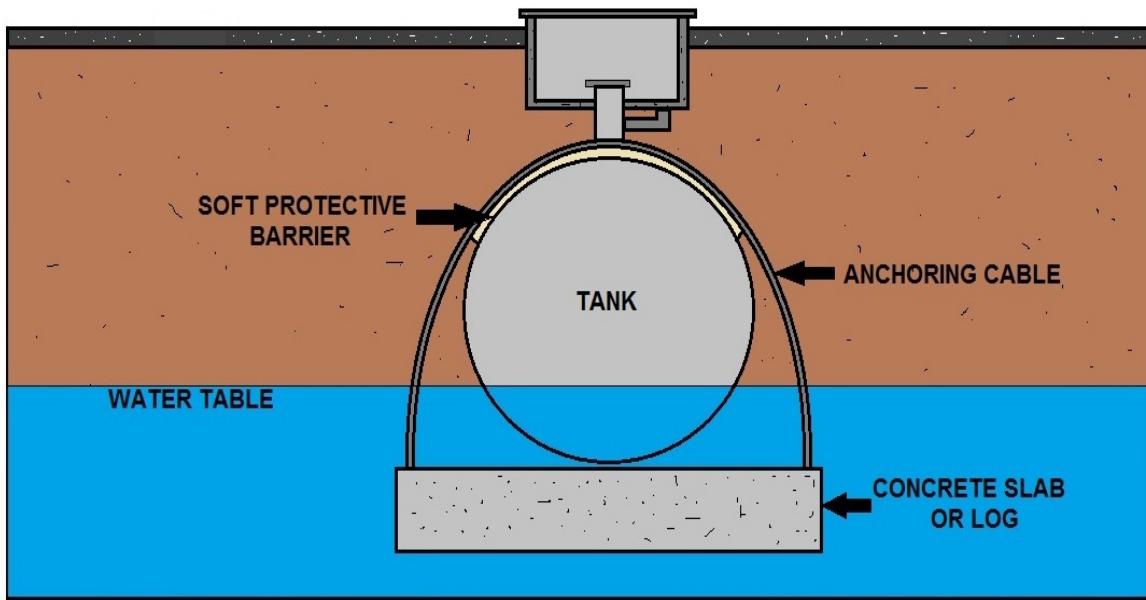
- (i) The tank is internally inspected and assessed to ensure that the tank is structurally sound and free of corrosion holes prior to installing the Cathodic protection system; or
- (ii) The tank has been installed for less than 10 years and is monitored monthly for releases in accordance with § 280.43 (d) through (h); or
- (iii) The tank has been installed for less than 10 years and is assessed for corrosion holes by conducting two (2) tightness tests that meet the requirements of § 280.43 (c). The first tightness test must be conducted prior to installing the Cathodic protection system. The second tightness test must be conducted between three (3) and six (6) months following the first operation of the Cathodic protection system; or
- (iv) The tank is assessed for corrosion holes by a method that is determined by the implementing agency to prevent releases in a manner that is no less protective of human health and the environment than paragraphs (b) (2) (i) through (iii) of this section.



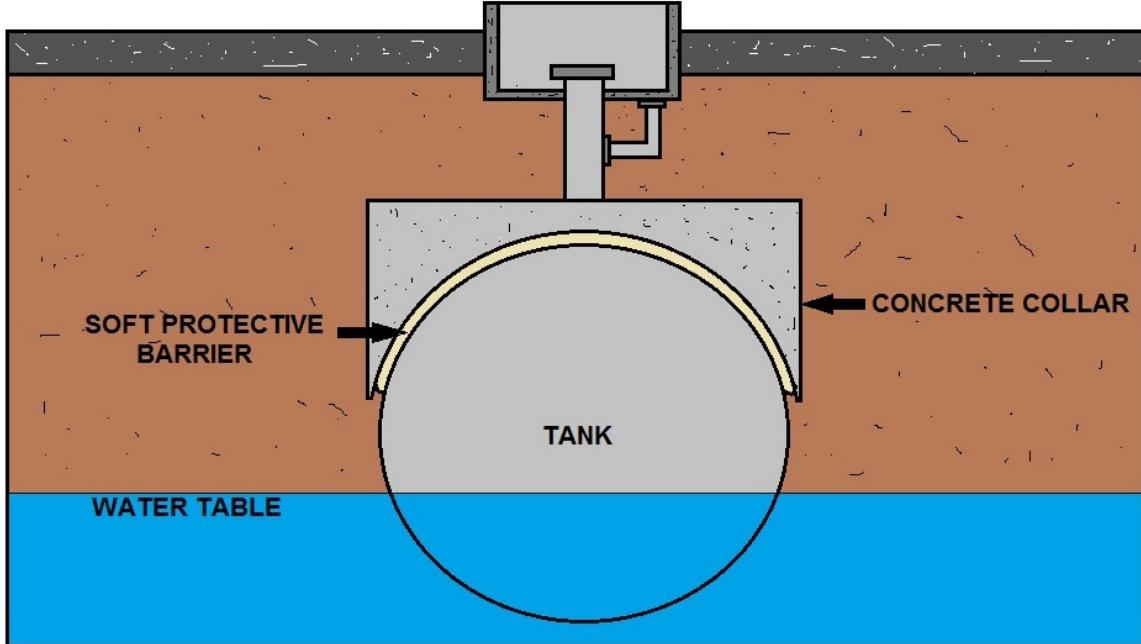
Piping

Metal pipe sections and fittings that have released product as a result of corrosion or other damage must be replaced. Loose fittings can be tightened, and in some cases that may solve the problem.

Piping made of fiberglass-reinforced plastic can be repaired, but only in accordance with the manufacturer's instructions or national codes of practice. Within 30 days of the repair, piping must be tested in the same ways noted above for testing tank repairs (except for internal inspection).



ANCHORING WITH HIGH GROUNDWATER



HIGH GROUNDWATER ANCHORING

Tank Testing

Inventory Control and Tank-Tightness Testing

Inventory control and tank-tightness testing can only be used for 10 years after a new installation or upgrade of an existing UST. When used in conjunction with inventory control, tank-tightness tests are required once every five years during this 10-year period.

Line Tightness Testing

Line-tightness testing is required annually in conjunction with automatic line leak detectors on pressure lines. U.S. suction lines (line slopes to tank with a foot valve in the tank) require a line-tightness test every three years. European style suction (line slope to tank with no foot valve in tank or line) do not need line-tightness testing.

Corrosion Protection

If your UST system or any part of it is protected by either sacrificial anodes or an impressed current system, the Cathodic protection must be tested at least every three years to make sure it is still functioning properly. The required tests can be conducted by a qualified *Cathodic protection tester*. The Cathodic protection tester will take soil potential readings as directed by the State Agency or DEQ and provide the tank owner with the results. These results should be kept at the facility.

Who Can Answer Questions About UST Systems?

The underground storage tank (**UST**) program is primarily implemented by states and territories. Your first point of contact is the state or territorial regulatory agency that has jurisdiction where the USTs are physically located. A list of State and Territorial UST Program Offices is provided for your convenience.

If you have an UST question that involves USTs in Indian Country, contact your EPA Regional Office. EPA has responsibility for, and authority over, USTs in Indian Country.

For general questions about the federal UST program, you can contact EPA's RCRA, Superfund, and EPCRA Call Center at their toll-free number (800-424-9346); for the hearing impaired, the number is TDD 800-553-7672. The Call Center is staffed from Monday through Friday, 9:00 a.m. to 5:00 p.m. EST. Note that the Call Center is closed on all federal holidays.

The Call Center also maintains a Web site at
<http://www.epa.gov/epaoswer/hotline/index.htm>.

How Can I Tell If A Release Has Occurred?

Various warning signals can indicate that your underground storage tank (**UST**) may be leaking and creating problems for the environment and your business. You can minimize these problems by paying careful attention to early warning signals and reacting to them quickly before major problems develop.

You should suspect a leak when you discover any of the following warning signals:

- You, your coworkers, or customers smell escaped product or see anything like an oily sheen on water near the facility.
- Your neighbors complain of vapors in their basements or about water that tastes or smells like petroleum.
- Someone reports unusual operating conditions at your facility, such as erratic behavior of the dispensing pump.

- You receive or generate results from leak detection monitoring and testing that indicate a leak.

If you suspect that a release may have occurred, you must immediately notify your state or local implementing agency. If your tank is in Indian Country, then you must contact the EPA Regional UST program office.

Quick action on your part can minimize the extent of environmental damage and the threat to human health and safety, and it can minimize your share of the high costs that can result from cleaning up extensive releases and responding to third-party liability claims.

See the answer to "***How Do You Report A Release From An UST System?***" for more details on reporting releases.



How Do I Report a Release from an UST System?

If a release from an underground storage tank (**UST**) system is suspected, the owner or operator must report the release to the state or local implementing agency within 24 hours, or another reasonable time period specified by the implementing agency. If the leak takes place in Indian Country, then the EPA's Regional UST program should be contacted.

Steps should also be taken immediately to stop the release and ensure that there is no threat to the safety of persons in the vicinity of the release. It is not necessary to notify the implementing agency of aboveground spills or overfills of petroleum of less than 25 gallons (or another reasonable amount specified by the implementing agency) if the release can be contained and cleaned up within 24 hours. It is also not necessary to notify the implementing agency of a spill or overfill of a hazardous substance which results in a release to the environment that is less than its reportable quantity under CERCLA if it can be contained and cleaned up within 24 hours (for more information see 40 CFR 302.5 of CERCLA.)



What Do I Do About UST Releases?

You need to call your regulatory authority and report suspected leaks. Then find out quickly if these suspected leaks are actual leaks using the following investigative steps:

- Conduct tightness testing of the entire UST system.
- Check the site for additional information on the presence and source of contamination.

You must respond quickly to any evidence of leaked petroleum that appears at or near your site. Your response to confirmed releases comes in two stages: short-term and long-term.

Short-Term Actions

- Take immediate action to stop and contain the release.
- Report the release to the regulatory authority within 24 hours. However, petroleum spills and overfills of less than 25 gallons do not have to be reported if you immediately contain and clean up these releases.
- Make sure the release poses no immediate hazard to human health and safety by removing explosive vapors and fire hazards. Your fire department should be able to help or advise you with this task. You must also make sure you handle contaminated soil properly so that it poses no hazard (for example, from vapors or direct contact).
- Remove petroleum from the UST system to prevent further release into the environment.
- Find out how far the petroleum has moved and begin to recover the leaked petroleum (such as product floating on the water table). Report your progress and any information you have collected to the regulatory authority no later than 20 days after confirming a release.
- Investigate to determine if the release has damaged or might damage the environment. This investigation must determine the extent of contamination both in soils and groundwater. You must report to the regulatory authority what you have learned from an investigation of your site according to the schedule established by the regulatory authority. At the same time, you must also submit a report explaining how you plan to clean up the site. Additional site studies may be required.

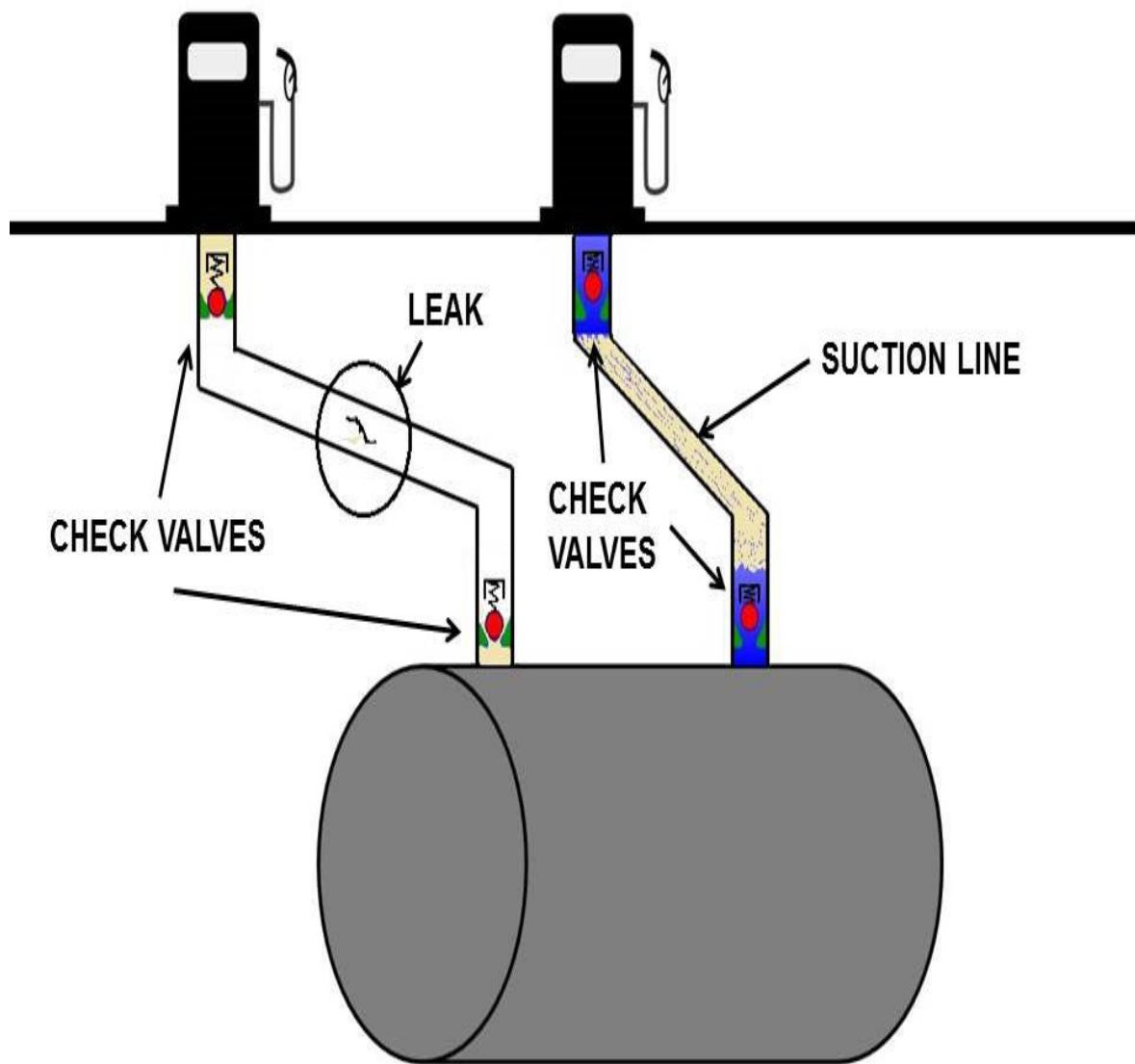
Long-Term Actions

Based on the information you have provided, the regulatory authority will decide if you must take further action at your site.

You may need to develop and submit a Corrective Action Plan that shows how you will meet requirements established for your site by the regulatory authority. Also, make sure you implement the steps approved by the regulatory authority for your site.



Disposal of contaminated soil



SAFETY CHECK VALVE DIAGRAM

Removal and Backfilling of LUST Examples



A backhoe
is used for
excavating
USTs.

Make Sure
you have
located
buried
utilities prior
to
excavation.



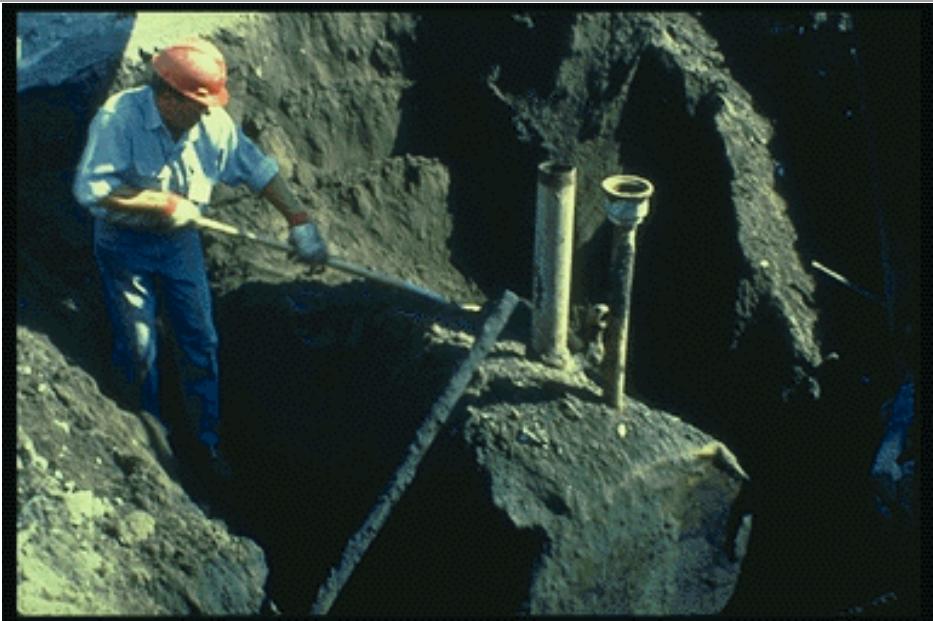
Always
contact your
State
Agency for
proper
permits prior
to UST
removal.



Exposed piping during the early stages of UST removal.



Early stages of removal of 3 USTs and product piping.



Manual labor during an UST excavation. Beware of toxic gases and install shoring where needed.



Rainwater which partially filled the UST excavation caused an UST to float and roll over to one side complicating removal.



A large backhoe removes an UST.



A pair of excavated USTs awaiting proper disposal.



Product leaking from holes in a freshly excavated UST.



Rows of excavated USTs awaiting proper disposal.



Rows of rusty USTs await proper disposal???



Water(?) leaking from a hole in the side of a freshly excavated UST.



A partially excavated UST being filled with an inert material for disposal-in-place.

Photographs courtesy of the US EPA

Excavation Safety Plan

An excavation safety plan is required in written form. This plan is to be developed to the level necessary to insure complete compliance with the OSHA Excavation Safety Standard and state and local safety standards.

Excavation safety plan factors:

- Utilization of the local one-call system
- Determination of locations of all underground utilities
- Consideration of confined space atmosphere potential
- Proper soil protection systems and personal protective equipment and clothing
- Determination of soil composition and classification
- Determination of surface and subsurface water
- Depth of excavation and length of time it will remain open

Proper adherence to all OSHA Standards, this excavation and trenching safety program, and any other coinciding safety programs.

Cleaning Up Underground Storage Tank System Releases

Why do UST releases need to be cleaned up?

EPA's federal underground storage tank (UST) regulations require that contaminated UST sites must be cleaned up to restore and protect groundwater resources and create a safe environment for those who live or work around these sites. Petroleum releases can contain contaminants like MTBE and other contaminants of concern that can make water unsafe or unpleasant to drink. Releases can also result in fire and explosion hazards, as well as produce long-term health effects.

How many UST releases are there?

Over 418,000 UST releases had been confirmed as of September 30, 2001. Steady cleanup work has progressed for over a decade and more than 268,000 contaminated sites have been cleaned up. While much good work has been and continues to be done, there are about 150,000 UST sites remaining to be cleaned up. You can go to our corrective action measures archive to see periodic reports on the number of releases and cleanup actions taken (data displayed by state, EPA Region, and Indian Country).

With the exception of UST systems located on Indian Lands, states have the primary authority to implement the UST program within their boundaries. For the latest information on the status of the UST programs in the states, click on the applicable state (or Region) below. These links provide state (or Regional) contact information, plus up-to-date data on the UST system universe in each state (or Region) as well as the status of implementing various national program initiatives.



Data obtained from California State Water Resource Control Board as identified on the SWRCB July through September 2002 Quarterly Report

Active petroleum USTs:	42,442
Active hazardous substance USTs:	3,878
Total Active USTs:	46,320
Number of USTs with California approved leak detection systems:	39,896
Percentage of USTs with California approved leak detection systems:	94%
Number of USTs in significant operational compliance with 1998 upgrade requirements:	40,320
Percentage of USTs in significant operational compliance with 1998 upgrade requirements:	95%



State Programs See the rear of this manual for more information

Region 1 - comprised of the states Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

Region 2 - comprised of the states New Jersey, New York, and the Commonwealth of Puerto Rico and the U.S. Virgin Islands.

Region 3 - comprised of the states Delaware, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia.

Region 4 - comprised of the states Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee.

Region 5 - comprised of the states Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.

Region 6 - comprised of the states Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.

Region 7 - comprised of the states Iowa, Kansas, Missouri, and Nebraska.

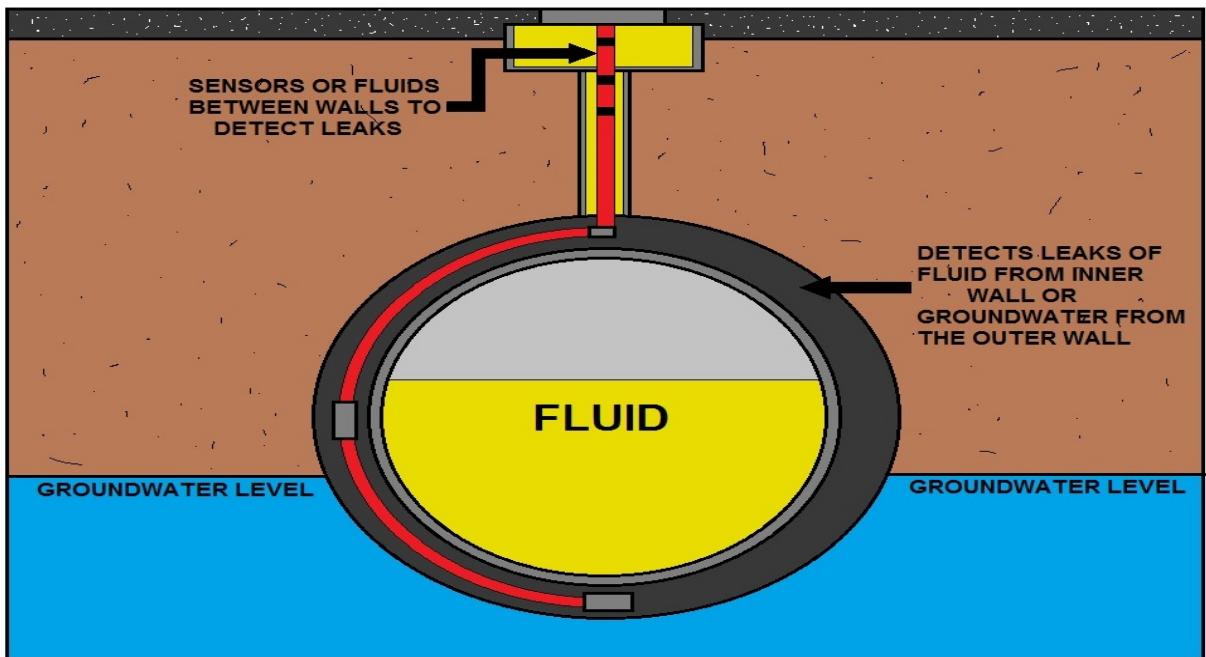
Region 8 - comprised of the states Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming.

Region 9 - comprised of the states Arizona, California, Hawaii, Nevada, and the territories of Guam and American Samoa, and the Commonwealth of the Northern Mariana Islands.

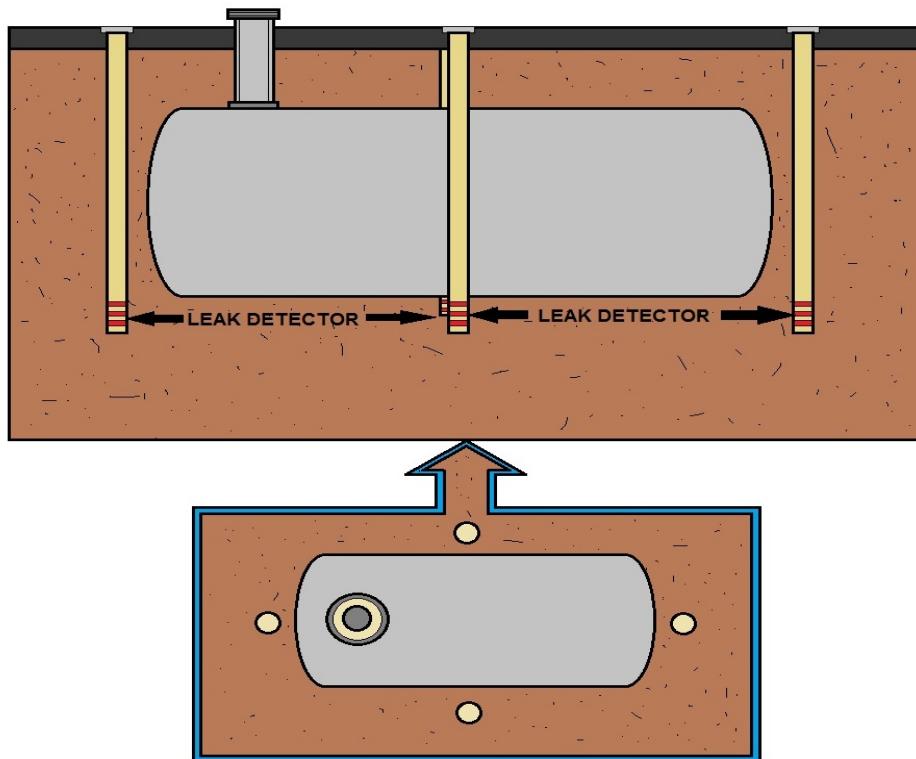
Region 10 - comprised of the states Alaska, Idaho, Oregon, and Washington.



Leak testing Equipment



DOUBLE WALLED TANK



UNDERGROUND TANK LEAK DETECTION SYSTEM INSTALLATION

What Are The Responsibilities Of An UST Owner Or Operator?

All federally regulated USTs must:

- Be registered with the appropriate regulatory authority, and
- Meet leak detection requirements

In addition owners and operators must:

- Meet financial responsibility requirements,
- Perform a site check and corrective action in response to leaks, spills and overfills,
- Follow regulatory rules during installation of new tanks and closure of existing tanks,
- Maintain records as required, and
- Have periodic checks performed on corrosion protection and leak detection systems.

UST owners and operators need to contact their state or local agency that implements the UST program to receive specific information on requirements for their tanks. If the tanks are located in Indian Country, then you should contact the EPA Regional Office.

For more information refer to the Code of Federal Regulations (**CFR**). Located in the rear of this manual.

What Are My Reporting Responsibilities As An Owner/Operator?

You need to report to the regulatory authority on the following occasions:

- When you install an UST, you have to fill out a notification form and submit it to your state or local regulatory agency. This form provides information about your UST, including a certification of correct installation. (You should have already used this form to identify your existing USTs. If you haven't done that yet, be sure you do so now.)
- You must report suspected releases to the regulatory authority. If a release is confirmed, you must also report follow-up actions you plan or have taken to correct the damage caused by your UST.
- You must notify the regulatory authority 30 days before you permanently close your UST.

You should check with your regulatory authority about the particular reporting requirements in your area, including any additional or more stringent requirements than those noted above. A list of state UST contacts is provided for your convenience.

Are all contaminated UST sites equally dangerous or costly to clean up?

Contaminated UST sites vary considerably. Some are very contaminated sites at which groundwater resources have been adversely impacted and may involve years of cleanup activities that can cost over \$1 million.

Other sites may involve relatively minor or no groundwater contamination that may allow cleanup contractors to restore the site more quickly and at less cost.



Some contaminated sites have impacted only surrounding soil and have not involved groundwater—these are generally easier and less expensive to clean up.

The average cleanup cost for a contaminated UST site is about \$125,000.



What cleanup methods are available?

Several methods have been successfully used for over a decade to clean up thousands of sites. Often the specific characteristics of the site (its type of soil, proximity to groundwater, and so on) make it a better candidate for some cleanup methods rather than others.

A contaminated site will need a site characterization (also referred to as "**site assessment**" as the terms are used interchangeably) that can help professionals choose the best cleanup method. Professional cleanup contractors base their decisions on site-specific investigations and with local environmental agency approval. In some cases, state or federal regulators take the lead at a contaminated UST site and will make all the cleanup decisions.

Are there ways to control the cost of these potentially expensive cleanups?

EPA is committed to helping state and local agencies make cleanups faster, more effective, and less expensive.

EPA is working with states to encourage the use of expedited site assessment and alternative cleanup technologies. We are also encouraging state and local agencies to incorporate risk-based decision-making and pay-for-performance agreements into their corrective action programs.



EPA also has an USTfields Initiative that encourages both environmentally effective cleanups and the redevelopment of these areas.

Looking for more information on UST cleanups?

The following topic areas contain links to many resources within EPA and outside the Agency:

- [General Corrective Action Information](http://www.epa.gov/OUST/cat/general.htm) <http://www.epa.gov/OUST/cat/general.htm>
- [Site Characterization/Assessment](http://www.epa.gov/OUST/cat/sitechar.htm) <http://www.epa.gov/OUST/cat/sitechar.htm>
- [Remediation/Cleanup Technologies](http://www.epa.gov/OUST/cat/remedial.htm) <http://www.epa.gov/OUST/cat/remedial.htm>
- [Contaminants of Concern and Cleanup Levels](http://www.epa.gov/OUST/cat/coc.htm)
<http://www.epa.gov/OUST/cat/coc.htm>
- [Monitoring, Sampling, and Analysis](http://www.epa.gov/OUST/cat/monitor.htm) <http://www.epa.gov/OUST/cat/monitor.htm>
- [Site Redevelopment](http://www.epa.gov/OUST/cat/redevel.htm) <http://www.epa.gov/OUST/cat/redevel.htm>
- [Industry, Government, and Private Sector Standards and Other Guidance](http://www.epa.gov/OUST/cat/industry.htm)
<http://www.epa.gov/OUST/cat/industry.htm>
- [ORD Issue Papers](http://www.epa.gov/ada/pubs/issue.html) <http://www.epa.gov/ada/pubs/issue.html>

Leak Detection Methods

There is no one leak detection system that is best for all sites, nor is there a particular type of leak detection that is consistently the least expensive. Each leak detection method has unique characteristics.

For example, vapor detection devices work rapidly and most effectively in porous soils, while liquid detectors are only appropriate for areas with a high water table.

Identifying the best leak detection choice for your UST depends on a number of factors including cost (both initial installation cost and long-term operation and maintenance cost), facility configuration (such as complexity of piping runs and manifolded tanks), groundwater depth, soil type, seasonal rainfall and temperature ranges, availability of experienced installers, and other variables.

You should look around extensively for experienced, professional vendors and installers of leak detection. Ask questions that help you find the most reliable, cost-effective leak detection for your type of facility.

Some possible information sources are: references from fellow UST owners, oil marketers, equipment suppliers, trade journals, trade associations, state and local trade associations (especially those for petroleum marketers and UST owners), and state and local regulatory authorities. OUST maintains a List of State and Territorial UST Programs at this Web site: <http://www.epa.gov/OUST/states/statcon1.htm>

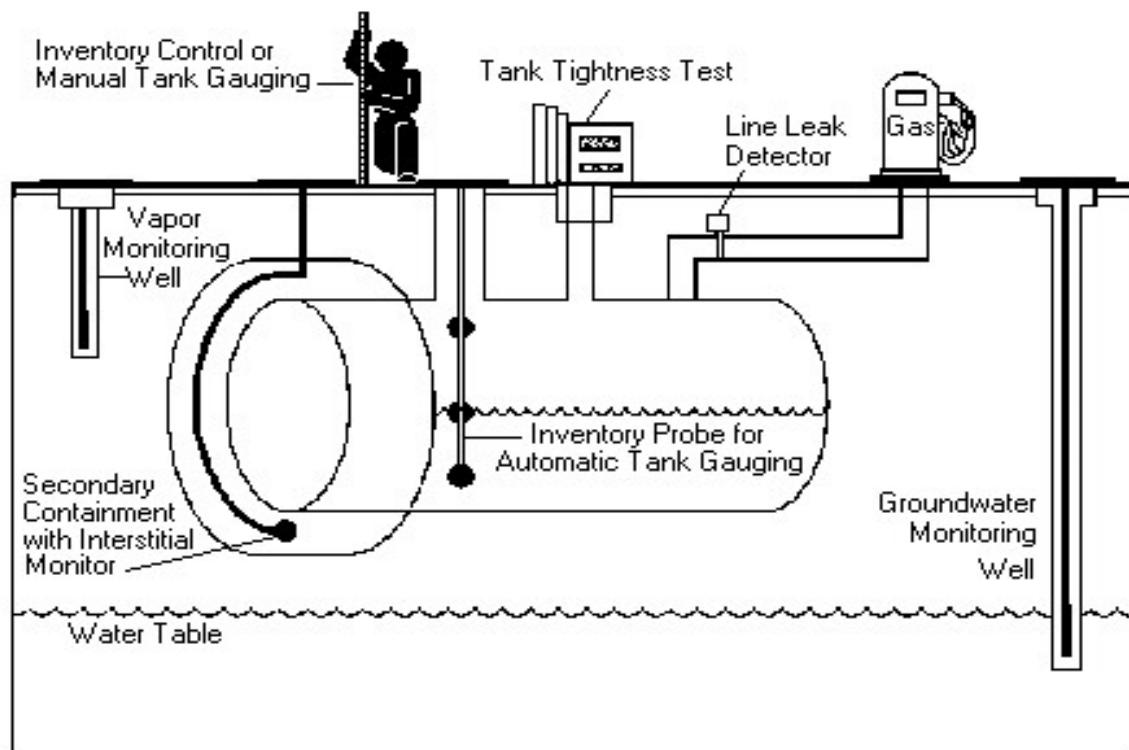
And once you have chosen your leak detection method, you must operate and maintain (**O&M**) it so that it functions correctly week after week. Good O&M of your UST system and its multiple parts can help you avoid leaks.

Monitoring for Vapors in the Soil

How does the leak detection method work?

This method samples vapors in the soil gas surrounding the UST. Leaked petroleum produces vapors that can be detected in the soil gas. The regulations describe several requirements for using this leak detection method.

For example, this method requires using porous soils in the backfill and locating the monitoring devices in these porous soils near the UST system.



Features of vapor monitoring systems are:

- Vapor monitoring senses or measures "**fumes**" from leaked product in the soil around the tank to determine if the tank is leaking.
- Fully automated vapor monitoring systems have permanently installed equipment to continuously or periodically gather and analyze vapor samples and respond to a release with a visual or audible alarm.
- Manually operated vapor monitoring systems range from equipment that immediately analyzes a gathered vapor sample to devices that gather a sample that must be sent to a laboratory for analysis. Monitoring results from manual systems are generally less accurate than those from automated systems. Manual systems must be used at least once a month to monitor a site.
- All vapor monitoring devices should be periodically calibrated according to the manufacturer's instructions to ensure that they are properly responding.
- Before installation, a site assessment is necessary to determine the soil type, groundwater depth and flow direction, and the general geology of the site. This can only be done by a trained professional.
- The number of wells and their placement is very important. Only an experienced contractor can properly design and construct an effective monitoring well system. Vapor monitoring requires the installation of monitoring wells within the tank backfill. A minimum of two wells is recommended for a single tank excavation. Three or more wells are recommended for an excavation with two or more tanks. Some state and local agencies have developed regulations for monitoring well placement.

What are the regulatory requirements?

- The UST backfill must be sand, gravel or another material that will allow the vapors to easily move to the monitor.
- The backfill should be clean enough that previous contamination does not interfere with the detection of a current leak.
- The substance stored in the UST must vaporize easily so that the vapor monitor can detect a release.
- High groundwater, excessive rain, or other sources of moisture must not interfere with the operation of vapor monitoring for more than 30 consecutive days.
- Monitoring wells must be secured and clearly marked.

Will it work at your site?

Before installing a vapor monitoring system, a site assessment must be done to determine whether vapor monitoring is appropriate at the site.

A site assessment usually includes at least a determination of the groundwater level, background contamination, stored product type, and soil type. This assessment can only be done by a trained professional.

Will you be in compliance?

When installed and operated according to the manufacturer's instructions, vapor monitoring meets the federal leak detection requirements for new and existing USTs.

Operation of a vapor monitoring system at least once each month fulfills the requirements for the life of the tank. Vapor monitoring can also be installed to detect leaks from piping.

Repairing, Repainting and Testing Section



Entering a partially exposed UST using proper confined space entry techniques.



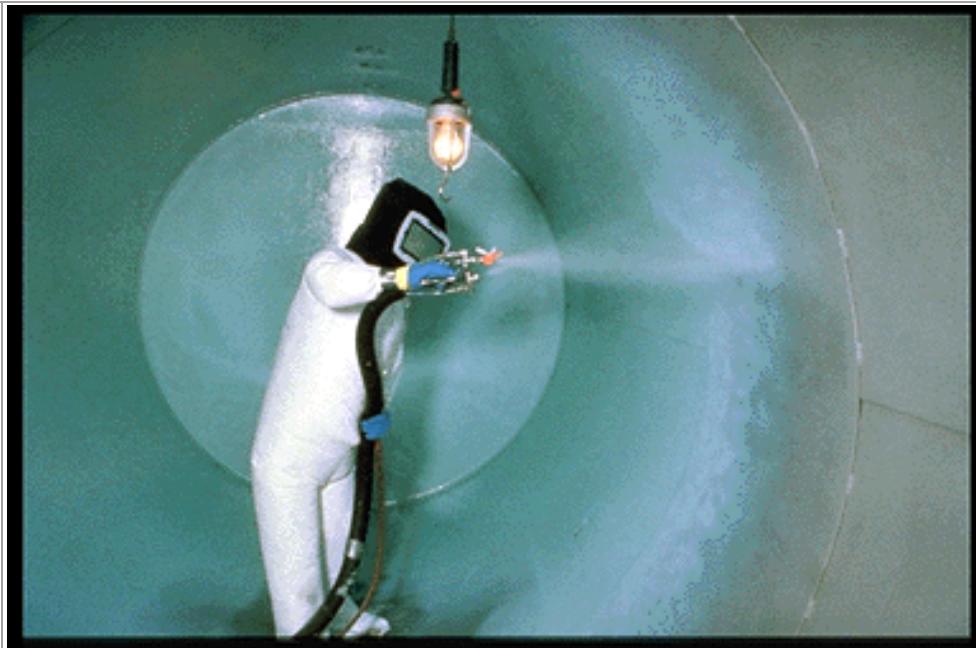
Applying the coating to the inside of a properly prepared UST.



Cleaning the inside of an UST.



Sandblasting
the inside of
an UST.



Applying
non-
corrodible
lining on the
inside of an
UST.

Definition of Confined Spaces Requiring an Entry Permit

A Confined space:

1. Is large enough or so configured that an employee can bodily enter and perform work.
2. Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).
3. Is not designed for continuous employee occupancy.



Checking for
"holidays" in
a recently
applied tank
lining.

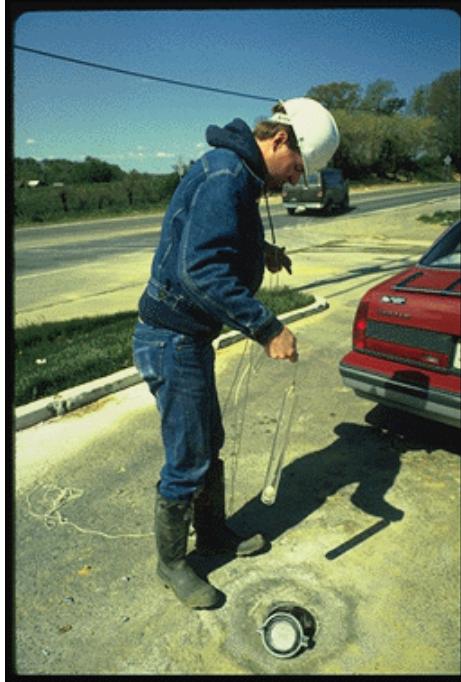


Testing a
recently
applied tank
lining for
uniformity in
thickness.

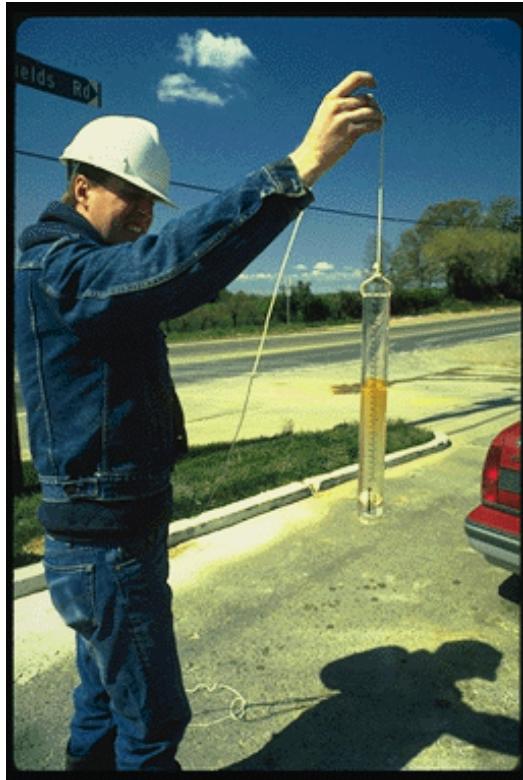


Testing
Hardness of
recently
applied tank
lining.

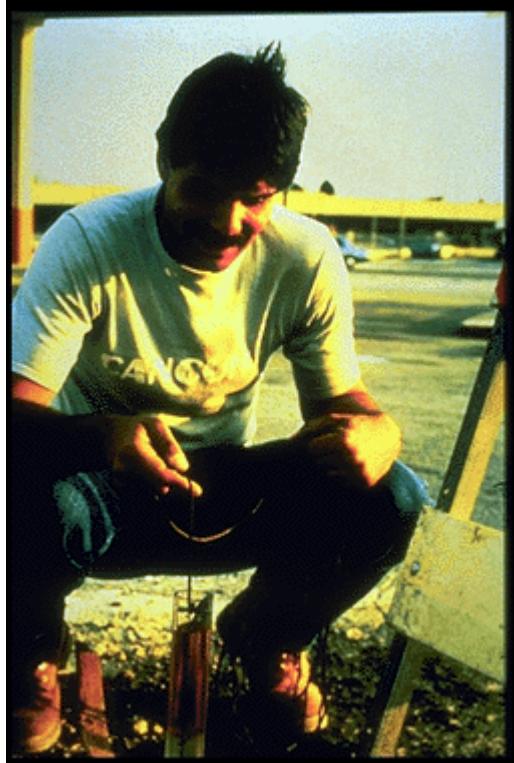
Tank Testing and Sampling Section



Preparing to collect a sample of gasoline from a groundwater monitoring well.



Collecting a sample of gasoline from a monitoring well using a clear bailer.



Collecting a sample of gasoline from a groundwater monitoring well.



Sludge and Gasoline



Free-phase oil released into the environment.



Air-stripping tower for treatment of contaminated groundwater.



Twin air-stripping
towers for
treating
contaminated
groundwater.



A complex
above-
groundwater
treatment system.



Unsettled and
unstable gasoline
pumps



You can see the galvanic destruction in various stages on this gas tank.



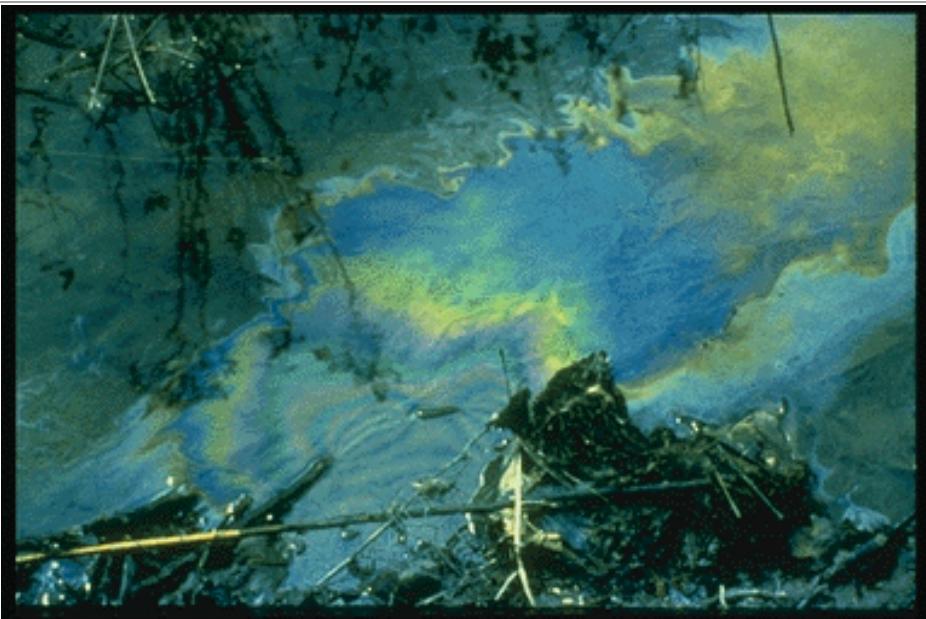
The man does not seem to think that the leaking gas poses a treat.



Vacuum truck extracting fluids from a monitoring well.



An absorbent boom on a surface water body to prevent migration of oil.



The iridescent sheen caused by oil on water.

Photographs courtesy of the US EPA

Tank Closure Section

Tank closure is one way to help protect human health and the environment, particularly groundwater, from the threats posed by many older underground storage tanks. You can close your UST **temporarily** or **permanently**. In either case, tanks must be closed properly.

Closing Temporarily

You may temporarily close your UST for up to 12 months by following these requirements for temporary closure:

- Continue to monitor for leaks by maintaining the UST's leak detection. (If your UST is empty, you do not need to maintain leak detection.) Also, continue to monitor and maintain any corrosion protection systems. If a release is discovered, quickly stop the release, notify your regulatory authority, and take appropriate action to clean up the site.
- If the UST remains temporarily closed for more than 3 months, leave vent lines open, but cap and secure all other lines, pumps, manways, and ancillary equipment.

After 12 months of temporary closure, you have three options:

1. You must permanently close your UST if it doesn't meet the applicable requirements for new or upgraded USTs (except for spill and overfill).
2. You can ask your regulatory authority for an extension beyond 12 months, if you provide an assessment that determines whether contamination is present at your site.
3. Your UST can remain temporarily closed without needing an extension granted by the regulatory authority if the UST meets the applicable requirements for new or upgraded USTs (except for spill and overfill) and the requirements noted above for temporary closure.

Closing Permanently

If you decide to close your UST permanently, follow these requirements for permanent closure:

- Notify the regulatory authority at least 30 days before you close your UST.
- Determine if contamination from your UST is present in the surrounding environment. If there is contamination, you may have to take corrective action. For at least 3 years, keep a record of the actions you take to determine if contamination is present at the site (or you can mail this record to your regulatory authority).
- Either remove the UST from the ground or leave it in the ground. In both cases, the tank must be emptied and cleaned by removing all liquids, dangerous vapor levels, and accumulated sludge. These potentially very hazardous actions need to be carried out carefully by trained professionals who follow standard safety practices. If you leave the UST in the ground, have it filled with a harmless, chemically inactive solid, like sand.

Safe Closure Is A Must

People who do not follow standard safety practices are killed or injured every year while closing or removing tanks. For a safe closure, you need qualified professionals who will use standard safety practices.

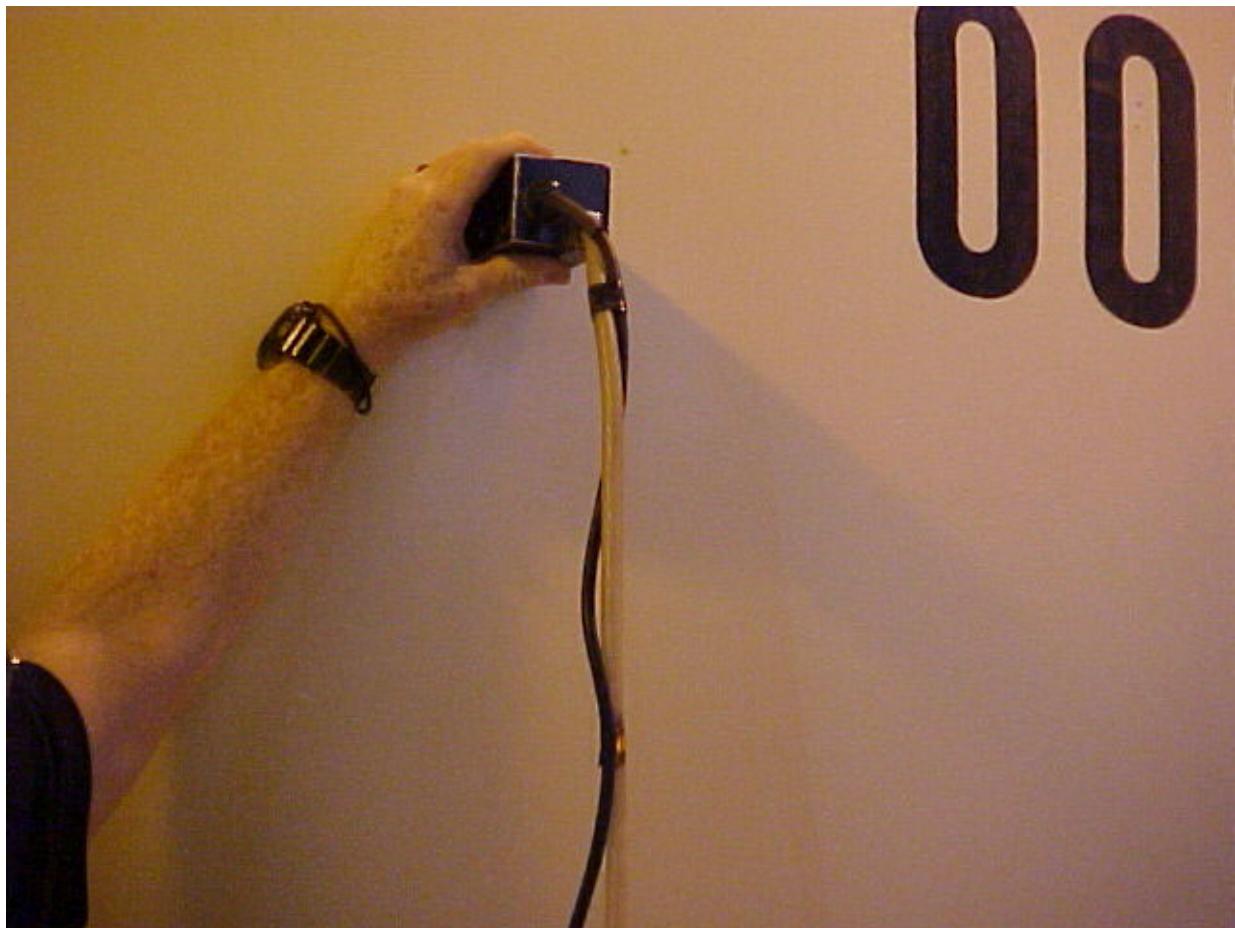
For more information on standard safety practices, UST owners and closure contractors should refer to "**Closure of Underground Petroleum Storage Tanks**," API Recommended Practice 1604 (1996), which is available for about \$22 from the American Petroleum

Institute, 1220 L Street, NW, Washington, DC 20005, or call (202) 682-8000 for assistance. You can also visit API's Web site. <http://www.api.org/>

A video and companion booklet called "**Tank Closure Without Tears: An Inspector's Safety Guide**" is available for \$35 from the New England Interstate Environmental Training Center, **ATTN: VIDEOS**, 2 Fort Road, South Portland, ME 04106, or call (207) 767-2539 for assistance.

Want More Information?

You can contact EPA's RCRA, Superfund & EPCRA Call Center at their toll-free number 800-424-9346. For the hearing impaired, the number is TDD 800-553-7672. The Call Center is staffed from Monday through Friday, 9:00 a.m. to 5:00 p.m. EST. Note that the Call Center is closed on all Federal holidays. At any time you can visit the Call Center Web site.



Leak Detection Equipment

Remediation

State Petroleum Release Section

The goal of your department of environmental quality's Petroleum Release Section is to protect human health and the environment from petroleum and hazardous substance releases from storage tank systems, both underground and above ground. Meeting this goal requires definition of the extent and magnitude of the contamination and implementation of the necessary corrective action. Petroleum Release Section staff or equivalent program includes geologists, hydrogeologists, engineers, and environmental scientists who direct and oversee cleanup of petroleum releases. They are available as technical resources for tank owners and operators, local government officials, and the public to help respond to questions or concerns about tank leaks.

Petroleum and hazardous substance releases can contaminate soil, groundwater and surface water, and may threaten or impact public and private drinking water supplies. In addition, harmful and potentially explosive hydrocarbon vapors can accumulate in confined spaces such as basements, crawl spaces and utility corridors. If a petroleum release occurs, the Petroleum Release Section assists and oversees the efforts of the facility owner or operator in assessing the potential threat to human health and the environment, and provides assistance with corrective action.

The section works closely with the Petroleum Tank Release Compensation Board (**PTRCB**) or equivalent funding agency which provides financial reimbursement of eligible corrective action cleanup costs to tank owners and operators.

The Petroleum Release Section also administers the federal Leaking Underground Storage Tank (**LUST**) Trust Fund Program. This program conducts investigation and remediation activities at release sites that threaten human health and the environment where: (1) the release source is unknown or (2) the tank owner is insolvent or recalcitrant.

The LUST Trust Program or equivalent program will conduct emergency response activities to mitigate immediate human health hazards such as petroleum-impacted drinking water supplies, and buildings impacted with petroleum vapors.

The following functions are administered by the Petroleum Release Section:

- receives and investigates reports of environmental storage tank releases;
- assists local fire and health authorities in responding to the immediate threats resulting from contaminated drinking water supplies and explosive vapors created by releases;
- requires, approves and oversees release investigation and remediation activities conducted by storage tank owners and operators;
- reviews and recommends PTRCB reimbursement claims for completed investigation and remediation activities;
- conducts final release site closure determinations at the conclusion of the remediation;
- in the event the source of the release cannot be identified or the owner is recalcitrant, the LUST Trust Program utilizes federal LUST Trust funding to respond, investigate and remediate any health or environmental threats posed by the release.

Tank Installation Section

NOTE: Photographs are for illustrative purposes only. EPA does not endorse one type of tank or a specific manufacturer over another and no official endorsement should be inferred.



An
impermeable
excavation
liner.



Bonding the
seams of an
excavation
liner.



Installing a
steel UST.



Installing a
steel UST.



Installing a
steel UST.



Fiberglass-
reinforced
plastic (FRP)
tanks being
offloaded from
a transport
truck.



Steel tanks and piping await backfilling.



Lowering a fiberglass tank into an excavation.



Large steel tanks being installed.



A steel tank installed in a lined excavation.



Backfilling FRP tanks.



A spill bucket on a newly installed steel UST.



Inspecting the depth and grade of an UST excavation.



Backfilling new FRP tanks.



Installing a FRP tank.



Open manway showing catch basin and pressurize piping (without line leak detector installed [yet?]).



New piping and overfill protection at a new installation.

Photographs courtesy of the US EPA

Hazardous Substance USTs Section

Underground storage tank (**UST**) systems that store substances identified as being hazardous under the Comprehensive Environmental Response, Compensation, and Liability Act (**CERCLA**) are subject to the same requirements as petroleum UST systems except that hazardous substance tanks must have secondary containment. Hazardous wastes are already regulated under Subtitle C of the Resource Conservation and Recovery Act (RCRA and therefore are not covered by the UST regulations see 40 CFR Part 260 and see 40 CFR Part 270 for the hazardous waste regulations). See TLC's courses, RCRA and HAZWOPER.

Currently about 1,200 substances (excluding radionuclides) are identified as hazardous under CERCLA (see 40 CFR 302, section 302.4).

Additional information on the CERCLA hazardous substances is available on the CERCLA Web site (see <http://www.epa.gov/superfund/programs/er/hazsubs/cercsubs.htm>) or from EPA's RCRA, Superfund, and EPCRA Call Center at 800-424-9346. The Call Center also maintains a Web site at <http://www.epa.gov/epaoswer/hotline/index.htm>.

What Requirements Apply To Hazardous Substance USTs?

Hazardous substance USTs have to meet the same requirements for petroleum USTs concerning correct installation, spill, overfill and corrosion protection, corrective action, and closure.

In addition, hazardous substance USTs must have secondary containment and interstitial monitoring for leak detection, as described below.

What Is Secondary Containment?

All hazardous substance USTs must have "**secondary containment**." A single-walled tank is the first or "**primary**" containment. Using only primary containment, a leak can escape into the environment.

But by enclosing an UST within a second wall, leaks can be contained and detected quickly before harming the environment. There are several ways to construct secondary containment:

- Placing one tank inside another tank or one pipe inside another pipe (making them double-walled systems).
- Placing the UST system inside a concrete vault.
- Lining the excavation zone around the UST system with a liner that cannot be penetrated by the hazardous substance.

What Is Interstitial Monitoring?

The hazardous substance UST must have a leak detection system that can indicate the presence of a leak in the confined space between the first and the second wall.

Several devices are available to monitor this confined "**interstitial**" space. ("**Interstitial**" simply means "**between the walls**.") The UST regulations describe these various methods and the requirements for their proper use.



You can apply for an exception, called a variance, from the requirement for secondary containment and interstitial monitoring.

To obtain a variance you must demonstrate to the regulatory authority that your alternative leak detection method will work effectively by providing detailed studies of your site, proposed leak detection method, and available methods for corrective action.

What About Leak Detection?

All UST systems are required to have leak detection, and the method must be properly operated and maintained.



What About Spill, Overfill, and Corrosion Protection?

All UST systems are required to have spill, overfill, and corrosion protection.

What If You Have A Hazardous Substance Release?

Whether you have a confirmed release, or even if you suspect that you might have a release, you must follow the basic actions described below:

- You must take necessary and appropriate steps to stop further release and contain what has been released to ensure that there are no immediate threats to the safety and health of those nearby.
- You must immediately report hazardous substance spills or overfills that meet or exceed their "reportable quantities" to the National Response Center at 800 424-8802 or 202 267-2675.
- You must also report hazardous substance spills or overfills that meet or exceed their "reportable quantities" to the regulatory authority within 24 hours. However, if these spills or overfills are smaller than their "**reportable quantities**" and are immediately contained and cleaned up, they do not need to be reported. You can get information on the "**reportable quantities**" by calling the RCRA, Superfund, and EPCRA Call Center at 800-424-9346.
- Based on the information you have provided, the regulatory authority will decide if you must take further action at your site. You may need to develop and submit a Corrective Action Plan that shows how you will meet requirements established for your site by the regulatory authority. Make sure you implement the corrective action steps approved by the regulatory authority for your site.

Records and Reporting Section

You will have to keep records that can be provided to an inspector during an on-site visit that proves your facility meets certain requirements. These records must be kept long enough to show your facility's recent compliance status in four major areas:

- You will have to keep records of leak detection performance and maintenance:
 - The last year's monitoring results and the most recent tightness test.
 - Copies of performance claims provided by leak detection manufacturers.
 - Records of recent maintenance, repair, and calibration of on-site leak detection equipment.
- You will have to keep records showing the required inspections and tests of your corrosion protection system.
- You must keep records showing that a repaired or upgraded UST system was properly repaired or upgraded.
- For at least 3 years after closing an UST, you must keep records of the site assessment results required for permanent closure. (These results show what impact your UST has had on the surrounding area.)
- You must keep records that document your financial responsibility, as explained in EPA's booklet, **Dollars And Sense**. <http://www.epa.gov/OUST/pubs/dollars>

You should check with your regulatory authority <http://www.epa.gov/OUST/faqs/call1st.htm> about the particular recordkeeping requirements in your area.

Generally, you should follow this useful rule of thumb for recordkeeping: When in doubt, keep it.

WHAT DO YOU NEED TO REPORT?

You need to report to the regulatory authority on the following occasions:

- When you install an UST, you have to fill out a notification form <http://www.epa.gov/OUST/fedlaws/ustformand> submit it to your state or local agency. This form provides information about your UST, including a certification of correct installation. (You should have already used this form to identify your existing USTs. If you haven't done that yet, be sure you do so now.)
- You must report suspected releases to the regulatory authority. If a release is confirmed, you must also report follow-up actions you plan or have taken to correct the damage caused by your UST.
- You must notify the regulatory authority 30 days before you permanently close your UST.

You should check with your regulatory authority about the particular reporting requirements in your area, including any additional or more stringent requirements than those noted above.

You should check with your regulatory authority about the particular recordkeeping requirements in your area. Generally, you should follow this useful rule of thumb for recordkeeping: **When in doubt, keep it.** The preceding discussion is summarized from the regulatory language in 40 CFR Part 280.34 as published in the Federal Register, Vol. 53, No. 185, Friday, September 23, 1988. This text is presented below for informational purposes only--for legal issues, you should obtain a printed copy from the Government Printing Office.

40 CFR 280.34 Reporting and Recordkeeping

Owners and operators of UST systems must cooperate fully with inspections, monitoring and testing conducted by the implementing agency, as well as requests for document submission, testing, and monitoring by the owner or operator pursuant to section 9005 of Subtitle I of the Resource Conservation and Recovery Act, as amended.

- (a) **Reporting.** Owners and operators must submit the following information to the implementing agency:
 - (1) Notification for all UST systems (40 CFR 280.22), which includes certification of installation for new UST systems (40 CFR 280.20(e)),
 - (2) Reports of all releases including suspected releases (40 CFR 280.50), spills and overfills (40 CFR 280.53), and confirmed releases (40 CFR 280.61);
 - (3) Corrective actions planned or taken including initial abatement measures (40 CFR 280.62), initial site characterization (40 CFR 280.63), free product removal (40 CFR 280.64), investigation of soil and groundwater cleanup (40 CFR 280.65), and corrective action plan (40 CFR 280.66); and
 - (4) A notification before permanent closure or change-in-service (40 CFR 280.71).
- (b) **Recordkeeping.** Owners and operators must maintain the following information:
 - (1) A corrosion expert's analysis of site corrosion potential if corrosion protection equipment is not used (40 CFR 280.20(a)(4); 40 CFR 280.20(b)(3)).
 - (2) Documentation of operation of corrosion protection equipment (40 CFR 280.31);
 - (3) Documentation of UST system repairs (40 CFR 280.33(f));
 - (4) Recent compliance with release detection requirements (40 CFR 280.45); and
 - (5) Results of the site investigation conducted at permanent closure (40 CFR 280.74).
- (c) **Availability and Maintenance of Records.** Owners and operators must keep the records required either:
 - (1) At the UST site and immediately available for inspection by the implementing agency; or
 - (2) At a readily available alternative site and be provided for inspection to the implementing agency upon request.
 - (3) In the case of permanent closure records required under 40 CFR 280.74, owners and operators are also provided with the additional alternative of mailing closure records to the implementing agency if they cannot be kept at the site or an alternative site as indicated above.

Note: The recordkeeping and reporting requirements in this section have been approved by the Office of Management and Budget and have been assigned OMB Control No. 2050-0068.

Safety Section

Excavation & Trenching

This section outlines procedures and guidelines for the protection of employees working in and around excavations and trenches. This section requires compliance with OSHA Standards described in Subpart P (**CFR 1926.650**) for the construction industry.

Safety compliance is mandatory to ensure employee protection when working in or around excavations.

The competent person(s) must be trained in accordance with the OSHA Excavation Standard, and all other programs that may apply (examples Hazard Communication, Confined Space, and Respiratory Protection), and must demonstrate a thorough understanding and knowledge of the programs and the hazards associated.

All other employees working in and around the excavation must be trained in the recognition of hazards associated with trenching and excavating.

REFERENCES

- 29 CFR 1926.650, Subpart P - Excavations
- Excavation Equipment Manufacturer Safety Procedures

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FEBRUARY 28, 1999

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VALLEY & STATE

AJ ditch cave-in kills teen

Wall collapses on boy working in trench

By Rachel Ochoa and Laura Trujillo
The Arizona Republic

A 17-year-old Chandler boy who was shoveling debris at the bottom of a sewer ditch was killed Saturday when a huge slab of dirt and rocks collapsed onto him, authorities said.

Joshua Holt Castro, a Dobson High School football player, was working without shoring or support in the 15- to 25-foot deep trench at an Apache Junction condominium complex when the avalanche buried him.

The Apache Junction Police Department is investigating the case and will look into the past performance of Galloway Construction, where Castro worked a part-time weekend job.

The Apache Junction Sewer District contracted with the construction company to hook up a the condos to city sewer lines, according to Lt. Brian Duncan, a police spokesman.

Lost Dutchman Blvd.
Ironwood Dr.
Apache Trail
Broadway Ave.
Idaho Rd.
Site of accident
Superstition Blvd.
Tontohawk Rd.
Mesa
APACHE JUNCTION

The Arizona Republic

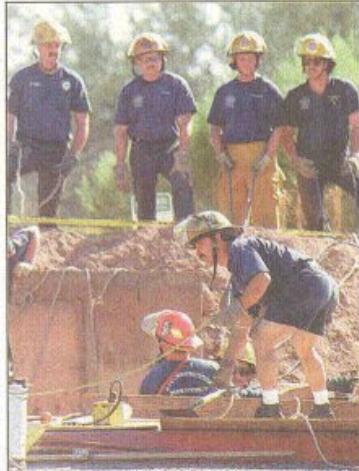
"It could have been prevented if proper shoring had been there and had competent personnel been on the scene," said Brian Wyatt, a spokesman for the Apache Junction Fire Department. He added that shoring is required while digging trenches.

Patrick Galloway, who owns the construction company and had just left the site before Castro was killed, could not be reached Saturday night. He spent much of Saturday talking with investigators.

OSHA also is investigating the death, which occurred just after noon, but officials wouldn't discuss the case Saturday.

It took Apache Junction and Mesa firefighters more than nine hours to retrieve the boy's body, buried under heavy rock and dirt just south of the Quail Creek Condominium Complex on North Idaho Road.

The only witness to the death was Galloway's 10-year-old son, Riley. Galloway and his 17-year-



Firefighters work to remove the body of 17-year-old Joshua Holt Castro, who was killed Saturday afternoon when the trench he was in collapsed, burying him under earth and rocks.

Randy Reid/The Arizona Republic

— Please see CAVE-IN, Page B3



Trench Shield

Hazards

One of the reasons OSHA requires a competent person on-site during excavation & trenching are the numerous potential hazardous that may be encountered or created. Hazards include:

- ✓ Electrocution
- ✓ Gas Explosion
- ✓ Entrapment
- ✓ Struck by equipment
- ✓ Suffocation

Hazard Controls

Before any work is performed and before any employees enter the excavation, a number of items must be checked and insured:

- Before any excavation, underground installations must be determined. This can be accomplished by either contacting the local utility companies or the local "**one-call**" center for the area. All underground utility locations must be documented on the proper forms. All overhead hazards (**surface encumbrances**) that create a hazard to employees must be removed or supported to eliminate the hazard.
- If the excavation is to be over 20 feet deep, it must be designed by a registered professional engineer who is registered in the state where work will be performed.
- Adequate protective systems will be utilized to protect employees. This can be accomplished through sloping, shoring, or shielding.
- The worksite must be analyzed in order to design adequate protection systems and prevent cave-ins. There must also be an excavation safety plan developed to protect employees.
- Workers must be supplied with and wear any personal protective equipment deemed necessary to assure their protection.
- All spoil piles will be stored a minimum of two (2) feet from the sides of the excavation. The spoil pile must not block the safe means of egress.
- If a trench or excavation is 4 feet or deeper, stairways, ramps, or ladders will be used as a safe means of access and egress. For trenches, the employee must not have to travel any more than 25 feet of lateral travel to reach the stairway, ramp, or ladder.

- No employee will work in an excavation where water is accumulating unless adequate measures are used to protect the employees.
- A competent person will inspect all excavations and trenches daily, prior to employee exposure or entry, and after any rainfall, soil change, or any other time needed during the shift. The competent person must take prompt measures to eliminate any and all hazards.
- Excavations and trenches 4 feet or deeper that have the potential for toxic substances or hazardous atmospheres will be tested at least daily. If the atmosphere is inadequate, protective systems will be utilized.
- If work is in or around traffic, employees must be supplied with and wear orange reflective vests. Signs and barricades must be utilized to ensure the safety of employees, vehicular traffic, and pedestrians.

Competent Person Responsibilities

The OSHA Standards require that the competent person must be capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees, and have authorization to take prompt corrective measures to eliminate them and, if necessary, to stop the work.

A competent person is required to:

- Have a complete understanding of the applicable safety standards and any other data provided.
- Assure the proper locations of underground installations or utilities, and that the proper utility companies have been contacted.
- Conduct soil classification tests and reclassify soil after any condition changes.
- Determine adequate protective systems (sloping, shoring, or shielding systems) for employee protection.
- Conduct all air monitoring for potential hazardous atmospheres.
- Conduct daily and periodic inspections of excavations and trenches.
- Approve design of structural ramps, if used. .

Soil Classification and Identification

The OSHA Standards define soil classifications within the Simplified Soil Classification Systems, which consist of four categories: Stable rock, Type A, Type B, and Type C. Stability is greatest in stable rock and decreases through Type A and B to Type C, which is the least stable.

Appendix A of the Standard provides soil mechanics terms and types of field tests used to determine soil classifications.

Stable rock is defined as natural solid mineral matter that can be excavated with vertical sides and remain intact while exposed.

Type A soil is defined as:

- Cohesive soils with an unconfined compressive strength of 1.5 tons per square foot (**TSF**) or greater.
- Cemented soils like caliche and hardpan are considered Type A.

Soil is NOT Type A if:

- It is fissured.
- The soil is subject to vibration from heavy traffic, pile driving or similar effects.
- The soil has been previously disturbed.
- The material is subject to other factors that would require it to be classified as a less stable material.
- The exclusions for Type A most generally eliminate it from most construction situations.

Type B soil is defined as:

- Cohesive soil with an unconfined compressive strength greater than .5 TSF, but less than 1.5 TSF.
- Granular cohesion-less soil including angular gravel, silt, silt loam, and sandy loam.
- The soil has been previously disturbed except that soil classified as Type C soil.
- Soil that meets the unconfined compressive strength requirements of Type A soil, but is fissured or subject to vibration.
- Dry rock that is unstable.

Type C soil is defined as:

- Cohesive soil with an unconfined compressive strength of .5 TSF or less.
- Granular soils including gravel, sand and loamy sand.
- Submerged soil or soil from which water is freely seeping.
- Submerged rock that is not stable.

Soil Test & Identification

The competent person will classify the soil type in accordance with the definitions in Appendix A based on at least one visual and one manual analysis.

These tests should be run on freshly excavated samples from the excavation and are designed to determine stability based on a number of criteria: the cohesiveness, the presence of fissures, the presence and amount of water, the unconfined compressive strength, the duration of exposure, undermining, and the presence of layering, prior excavation and vibration.

The cohesion tests are based on methods to determine the presence of clay. Clay, silt, and sand are size classifications, with clay being the smallest sized particles, silt intermediate and sand the largest. Clay minerals exhibit good cohesion and plasticity (can be molded). Sand exhibits no elasticity and virtually no cohesion unless surface wetting is present. The degree of cohesiveness and plasticity depend on the amounts of all three types and water.

When examining the soil, three questions must be asked: Is the sample granular or cohesive? Fissured or non-fissured? What is the unconfined compressive strength measured in TSF?

Methods of testing soils:

- Visual test: If the excavated soil is in clumps, it is cohesive. If it breaks up easily, not staying in clumps, it is granular.
- Wet manual test: Wet your fingers and work the soil between them. Clay is a slick paste when wet, meaning it is cohesive. If the clump falls apart in grains, it is granular.
- Dry strength test: Try to crumble the sample in your hands with your fingers. If it crumbles into grains, it is granular. Clay will not crumble into grains, only into smaller chunks.
- Pocket penetrometer test: This instrument is most accurate when soil is nearly saturated. This instrument will give unconfined compressive strength in tons per square foot. The spring-operated device uses a piston that is pushed into a coil up to a calibration groove. An indicator sleeve marks and retains the reading until it is read. The reading is calibrated in tons per square foot (**TSF**) or kilograms per cubic centimeter.



Every excavation requires a ladder

Thumb penetration test: The competent person attempts to penetrate a fresh sample with thumb pressure. If the sample can be dented, but penetrated only with great effort, it is Type A. If it can be penetrated several inches and molded by light pressure, it is Type C. Type B can be penetrated with effort and molded.

Shearvane: Measures the approximate shear strength of saturated cohesive soils. The blades of the vane are pressed into a flat section of undisturbed soil, and the knob is turned slowly until soil failure. The dial is read directly when using the standard vane. The results will be in tons per square foot or kilograms per cubic centimeter.

The competent person will perform several tests of the excavation to obtain consistent, supporting data along its depth and length. The soil is subject to change several times within the scope of an excavation and the moisture content will vary with weather and job conditions. The competent person must also determine the level of protection based on what conditions exist at the time of the test, and allow for changing conditions.

Excavation Protection Systems

The three basic protective systems for excavations and trenches are sloping and benching systems, shoring, and shields.

The protective systems shall have the capacity to resist without failure all loads that are intended or could reasonably be expected to be applied to or transmitted to the system. Every employee in an excavation shall be protected from cave-ins by an adequate protective system.

- Exceptions to using protective system:
- Excavations are made entirely in stable rock
- Excavations are less than 5 feet deep and declared safe by a competent person

SLOPING AND BENCHING SYSTEMS

There are four options for sloping:

- Slope to the angle required by the Standard for Type C, which is the most unstable soil type.
- The table provided in Appendix B of the Standard may be used to determine the maximum allowable angle (after determining the soil type).
- Tabulated data prepared by a registered professional engineer can be utilized.
- A registered professional engineer can design a sloping plan for a specific job.

Sloping and benching systems for excavations five (5) to twenty (20) feet in depth must be constructed under the instruction of a designated competent person.

Sloping and benching systems for excavations greater than twenty (20) feet must be designed and stamped by a registered professional engineer.

Sloping and benching specifications can be found in Appendix B of the OSHA Standard (Subpart P).

One-Call Center or Bluestakes Section

You are required to locate or call for proper buried utility locations before you dig or excavate. You will usually need a 48-hour notice before you excavate. Please check your local One-Call system.



Red-Electricity, Yellow-Gas, Blue-Water



Orange telephone & Fiber Optics

One Call Program

According to federal safety statistics, damage from unauthorized digging is the major cause of natural gas pipeline failures. To prevent excavation damage to all utilities, including pipelines, all 50 states have instituted "**One Call**" Programs. The programs provide telephone numbers for excavation contractors to call before excavation begins.

The One Call operator will notify a pipeline company of any planned excavation in the vicinity of its pipeline so that the company can flag the location of the pipeline and assign personnel to be present during excavation, if necessary.

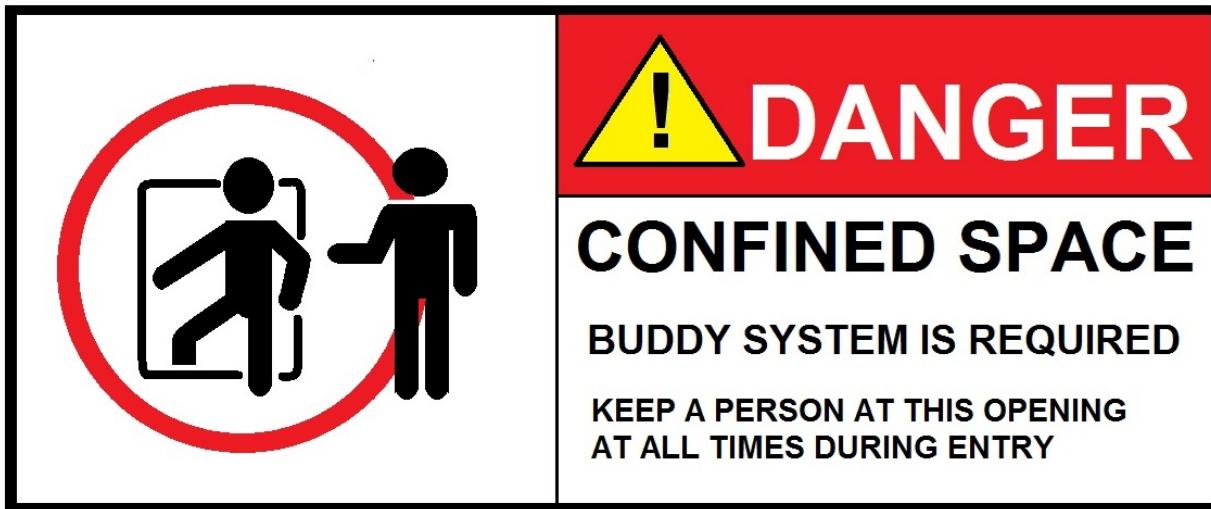
In a related effort, a joint government-industry team has developed a public education program entitled "**Dig Safely**". The team involved representatives from the U.S. Department of Transportation, gas and liquid pipeline companies, distribution companies, excavators, the insurance industry, one-call systems and the telecommunications industry. This campaign provides information to the general public concerning underground utilities and the danger of unknowingly digging into buried lines and cables.

The program has posters, brochures and other printed materials available for use by interested organizations. For more information, contact www.digsafely.com.



Buried Telephone Cables

Confined Space Section



EXAMPLE OF A CONFINED SPACE ENTRY DANGER SIGN

Definition of Confined Spaces Requiring an Entry Permit

A Confined space:

Is large enough or so configured that an employee can bodily enter and perform work.

Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).

Is not designed for continuous employee occupancy.

Confined Spaces are

- large enough to allow entry of any body part, and
- limited or restricted entry or exit, and
- not designed for continuous employee occupancy

Permit Required Confined Spaces are confined spaces that have any of the following

- potential hazardous atmosphere
- material inside that may engulf or trap you
- internal design that could trap or asphyxiate you
- any other serious safety or health hazard

Entry Permits are required before you enter any "Permit Required Confined Space"

Hazards include

- Fire & Explosion
- Engulfment
- Asphyxiation
- Entrapment
- Slips & Falls
- Electric Shock
- Noise & Vibration
- Chemical Exposure
- Toxic Atmospheres
- Thermal / Chemical Burns

Engineering Controls

- Ventilation
- Locked Access
- Lighting

Administrative Controls

- Controlled Access
- Hazard Assessments
- Entry Permits & Procedures
- Signs & Lockout Tagout
- Training

Smart Safety Rules

Know what you are getting into

Know how to get out in an emergency.

Know the hazards & how they are controlled

Only authorized & trained person may enter a Confined Space or act as an attendant.

No smoking in Confined Space or near entrance or exit area

Attendant must be present at all times

Constant visual or voice communication must be maintained between the attendant and entrants

No bottom or side entry will be made or work conducted below the level any hanging material or material which could cause engulfment.

Air and oxygen Monitoring is required before entering a Permit-Required Confined Space

Ventilation & oxygen monitoring is required when welding is performed

Confined Space Defined

Purpose

The Confined Space Entry Program is provided to protect authorized employees that will enter confined spaces and may be exposed to hazardous atmospheres, engulfment in materials, conditions which may trap or asphyxiate due to converging or sloping walls, or contains any other safety or health hazards. Reference: OSHA-Permit-Required Confined Spaces (29 CFR 1910.146).

Scope

You are required to recognize the dangers and hazards associated with Confined Spaces and this program is designed to assist you in the safety of and compliance with the OSHA standards associated with such.

Most communities will utilize the Fire Department for all rescues and additional assistance dealing with confined spaces, understanding that most Fire Department operations utilize additional in house SOG's pertaining to such operations.

Definitions

Confined space:

- ✓ Is large enough or so configured that an employee can bodily enter and perform work.
- ✓ Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).
- ✓ Is not designed for continuous employee occupancy.

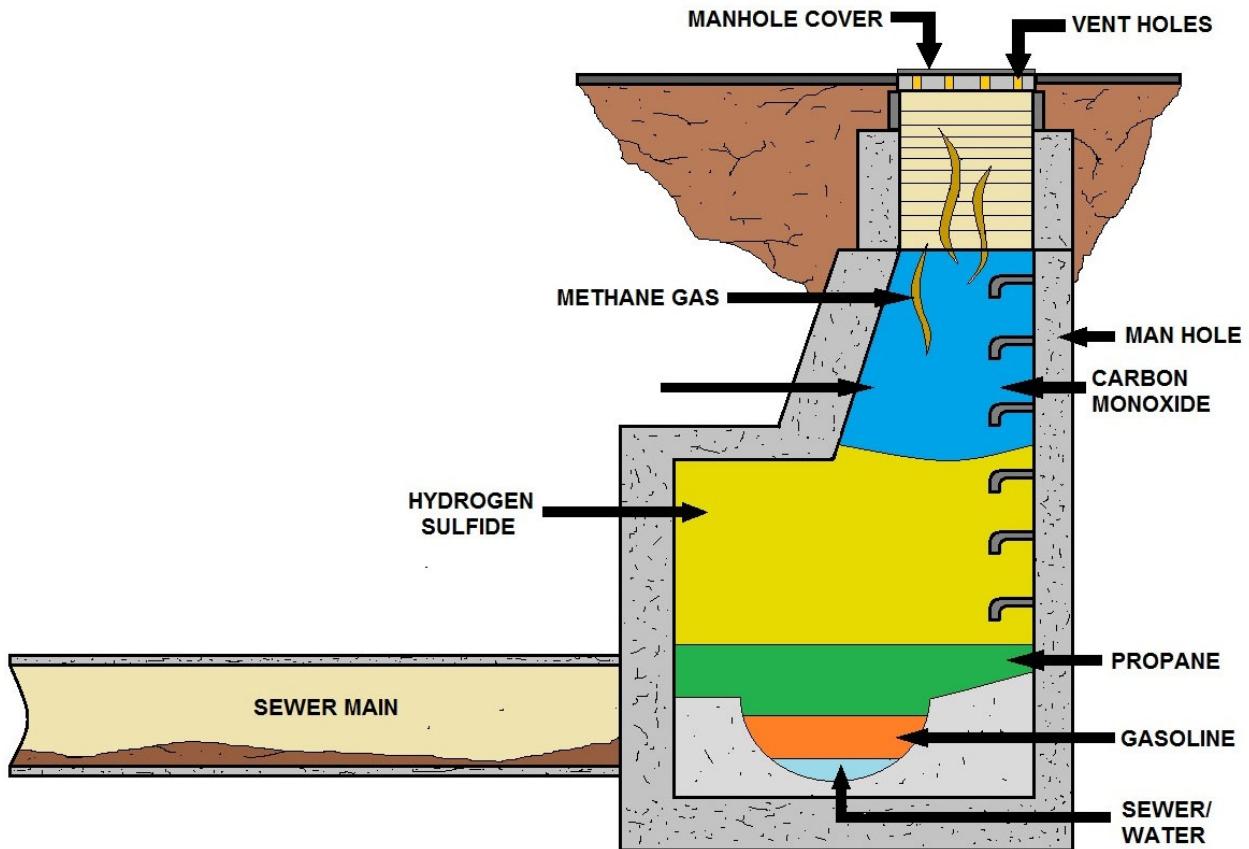
Permit required confined space (permit space), is a confined space that has one or more of the following characteristics:

1. Contains or has a potential to contain a hazardous atmosphere.
2. Contains a material that has the potential for engulfing an entrant.
3. Has an internal configuration such that an entrant could be trapped or asphyxiated by inwardly covering walls or by a floor which slopes downward and tapers to a smaller cross-section.
4. Contains any other recognized serious safety or health hazard.

Each Permit-Required Confined Space will be marked



"Confined Space - Entry Permit Required".



POSSIBLE HAZARDOUS ATMOSPHERES PRESENT IN A CONFINED SPACE (EXAMPLE IS OF A SEWER MAIN)

Examples of "**Permit Required Confined Spaces**" Make sure you comply with these Confined Space rules or face civil and/or criminal charges.

Several States' have criminally charged Supervisors for the actions of the employees in a Confined Space/Permit Required Confined Space. ***Don't risk dead or the chance of going to jail in order to speed up your job!***

Permitted Confined Space Entry Program

Definition of Confined Spaces Requiring an Entry Permit

Confined space:

- ✓ Is large enough or so configured that an employee can bodily enter and perform work.
- ✓ Has limited or restricted means for entry or exit (i.e. tanks, vessels, silos, storage bins, hoppers, vaults, and pits are spaces that may have limited means of entry).
- ✓ Is not designed for continuous employee occupancy.

Purpose

The Permit Required Space (**PRCS**) Program is provided to protect authorized employees that will enter confined spaces and may be exposed to hazardous atmospheres, engulfment in materials, conditions which may trap or asphyxiate due to converging or sloping walls, or contains any other safety or health hazards.

Many workplaces contain confined spaces not designed for human occupancy which due to their configuration hinder employee activities including entry, work and exit. Asphyxiation is the leading cause of death in confined spaces.

Subpart P applies to all open excavations in the earth's surface.

- ✓ **All trenches are excavations.**
- ✓ **All excavations are not trenches.**

Permit Required Confined Space Entry General Rules

During all Confined Space Entries, the following Safety Rules must be strictly enforced:

1. Only Authorized and Trained Employees may enter a Confined Space or act as Safety Watchmen.
2. No Smoking is permitted in a Confined Space or near entrance/exit area.
3. During Confined Space Entries, a Watchmen must be present at all times.
4. Constant visual or voice communication will be maintained between the Safety Watchmen and Employees entering a Confined Space.
5. No bottom or side entry will be made or work conducted below the level any hanging material or material which could cause engulfment.
6. Air and Oxygen Monitoring is required before entering any Permit-Required Confined Space. Oxygen levels in a Confined Space must be between 19.5 and 23.5 percent. Levels above or below will require the use of an SCBA or other approved air supplied respirator. Additional ventilation and Oxygen Level Monitoring is required when welding is performed. The monitoring will check Oxygen Levels, Explosive Gas Levels and Carbon Monoxide Levels. Entry will not be permitted if explosive gas is detected above one-half the Lower Explosive Limit (**LEL**).
7. To prevent injuries to others, all openings to Confined Spaces will be protected by a barricade when covers are removed.

COMMON HAZARDOUS GASES THAT MAY BE PRESENT IN CONFINED SPACE					
SUBSTANCE *	8-HOUR TIME-WEIGHTED AVERAGE (TWA)	15-MINUTE SHORT-TERM EXPOSURE LIMIT (STEL)	CEILING LIMIT (Never To Be Exceeded)	IMMEDIATELY DANGEROUS TO LIFE AND HEALTH (IDLH)	RECOMMENDED ALARM SETTINGS (Low / High)
AMMONIA	25 ppm	35 ppm	—	300 ppm	13 ppm / 25 ppm
CARBON MONOXIDE	25 ppm	100 ppm	—	1200 ppm	13 ppm / 25 ppm
CHLORINE	0.5 ppm	1 ppm	—	10 ppm	0.25 ppm / 0.5 ppm
HYDROGEN SULFIDE	—	—	10 ppm	100 ppm	5 ppm / 10 ppm
METHANE	1000 ppm	—	—	—	500 ppm / 1000 ppm
NITROGEN DIOXIDE	—	—	1 ppm	20 ppm	0.5 ppm / 1 ppm
SULFUR DIOXIDE	2 ppm	5 ppm	—	100 ppm	1 ppm / 2 ppm
OXYGEN	—	—	—	—	20.5 % of Atmosphere
LOWER EXPLOSIVE LIMIT (LEL)	—	—	—	—	5 % LEL

EXAMPLE OF A CHART OF CONFINED SPACE GASES

Confined Space Entry Permit Example

Date & Time Issued		Date & time Expires	
Space I.D.		Supervisor	
Equipment Affected		Task	
Standby Team			
Pre-Entry Atmospheric Checks	Time (am - pm)		
	Oxygen		
	Explosive (% LEL)		
	Toxic (PPM)		
	Testers Signature		
Pre-entry Fluid System Isolation		Yes	No
Pumps /lines blinded, blocked, disconnected			
Ventilation Source Established			
Mechanical Forced Air			
Natural Ventilation			
Post Ventilation Pre-Entry Atmospheric Checks			
Time			
Oxygen (%)			
Explosive (% LEL)			
Toxic (PPM)			
Tester Signature			
Communication Procedures Established per specific Confined Space SOP			
Rescue Procedures established per specific Confined Space SOP			

Training Verification - for the following persons & space to be entered					YES	NO
All persons entering Confined Space						
All persons acting as Supervisor for the Entry						
All persons assigned backup positions						
All persons assigned to monitor access and interior activities						
All persons assigned to emergency rescue team						
Equipment on Scene	YES	NO	NA		YES	NO
Gas Monitor				Life Line		
Safety Harness				Hoisting Equipment		
Fall Arrest Gear				Powered Comm Eq.		
SCBAs				Air Line Respirators		

Protective Clothing				Elect Gear Properly Rated			
Periodic Atmospheric Checks							
Time (am - pm)							
Oxygen							
Explosive (% LEL)							
Toxic (PPM)							
Testers Signature							

A review of the work authorized by this permit and the information contained on this Entry Permit. Written instructions and safety procedures have been received and are understood. Entry cannot be approved if any squares are marked in the "No" column. This permit is not valid unless all appropriate items are completed.

Permit Prepared By: (Supervisor) _____
 Approved By: (Unit Supervisor) _____

This permit to be kept at job site.

Return job site copy to Safety Office following job completion.

Copies: Safety Office, Unit Supervisor, Job site

Confined Space Duties & Responsibilities

Examples of assignments

Employees

- Follow program requirements
- Report any previously un-identified hazards associated with confined spaces
- Do not enter any confined spaces that have not been evaluated for safety concerns.

Management

- Provide annual Confined Space training to all employees that may need confined space training.
- Ensure confined space assessments have been conducted
- Annually review this program and all Entry Permits
- Annually review this program and all Entry Permits

Rescue or Training Department

- Ensure proper training for entry & rescue teams
- Provide proper equipment for entry & rescue teams
- Ensure all permit required confined spaces are posted
- Evaluate Rescue Teams/Service to ensure they are adequately trained and prepared
- Ensure rescue team at access during entry into spaces with IDLH atmospheres
- Provide annual Confined Space awareness training to all employees that may need confined space awareness training.

Entry Supervisor

Entry supervisors are responsible for the overall permit space entry and must coordinate all entry procedures, tests, permits, equipment and other relevant activities. The following entry supervisor duties are required:

- ✓ Know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure.
- ✓ Verifies, by checking that the appropriate entries have been made on the permit, all tests specified by the permit have been conducted and that all procedures and equipment specified by the permit are in place before endorsing the permit and allowing entry to begin.
- ✓ Terminate the entry and cancel the permit when the entry is complete or there is a need for terminating the permit.
- ✓ Verify that rescue services are available and that the means for summoning them are operable.
- ✓ Remove unauthorized persons who enter or attempt to enter the space during entry operations.
- ✓ Determine whenever responsibility for a permit space entry operation is transferred and at intervals dictated by the hazards and operations performed within the space that entry operations remain consistent with the permit terms and that acceptable entry conditions are maintained.

Entry Attendants

- At least one attendant is required outside the permit space into which entry is authorized for the duration of the entry operation. Responsibilities include:
- To know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure
- To be aware of possible behavioral effects of hazard exposure on entrants
- To continuously maintain an accurate count of entrants in the permit space and ensures a means to accurately identify authorized entrants
- To remain outside the permit space during entry operations until relieved by another attendant (once properly relieved, they may participate in other permit space activities, including rescue if they are properly trained and equipped).
- To communicate with entrants as necessary to monitor entrant status and alert entrants of the need to evacuate.
- To monitor activities inside and outside the space to determine if it is safe for entrants to remain in the space and orders the entrants to immediately evacuate if: the attendant detects a prohibited condition, detects entrant behavioral effects of hazard exposure, detects a situation outside the space that could endanger the entrants; or if the attendant cannot effectively and safely perform all the attendant duties.
- To summon rescue and other emergency services as soon as the attendant determines the entrants need assistance to escape the permit space hazards.
- To perform non-entry rescues as specified by that rescue procedure and entry supervisor
- Not to perform duties that might interfere with the attendants' primary duty to monitor and protect the entrants.

To take the following action when unauthorized persons approach or enter a permit space while entry is under way:

1. Warn the unauthorized persons that they must stay away from the permit space,
2. Advise unauthorized persons that they must exit immediately if they have entered the space, and
3. Inform the authorized entrants and the entry supervisor if unauthorized persons have entered the permit space.

Entrants

All entrants must be authorized by the entry supervisor to enter permit spaces, have received the required training, used the proper equipment, and observes the entry procedures and permit. The following entrant duties are required:

Know the hazards that may be faced during entry, including information on the mode, signs or symptoms, and consequences of the exposure;

Properly use the equipment required for safe entry;

Communicate with the attendant as necessary to enable the attendant to monitor the status of the entrants and to enable the attendant to alert the entrants of the need to evacuate the space if necessary. Alert the attendant whenever; the entrant recognizes any warning signs or symptoms of exposure to a dangerous situation, or any prohibited condition is detected; and

Exit the permit space as quickly as possible whenever the attendant or entry supervisor gives an order to evacuate the permit space, the entrant recognized any warning signs or symptoms of exposure to a dangerous situation, the entrant detects a prohibited condition, or an evacuation alarm activated.

Hazards

- ✓ Explosive / Flammable Atmospheres
- ✓ Toxic Atmospheres
- ✓ Engulfment
- ✓ Asphyxiation
- ✓ Entrapment
- ✓ Slips & falls
- ✓ Chemical Exposure
- ✓ Electric Shock
- ✓ Thermal / Chemical Burns
- ✓ Noise & Vibration

Hazard Controls

Engineering Controls

- Locked entry points
- Temporary ventilation
- Temporary Lighting



Administrative Controls

- Signs
- Employee training
- Entry procedures
- Atmospheric Monitoring
- Rescue procedures
- Use of prescribed Personal Protective Equipment

Entry Standard Operating Procedures

- Hazards
- Hazard Control & Abatement
- Acceptable Entry Conditions
- Means of Entry
- Entry Equipment Required
- Emergency Procedures

Permit Required Confined Space Entry General Rules

During all Confined Space Entries, the following Safety Rules must be strictly enforced:

1. Only Authorized and Trained Employees may enter a Confined Space or act as Safety Watchman.
2. No Smoking is permitted in a Confined Space or near entrance/exit area.
3. During Confined Space Entries, a Watchman must be present at all times.
4. Constant visual or voice communication will be maintained between the Safety Watchman and Employees entering a Confined Space.
5. No bottom or side entry will be made or work conducted below the level of any hanging material or material which could cause engulfment.
6. Air and Oxygen Monitoring is required before entering any Permit-Required Confined Space. Oxygen levels in a Confined Space must be between 19.5 and 23.5 percent. Levels above or below will require the use of an SCBA or other approved air supplied respirator. Additional ventilation and Oxygen Level Monitoring is required when welding is performed. The monitoring will check Oxygen Levels, Explosive Gas Levels and Carbon Monoxide Levels. Entry will not be permitted if explosive gas is detected above one-half the Lower Explosive Limit (**LEL**), or 10%.
7. To prevent injuries to others, all openings to Confined Spaces will be protected by a barricade when covers are removed.

Confined Space Entry Procedures

Each employee who enters or is involved in the entry must:

1. Understand the procedures for confined Space Entry
2. Know the Hazards of the specific space
3. Review the specific procedures for each entry
4. Understand how to use entry and rescue equipment

Confined Space Entry Permits

Confined Space Entry Permits must be completed before any Employee enters a Permit-Required Confined Space. The Permit must be completed and signed by an Authorized Member of Management before entry.

Permits will expire before the completion of the shift or if any pre-entry conditions change. Permits will be maintained on file for 12 months.



Confined Space Hazards

Fatalities and injuries constantly occur among construction workers who, during the course of their jobs, are required to enter confined spaces. In some circumstances, these workers are exposed to multiple hazards, any of which may cause bodily injury, illness, or death.

Newspaper and magazine articles abound with stories of workers injured and killed from a variety of atmospheric factors and physical agents. Throughout the construction jobsite, contractors and workers encounter both inherent and induced hazards within confined workspaces.

Inherent Hazards

Inherent hazards, such as electrical, thermal, chemical, mechanical, etc., are associated with specific types of equipment and the interactions among them.

Examples include high voltage (shock or corona discharge and the resulting burns), radiation generated by equipment, defective design, omission of protective features (no provision for grounding non-current-carrying conductive parts), high or low temperatures, high noise levels, and high-pressure vessels and lines (rupturing with resultant release of fragments, fluids, gases, etc.).

Inherent hazards usually cannot be eliminated without degrading the system or equipment, or without making them inoperative. Therefore, emphasis must be placed on hazard control methods.

Induced Hazards

Induced hazards arise, and are induced from, a multitude of incorrect decisions and actions that occur during the actual construction process. Some examples are: omission of protective features, physical arrangements that may cause unintentional worker contact with electrical energy sources, oxygen-deficient atmospheres created at the bottom of pits or shafts, lack of safety factors in structural strength, and flammable atmospheres.

Typical Examples of Confined Workspaces

Following are typical examples of confined workspaces in construction which contain both inherent and induced hazards.

Vaults

A variety of vaults are found on the construction jobsite. On various occasions, workers must enter these vaults to perform a number of functions.

The restricted nature of vaults and their frequently below-grade location can create an assortment of safety and health problems.

Oxygen-Deficient Atmosphere

One of the major problems confronting construction workers while working in vaults is the ever-present possibility of an oxygen-deficient atmosphere.



Explosive or Toxic Gases, Vapors, or Fumes

While working in an electrical vault, workers may be exposed to the build-up of explosive gases such as those used for heating (propane). Welding and soldering produce toxic fumes which are confined in the limited atmosphere.

Electrical Shock

Electrical shock is often encountered from power tools, line cords, etc. In many instances, such electrical shock results from the fact that the contractor has not provided an approved grounding system or the protection afforded by ground-fault circuit interrupters or low-voltage systems.

Purging

In some instances, purging agents such as nitrogen and argon may enter the vault from areas adjacent to it. These agents may displace the oxygen in the vault to the extent that it will asphyxiate workers almost immediately.

Materials Falling In and On

A hazard normally considered a problem associated with confined spaces is material or equipment which may fall into the vault or onto workers as they enter and leave the vault.

Vibration could cause the materials on top of the vault to roll off and strike workers. If the manhole covers were removed, or if they were not installed in the first place, materials could fall into the vault, causing injury to the workers inside.

Condenser Pits

A common confined space found in the construction of nuclear power plants is the condenser pit. Because of their large size, they are often overlooked as potentially hazardous confined spaces.

These below-grade areas create large containment areas for the accumulation of toxic fumes, gases, and so forth, or for the creation of oxygen-deficient atmospheres when purging with argon, Freon, and other inert gases.

Other hazards will be created by workers above dropping equipment, tools, and materials into the pit.

Manholes

Throughout the construction site, manholes are commonplace. As means of entry into and exit from vaults, tanks, pits, and so forth, manholes perform a necessary function. However, these confined spaces may present serious hazards which could cause injuries and fatalities.

A variety of hazards are associated with manholes. To begin with, the manhole could be a dangerous trap into which the worker could fall. Often covers are removed and not replaced, or else they are not provided in the first place.

Pipe Assemblies

One of the most frequently unrecognized types of confined spaces encountered throughout the construction site is the pipe assembly. Piping of sixteen to thirty-six inches in diameter is commonly used for a variety of purposes.

For any number of reasons, workers will enter the pipe. Once inside, they are faced with potential oxygen-deficient atmospheres, often caused by purging with argon or another inert gas. Welding

fumes generated by the worker in the pipe, or by other workers operating outside the pipe at either end, subject the worker to toxic atmospheres.

The generally restricted dimensions of the pipe provide little room for the workers to move about and gain any degree of comfort while performing their tasks. Once inside the pipe, communication is extremely difficult. In situations where the pipe bends, communication and extrication become even more difficult. Electrical shock is another problem to which the worker is exposed.

Ungrounded tools and equipment or inadequate line cords are some of the causes. As well, heat within the pipe run may cause the worker to suffer heat prostration.

Ventilation Ducts

Ventilation ducts, like pipe runs, are very common at the construction site. These sheet metal enclosures create a complex network which moves heated and cooled air and exhaust fumes to desired locations in the plant.

Ventilation ducts may require that workers enter them to cut out access holes, install essential parts of the duct, etc. Depending on where these ducts are located, oxygen deficiency could exist. They usually possess many bends, which create difficult entry and exit and which also make it difficult for workers inside the duct to communicate with those outside it. Electrical shock hazards and heat stress are other problems associated with work inside ventilation ducts.

Tanks

Tanks are another type of confined workspace commonly found in construction. They are used for a variety of purposes, including the storage of water, chemicals, etc.

Tanks require entry for cleaning and repairs. Ventilation is always a problem. Oxygen-deficient atmospheres, along with toxic and explosive atmospheres created by the substances stored in the tanks, present hazards to workers. Heat, another problem in tanks, may cause heat prostration, particularly on a hot day.

Since electrical line cords are often taken into the tank, the hazard of electrical shock is always present. The nature of the tank's structure often dictates that workers must climb ladders to reach high places on the walls of the tank.

Sumps

Sumps are commonplace. They are used as collection places for water and other liquids. Workers entering sumps may encounter an oxygen-deficient atmosphere.

Also, because of the wet nature of the sump, electrical shock hazards are present when power tools are used inside. Sumps are often poorly illuminated. Inadequate lighting may create an accident situation.

Containment Cavities

These large below-grade areas are characterized by little or no air movement. Ventilation is always a problem. In addition, the possibility of oxygen deficiency exists. As well, welding and other gases may easily collect in these areas, creating toxic atmospheres. As these structures near completion, more confined spaces will exist as rooms are built off the existing structure.

Electrical Transformers

Electrical transformers are located on the jobsite. They often contain a nitrogen purge or dry air. Before they are opened, they must be well vented by having air pumped in. Workers, particularly electricians and power plant operators, will enter these transformers through hatches on top for various work-related reasons. Testing for oxygen deficiency and for toxic atmospheres is mandatory.

Heat Sinks

These larger pit areas hold cooling water in the event that there is a problem with the pumps located at the water supply to the plant--normally a river or lake--which would prevent cooling water from reaching the reactor core.

When in the pits, workers are exposed to welding fumes and electrical hazards, particularly because water accumulates in the bottom of the sink.

Generally, it is difficult to communicate with workers in the heat sink, because the rebar in the walls of the structure deaden radio signals.



Contractor Entry



All work by non-company employees that involves the entry into confined spaces will follow the procedures of this program. The information of this program and specific hazards of the confined spaces to be entered will be provided to Contractor Management prior to commencing entry or work.

Confined Space Training

Training for Confined Space Entry includes:

1. Duties of Entry Supervisor, Entrant and Attendants
2. Confined Space Entry permits
3. Hazards of Confined Spaces
4. Use of Air Monitoring Equipment
5. First Aid and CPR Training
6. Emergency Action & Rescue Procedures
7. Confined Space Entry & Rescue Equipment
8. Rescue training, including entry and removal from representative spaces



To monitor activities inside and outside the space to determine if it is safe for entrants to remain in the space and orders the entrants to immediately evacuate if: the attendant detects a prohibited condition, detects entrant behavioral effects of hazard exposure, detects a situation outside the space that could endanger the entrants; or if the attendant cannot effectively and safely perform all the attendant duties.

Other Hazards

Flammable Atmospheres

A flammable atmosphere generally arises from enriched oxygen atmospheres, vaporization of flammable liquids, byproducts of work, chemical reactions, concentrations of combustible dusts, and desorption of chemical from inner surfaces of the confined space.

An atmosphere becomes flammable when the ratio of oxygen to combustible material in the air is neither too rich nor too lean for combustion to occur. Combustible gases or vapors will accumulate when there is inadequate ventilation in areas such as a confined space.

Flammable gases such as acetylene, butane, propane, hydrogen, methane, natural or manufactured gases or vapors from liquid hydrocarbons can be trapped in confined spaces, and since many gases are heavier than air, they will seek lower levels as in pits, sewers, and various types of storage tanks and vessels. In a closed top tank, it should also be noted that lighter than air gases may rise and develop a flammable concentration if trapped above the opening.

The byproducts of work procedures can generate flammable or explosive conditions within a confined space. Specific kinds of work such as spray painting can result in the release of explosive gases or vapors. Welding in a confined space is a major cause of explosions in areas that contain combustible gas.

Chemical reactions forming flammable atmospheres occur when surfaces are initially exposed to the atmosphere, or when chemicals combine to form flammable gases. This condition arises when dilute sulfuric acid reacts with iron to form hydrogen or when calcium carbide makes contact with water to form acetylene.

Other examples of spontaneous chemical reactions that may produce explosions from small amounts of unstable compounds are acetylene-metal compounds, peroxides, and nitrates. In a dry state, these compounds have the potential to explode upon percussion or exposure to increased temperature.

Another class of chemical reactions that form flammable atmospheres arise from deposits of pyrophoric substances (carbon, ferrous oxide, ferrous sulfate, iron, etc.) that can be found in tanks used by the chemical and petroleum industry. These tanks containing flammable deposits will spontaneously ignite upon exposure to air.

Combustible dust concentrations are usually found during the process of loading, unloading, and conveying grain products, nitrated fertilizers, finely ground chemical products, and any other combustible material.

High charges of static electricity, which rapidly accumulate during periods of relatively low humidity (below 50%), can cause certain substances to accumulate electrostatic charges of sufficient energy to produce sparks and ignite a flammable atmosphere.

These sparks may also cause explosions when the right air or oxygen to dust or gas mixture is present.

Toxic Atmospheres

The substances to be regarded as toxic in a confined space can cover the entire spectrum of gases, vapors, and finely-divided airborne dust in industry. The sources of toxic atmospheres encountered may arise from the following:

1. The manufacturing process (for example, in producing polyvinyl chloride, hydrogen chloride is used as well as vinyl chloride monomer, which is carcinogenic).
2. The product stored [removing decomposed organic material from a tank can liberate toxic substances, such as hydrogen sulfide (H_2S)].
3. The operation performed in the confined space (for example, welding or brazing with metals capable of producing toxic fumes).

During loading, unloading, formulation, and production, mechanical and/or human error may also produce toxic gases which are not part of the planned operation.

Carbon monoxide (**CO**) is a hazardous gas that may build up in a confined space. This odorless, colorless gas that has approximately the same density as air is formed from incomplete combustion of organic materials such as wood, coal, gas, oil, and gasoline; it can be formed from microbial decomposition of organic matter in sewers, silos, and fermentation tanks.

Carbon monoxide is an insidious toxic gas because of its poor warning properties. Early stages of CO intoxication are nausea and headache. Carbon monoxide may be fatal at 1000 ppm or 10% in air, and is considered dangerous at 200 ppm or 2%, because it forms Carboxyhemoglobin in the blood which prevents the distribution of oxygen in the body.

Carbon monoxide is a relatively abundant colorless, odorless gas, therefore, any untested atmosphere must be suspect. It must also be noted that a safe reading on a combustible gas indicator does not ensure that CO is not present. Carbon monoxide must be tested for specifically.

The formation of CO may result from chemical reactions or work activities, therefore fatalities due to CO poisoning are not confined to any particular industry. There have been fatal accidents in sewage treatment plants due to decomposition products and lack of ventilation in confined spaces.

Another area where CO results as a product of decomposition is in the formation of silo gas in grain storage elevators. In another area, the paint industry, varnish is manufactured by introducing the various ingredients into a kettle, and heating them in an inert atmosphere, usually town gas, which is a mixture of carbon dioxide and nitrogen.

In welding operations, oxides of nitrogen and ozone are gases of major toxicologic importance, and incomplete oxidation may occur and carbon monoxide can form as a byproduct. Another poor work practice, which has led to fatalities, is the recirculation of diesel exhaust emissions. Increased CO levels can be prevented by strict control of the ventilation and the use of catalytic converters.

Irritant (Corrosive) Atmospheres

Irritant or corrosive atmospheres can be divided into primary and secondary groups. The primary irritants exert no systemic toxic effects (effects on the entire body). Examples of primary irritants are chlorine, ozone, hydrochloric acid, hydrofluoric acid, sulfuric acid, nitrogen dioxide, ammonia, and sulfur dioxide. A secondary irritant is one that may produce systemic toxic effects in addition to surface irritation. Examples of secondary irritants include benzene, carbon tetrachloride, ethyl chloride, trichloroethane, trichloroethylene, and chloropropene.

Irritant gases vary widely among all areas of industrial activity. They can be found in plastics plants, chemical plants, the petroleum industry, tanneries, refrigeration industries, paint manufacturing, and mining operations.

Prolonged exposure at irritant or corrosive concentrations in a confined space may produce little or no evidence of irritation. This may result in a general weakening of the defense reflexes from changes in sensitivity. The danger in this situation is that the worker is usually not aware of any increase in his/her exposure to toxic substances.

Asphyxiating Atmospheres

The normal atmosphere is composed approximately of 20.9% oxygen and 78.1% nitrogen, and 1% argon with small amounts of various other gases. Reduction of oxygen in a confined space may be the result of either consumption or displacement.

The consumption of oxygen takes place during combustion of flammable substances, as in welding, heating, cutting, and brazing. A more subtle consumption of oxygen occurs during bacterial action, as in the fermentation process. Oxygen may also be consumed during chemical reactions as in the formation of rust on the exposed surface of the confined space (iron oxide). The number of people working in a confined space and the amount of their physical activity will also influence the oxygen consumption rate.

A second factor in oxygen deficiency is displacement by another gas. Examples of gases that are used to displace air, and therefore reduce the oxygen level are helium, argon, and nitrogen. Carbon dioxide may also be used to displace air and can occur naturally in sewers, storage bins, wells, tunnels, wine vats, and grain elevators. Aside from the natural development of these gases, or their use in the chemical process, certain gases are also used as inerting agents to displace flammable substances and retard pyrophoric reactions.

Gases such as nitrogen, argon, helium, and carbon dioxide, are frequently referred to as non-toxic inert gases but have claimed many lives. The use of nitrogen to inert a confined space has claimed more lives than carbon dioxide. The total displacement of oxygen by nitrogen will cause immediate collapse and death. Carbon dioxide and argon, with specific gravities greater than air, may lie in a tank or manhole for hours or days after opening. Since these gases are colorless and odorless, they pose an immediate hazard to health unless appropriate oxygen measurements and ventilation are adequately carried out.

Oxygen Deprivation

Oxygen deprivation is one form of asphyxiation. While it is desirable to maintain the atmospheric oxygen level at 21% by volume, the body can tolerate deviation from this ideal. When the oxygen level falls to 17%, the first sign of hypoxia is a deterioration to night vision which is not noticeable until a normal oxygen concentration is restored. Physiologic effects are increased breathing volume and accelerated heartbeat.

Between 14-16% physiologic effects are increased breathing volume, accelerated heartbeat, very poor muscular coordination, rapid fatigue, and intermittent respiration. Between 6-10% the effects are nausea, vomiting, inability to perform, and unconsciousness. Less than 6%, spastic breathing, convulsive movements, and death in minutes.

Mechanical Hazards

If activation of electrical or mechanical equipment would cause injury, each piece of equipment should be manually isolated to prevent inadvertent activation before workers enter or while they work in a confined space. The interplay of hazards associated with a confined space, such as the potential of flammable vapors or gases being present, and the build-up of static charge due to mechanical cleaning, such as abrasive blasting, all influence the precautions which must be taken.

To prevent vapor leaks, flashbacks, and other hazards, workers should completely isolate the space. To completely isolate a confined space, the closing of valves is not sufficient. All pipes must be physically disconnected or isolation blanks bolted in place. Other special precautions must be taken in cases where flammable liquids or vapors may re-contaminate the confined space.

The pipes blanked or disconnected should be inspected and tested for leakage to check the effectiveness of the procedure. Other areas of concern are steam valves, pressure lines, and chemical transfer pipes. A less apparent hazard is the space referred to as a void, such as double walled vessels, which must be given special consideration in blanking off and inerting.

Thermal Effects

Four factors influence the interchange of heat between people and their environment. They are: (1) air temperature, (2) air velocity, (3) moisture contained in the air, and (4) radiant heat. Because of the nature and design of most confined spaces, moisture content and radiant heat are difficult to control. As the body temperature rises progressively, workers will continue to function until the body temperature reaches approximately 102°F.

When this body temperature is exceeded, the workers are less efficient, and are prone to heat exhaustion, heat cramps, or heat stroke. In a cold environment, certain physiologic mechanisms come into play, which tend to limit heat loss and increase heat production. The most severe strain in cold conditions is chilling of the extremities so that activity is restricted. Special precautions must be taken in cold environments to prevent frostbite, trench foot, and general hypothermia.

Protective Insulated Clothing

Protective insulated clothing for both hot and cold environments will add additional bulk to the worker and must be considered in allowing for movement in the confined space and exit time. Therefore, air temperature of the environment becomes an important consideration when evaluating working conditions in confined spaces.

Noise

Noise problems are usually intensified in confined spaces because the interior tends to cause sound to reverberate and thus expose the worker to higher sound levels than those found in an open environment.

This intensified noise increases the risk of hearing damage to workers which could result in temporary or permanent loss of hearing. Noise in a confined space which may not be intense enough to cause hearing damage may still disrupt verbal communication with the emergency standby person on the exterior of the confined space. If the workers inside are not able to hear commands or danger signals due to excessive noise, the probability of severe accidents can increase.

Vibration

Whole body vibration may affect multiple body parts and organs depending upon the vibration characteristics. Segmental vibration, unlike whole body vibration, appears to be more localized in creating injury to the fingers and hands of workers using tools, such as pneumatic hammers, rotary grinders or other hand tools which cause vibration.

Other Hazards

Some physical hazards cannot be eliminated because of the nature of the confined space or the work to be performed. These hazards include such items as scaffolding, surface residues, and structural hazards. The use of scaffolding in confined spaces has contributed too many accidents caused by workers or materials falling, improper use of guard rails, and lack of maintenance to insure worker safety.

The choice of material used for scaffolding depends upon the type of work to be performed, the calculated weight to be supported, and the surface on which the scaffolding is placed, and the substance previously stored in the confined space.

Surface residues in confined spaces can increase the already hazardous conditions of electrical shock, reaction of incompatible materials, liberation of toxic substances, and bodily injury due to slips and falls. Without protective clothing, additional hazards to health may arise due to surface residues.

Structural hazards within a confined space such as baffles in horizontal tanks, trays in vertical towers, and bends in tunnels, overhead structural members, or scaffolding installed for maintenance constitute physical hazards, which are exacerbated by the physical surroundings. In dealing with structural hazards, workers must review and enforce safety precautions to assure safety.

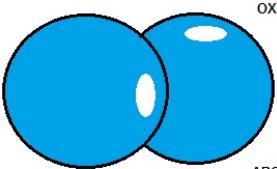
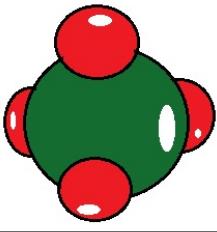
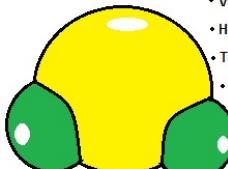
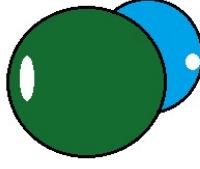
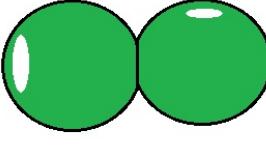
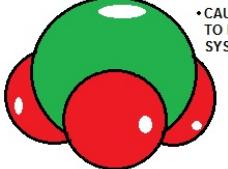
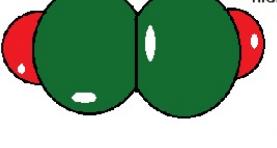
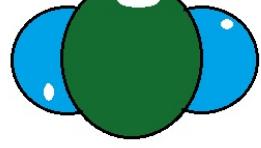
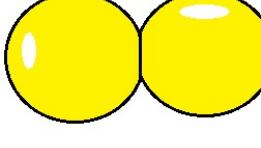
Abbreviations:

PEL - permissible exposure limit: Average concentration that must not be exceeded during 8-hour work shift of a 40-hour workweek.

STEL - Short-term exposure limit: 15-minute exposure limit that must not be exceeded during the workday.

REL - Recommended exposure limit: Average concentration limit recommended for up to a 10-hour workday during a 40-hour workweek.

IDLH - Immediately dangerous to life or health: Maximum concentration from which person could escape (in event of respirator failure) without permanent or escape-impairing effects within 30 minutes.

OXYGEN	O_2	METHANE	CH_4	HYDROGEN SULFIDE H_2S
	<ul style="list-style-type: none"> • BELOW 19.5% IS OXYGEN DEPLETED • ABOVE 23.5% IS OXYGEN ENRICHED 		<ul style="list-style-type: none"> • AN ASPHIXIANT <p>OXYGEN LEVELS SHOULD BE KEPT ABOVE 19.5%</p>	
CARBON MONOXIDE	CO	NITROGEN	N_2	AMMONIA NH_3
	<ul style="list-style-type: none"> • AN ASPHIXIANT <p>PERMISSABLE EXPOSURE LIMIT (PEL) IS 50ppm OVER AN 8-HOUR TWA</p>		<ul style="list-style-type: none"> • AN ASPHIXIANT <p>USED AS AN INERTING AGENT REPLACING OXYGEN IN THE AIR</p>	
ACETYLENE	C_2H_2	CARBON DIOXIDE	CO_2	CHLORINE Cl_2
	<ul style="list-style-type: none"> • LIGHTER THAN AIR • HIGHLY FLAMMABLE • USED FOR WELDING <p>LEL OF 2.5%</p>		<ul style="list-style-type: none"> • AN ASPHIXIANT <p>PEL IS 5000ppm OVER 8-HOUR TWA</p>	

COMMON GASES THAT CAN BE FOUND IN CONFINED SPACE

LUST Regulation Section

Subpart A--Program Scope and Interim Prohibition

Section 280.10 Applicability.

(a) The requirements of this Part apply to all owners and operators of an UST system as defined in § 280.12 except as otherwise provided in paragraphs (b), (c), and (d) of this section. Any UST system listed in paragraph (c) of this section must meet the requirements of § 280.11.

(b) The following UST systems are excluded from the requirements of this Part:

(1) Any UST system holding hazardous wastes listed or identified under Subtitle C of the Solid Waste Disposal Act, or a mixture of such hazardous waste and other regulated substances.

(2) Any wastewater treatment tank system that is part of a wastewater treatment facility regulated under § 402 or 307 (b) of the Clean Water Act.

(3) Equipment or machinery that contains regulated substances for operational purposes such as hydraulic lift tanks and electrical equipment tanks.

(4) Any UST system whose capacity is 110 gallons or less.

(5) Any UST system that contains a *de minimis* concentration of regulated substances.

(6) Any emergency spill or overflow containment UST system that is expeditiously emptied after use.

(c) **Deferrals.** Subparts B, C, D, E, and G do not apply to any of the following types of UST systems:

(1) Wastewater treatment tank systems;

(2) Any UST systems containing radioactive material that are regulated under the Atomic Energy Act of 1954 (42 U.S.C. 2011 and following);

(3) Any UST system that is part of an emergency generator system at nuclear power generation facilities regulated by the Nuclear Regulatory Commission under 10 CFR 50 Appendix A;

(4) Airport hydrant fuel distribution systems; and

(5) UST systems with field-constructed tanks.

(d) **Deferrals.** Subpart D does not apply to any UST system that stores fuel solely for use by emergency power generators.

Section 280.11 Interim Prohibition for deferred UST systems.

(a) No person may install an UST system listed in § 280.10 (c) for the purpose of storing regulated substances unless the UST system (whether of single- or double-wall construction):

(1) Will prevent releases due to corrosion or structural failure for the operational life of the UST system;

(2) Is cathodically protected against corrosion, constructed of noncorrodible material, steel clad with a noncorrodible material, or designed in a manner to prevent the release or threatened release of any stored substance; and

(3) Is constructed or lined with material that is compatible with the stored substance.

(b) Notwithstanding paragraph (a) of this section, an UST system without corrosion protection may be installed at a site that is determined by a corrosion expert not to be corrosive enough to cause it to have a release due to corrosion during its operating life. Owners and operators must maintain records that

demonstrate compliance with the requirements of this paragraph for the remaining life of the tank.

[Note: The National Association of Corrosion Engineers Standard RP-02-85, "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems," may be used as guidance for complying with paragraph (b) of this section.]

Section 280.12 Definitions.

"Aboveground release" means any release to the surface of the land or to surface water. This includes, but is not limited to, releases from the above-ground portion of an UST system and aboveground releases associated with overfills and transfer operations as the regulated substance moves to or from an UST system.

"Ancillary equipment" means any devices including, but not limited to, such devices as piping, fittings, flanges, valves, and pumps used to distribute, meter, or control the flow of regulated substances to and from an UST.

"Belowground release" means any release to the subsurface of the land and to groundwater. This includes, but is not limited to, releases from the belowground portions of an underground storage tank system and belowground releases associated with overfills and transfer operations as the regulated substance moves to or from an underground storage tank.

"Beneath the surface of the ground" means beneath the ground surface or otherwise covered with earthen materials.

"Cathodic protection" is a technique to prevent corrosion of a metal surface by making that surface the cathode of an electrochemical cell. For example, a tank system can be cathodically protected through the application of either galvanic anodes or impressed current.

"Cathodic protection tester" means a person who can demonstrate an understanding of the principles and measurements of all common types of Cathodic protection systems as applied to buried or submerged metal piping and tank systems. At a minimum, such persons must have education and experience in soil resistivity, stray current, structure-to-soil potential, and component electrical isolation measurements of buried metal piping and tank systems.

"CERCLA" means the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended.

"Compatible" means the ability of two or more substances to maintain their respective physical and chemical properties upon contact with one another for the design life of the tank system under conditions likely to be encountered in the UST.

"Connected piping" means all underground piping including valves, elbows, joints, flanges, and flexible connectors attached to a tank system through which regulated substances flow. For the purpose of determining how much piping is connected to any individual UST system, the piping that joins two UST systems should be allocated equally between them.

"Consumptive use" with respect to heating oil means consumed on the premises.

"Corrosion expert" means a person who, by reason of thorough knowledge of the physical sciences and the principles of engineering and mathematics acquired by a professional education and related practical experience, is qualified to engage in the practice of corrosion control on buried or submerged metal piping systems and metal tanks. Such a person must be accredited or certified as being qualified by the National Association of Corrosion Engineers or be a registered professional engineer who has certification or licensing that includes education and experience in corrosion control of buried or submerged metal piping systems and metal tanks.

"Dielectric material" means a material that does not conduct direct electrical current. Dielectric coatings are used to electrically isolate UST systems from the surrounding soils. Dielectric bushings are used to electrically isolate portions of the UST system (e.g., tank from piping).

"Electrical equipment" means underground equipment that contains dielectric fluid that is necessary for the operation of equipment such as transformers and buried electrical cable.

"Excavation zone" means the volume containing the tank system and backfill material bounded by the ground surface, walls, and floor of the pit and trenches into which the UST system is placed at the time of installation.

"Existing tank system" means a tank system used to contain an accumulation of regulated substances or for which installation has commenced on or before December 22, 1988. Installation is considered to have commenced if:

(a) the owner or operator has obtained all federal, state, and local approvals or permits necessary to begin physical construction of the site or installation of the tank system; and if,

(b) (1) either a continuous on-site physical construction or installation program has begun; or,

(b) (2) the owner or operator has entered into contractual obligations--which cannot be cancelled or modified without substantial loss--for physical construction at the site or installation of the tank system to be completed within a reasonable time.

"Farm tank" is a tank located on a tract of land devoted to the production of crops or raising animals, including fish, and associated residences and improvements. A farm tank must be located on the farm property. "Farm" includes fish hatcheries, rangeland and nurseries with growing operations.

"Flow-through process tank" is a tank that forms an integral part of a production process through which there is a steady, variable, recurring, or intermittent flow of materials during the operation of the process. Flow-through process tanks do not include tanks used for the storage of materials prior to their introduction into the production process or for the storage of finished products or by-products from the production process.

"Free product" refers to a regulated substance that is present as a nonaqueous phase liquid (e.g., liquid not dissolved in water.)

"Gathering lines" means any pipeline, equipment, facility, or building used in the transportation of oil or gas during oil or gas production or gathering operations.

"Hazardous substance UST system" means an underground storage tank system that contains a hazardous substance defined in § 101(14) of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (but not including any substance regulated as a hazardous waste under subtitle C) or any mixture of such substances and petroleum, and which is not a petroleum UST system.

"Heating oil" means petroleum that is No. 1, No. 2, No. 4--light, No. 4--heavy, No. 5--light, No. 5--heavy, and No. 6 technical grades of fuel oil; other residual fuel oils (including Navy Special Fuel Oil and Bunker C); and other fuels when used as substitutes for one of these fuel oils. Heating oil is typically used in the operation of heating equipment, boilers, or furnaces.

"Hydraulic lift tank" means a tank holding hydraulic fluid for a closed-loop mechanical system that uses compressed air or hydraulic fluid to operate lifts, elevators, and other similar devices.

"Implementing agency" means EPA, or, in the case of a state with a program approved under § 9004 (or pursuant to a memorandum of agreement with EPA), the designated state or local agency responsible for carrying out an approved UST program.

"Liquid trap" means sumps, well cellars, and other traps used in association with oil and gas production, gathering, and extraction operations (including gas production plants), for the purpose of collecting oil, water, and other liquids. These liquid traps may temporarily collect liquids for subsequent disposition or reinjection into a production or pipeline stream, or may collect and separate liquids from a gas stream.

"Maintenance" means the normal operational upkeep to prevent an underground storage tank system from releasing product.

"Motor fuel" means petroleum or a petroleum-based substance that is motor gasoline, aviation gasoline, No. 1 or No. 2 diesel fuel, or any grade of gasohol, and is typically used in the operation of a motor engine.

"New tank system" means a tank system that will be used to contain an accumulation of regulated substances and for which installation has commenced after December 22, 1988. (See also "Existing Tank System.")

"Noncommercial purposes" with respect to motor fuel means not for resale.

"On the premises where stored" with respect to heating oil means UST systems located on the same property where the stored heating oil is used.

"Operational life" refers to the period beginning when installation of the tank system has commenced until the time the tank system is properly closed under Subpart G.

"Operator" means any person in control of, or having responsibility for, the daily operation of the UST system.

"Overfill release" is a release that occurs when a tank is filled beyond its capacity, resulting in a discharge of the regulated substance to the environment.

"Owner" means: (a) in the case of an UST system in use on November 8, 1984, or brought into use after that date, any person who owns an UST system used for storage, use, or dispensing of regulated substances; and (b) in the case of any UST system in use before November 8, 1984, but no longer in use on that date, any person who owned such UST immediately before the discontinuation of its use.

"Person" means an individual, trust, firm, joint stock company, federal agency, corporation, state, municipality, commission, political subdivision of a state, or any interstate body. "Person" also includes a consortium, a joint venture, a commercial entity, and the United States Government.

"Petroleum UST system" means an underground storage tank system that contains petroleum or a mixture of petroleum with *de minimis* quantities of other regulated substances. Such systems include those containing motor fuels, jet fuels, distillate fuel oils, residual fuel oils, lubricants, petroleum solvents, and used oils.

"Pipe" or "Piping" means a hollow cylinder or tubular conduit that is constructed of non-earthen materials.

"Pipeline facilities (including gathering lines)" are new and existing pipe rights-of-way and any associated equipment, facilities, or buildings.

"Regulated substance" means:

(a) any substance defined in § 101(14) of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 (but not including any substance regulated as a hazardous waste under subtitle C), and

(b) petroleum, including crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure (60 degrees Fahrenheit and 14.7 pounds per square inch absolute). The term "regulated substance" includes but is not limited to petroleum and petroleum-based substances comprised of a complex blend of hydrocarbons derived from crude oil through processes of separation, conversion, upgrading, and finishing, such as motor fuels, jet fuels, distillate fuel oils, residual fuel oils, lubricants, petroleum solvents, and used oils.

"Release" means any spilling, leaking, emitting, discharging, escaping, leaching or disposing from an UST into groundwater, surface water or subsurface soils.

"Release detection" means determining whether a release of a regulated substance has occurred from the UST system into the environment or into the interstitial space between the UST system and its secondary barrier or secondary containment around it.

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

"Residential tank" is a tank located on property used primarily for dwelling purposes.

"SARA" means the Superfund Amendments and Reauthorization Act of 1986.

"Septic tank" is a water-tight covered receptacle designed to receive or process, through liquid separation or biological digestion, the sewage discharged from a building sewer. The effluent from such receptacle is distributed for disposal through the soil and settled solids and scum from the tank are pumped out periodically and hauled to a treatment facility.

"Storm-water or wastewater collection system" means piping, pumps, conduits, and any other equipment necessary to collect and transport the flow of surface water run-off resulting from precipitation, or domestic, commercial, or industrial wastewater to and from retention areas or any areas where treatment is designated to occur. The collection of storm water and wastewater does not include treatment except where incidental to conveyance.

"Surface impoundment" is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials) that is not an injection well.

"Tank" is 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.

"Underground area" means an underground room, such as a basement, cellar, shaft or vault, providing enough space for physical inspection of the exterior of the tank situated on or above the surface of the floor.

"Underground release" means any belowground release.

"Underground storage tank" or "UST" means 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. This term does not include any:

(a) Farm or residential tank of 1,100 gallons or less capacity used for storing motor fuel for noncommercial purposes;

(b) Tank used for storing heating oil for consumptive use on the premises where stored;

(c) Septic tank;

(d) Pipeline facility (including gathering lines) regulated under:

(1) The Natural Gas Pipeline Safety Act of 1968 (49 U.S.C. App. 1671, et seq.), or

(2) The Hazardous Liquid Pipeline Safety Act of 1979 (49 U.S.C. App. 2001, et seq.), or

(3) Which is an intrastate pipeline facility regulated under state laws comparable to the provisions of the law referred to in paragraph (d) (1) or (d) (2) of this definition;

(e) Surface impoundment, pit, pond, or lagoon;

(f) Storm-water or wastewater collection system;

(g) Flow-through process tank;

(h) Liquid trap or associated gathering lines directly related to oil or gas production and gathering operations; or

(i) Storage tank situated in an underground area (such as a basement, cellar, mineworking, drift, shaft, or tunnel) if the storage tank is situated upon or above the surface of the floor.

The term "underground storage tank" or "UST" does not include any pipes connected to any tank which is described in paragraphs (a) through (i) of this definition.

"Upgrade" means the addition or retrofit of some systems 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.

"UST system" or "Tank system" means an underground storage tank, connected underground piping, underground ancillary equipment, and containment system, if any.

"Wastewater treatment tank" means a tank that is designed to receive and treat an influent wastewater through physical, chemical, or biological methods.

Subpart B-- UST Systems: Design, Construction, Installation and Notification

Section 280.20 Performance standards for new UST systems.

In order to prevent releases due to structural failure, corrosion, or spills and overfills for as long as the UST system is used to store regulated substances, all owners and operators of new UST systems must meet the following requirements.

(a) **Tanks.** Each tank must be properly designed and constructed, and any portion underground that routinely contains product must be protected from corrosion, in accordance with a code of practice developed by a nationally recognized association or independent testing laboratory as specified below:

(1) The tank is constructed of fiberglass-reinforced plastic; or

[Note: The following industry codes may be used to comply with paragraph (a) (1) of this section:
Underwriters Laboratories Standard 1316, "Standard for Glass- Fiber-Reinforced Plastic Underground Storage Tanks for Petroleum Products"; Underwriter's Laboratories of Canada CAN4-S615-M83, "Standard for Reinforced Plastic Underground Tanks for Petroleum Products"; or American Society of Testing and Materials Standard D4021-86, "Standard Specification for Glass-Fiber-Reinforced Polyester Underground Petroleum Storage Tanks."]

(2) The tank is constructed of steel and cathodically protected in the following manner:

(i) The tank is coated with a suitable dielectric material;

(ii) Field-installed Cathodic protection systems are designed by a corrosion expert;

(iii) Impressed current systems are designed to allow determination of current operating status as required in 280.31(c); and

(iv) Cathodic protection systems are operated and maintained in accordance with 280.31 or according to guidelines established by the implementing agency; or

[Note: The following codes and standards may be used to comply with paragraph (a) (2) of this section:

(A) Steel Tank Institute "Specification for STI-P3 System of External Corrosion Protection of Underground Steel Storage Tanks";

(B) Underwriters Laboratories Standard 1746, "Corrosion Protection Systems for Underground Storage Tanks";

(C) Underwriters Laboratories of Canada CAN4-S603-M85, "Standard for Steel Underground Tanks for Flammable and Combustible Liquids," and CAN4-G03.1-M85, "Standard for Galvanic Corrosion Protection Systems for Underground Tanks for Flammable and Combustible Liquids," and CAN4-S631-M84, "Isolating Bushings for Steel Underground Tanks Protected with Coatings and Galvanic Systems"; or

(D) National Association of Corrosion Engineers Standard RP-02-85, "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems," and Underwriters Laboratories Standard 58, "Standard for Steel Underground Tanks for Flammable and Combustible Liquids."]

(3) The tank is constructed of a steel-fiberglass-reinforced-plastic composite; or

[Note: The following industry codes may be used to comply with paragraph (a) (3) of this section:
Underwriters Laboratories Standard 1746, "Corrosion Protection Systems for Underground Storage Tanks," or the Association for Composite Tanks ACT-100, "Specification for the Fabrication of FRP Clad

Underground Storage Tanks.]

(4) The tank is constructed of metal without additional corrosion protection measures provided that:

(i) The tank is installed at a site that is determined by a corrosion expert not to be corrosive enough to cause it to have a release due to corrosion during its operating life; and

(ii) Owners and operators maintain records that demonstrate compliance with the requirements of paragraph (a) (4) (i) of this section for the remaining life of the tank; or

(5) The tank construction and corrosion protection are determined by the implementing agency to be designed to prevent the release or threatened release of any stored regulated substance in a manner that is no less protective of human health and the environment than paragraphs (a) (1) through (4) of this section.

(b) **Piping.** The piping that routinely contains regulated substances and is in contact with the ground must be properly designed, constructed, and protected from corrosion in accordance with a code of practice developed by a nationally recognized association or independent testing laboratory as specified below:

(1) The piping is constructed of fiberglass-reinforced plastic; or

[Note: The following codes and standards may be used to comply with paragraph (b) (1) of this section:

(A) Underwriters Laboratories Subject 971, "UL Listed Non-Metal Pipe";

(B) Underwriters Laboratories Standard 567, "Pipe Connectors for Flammable and Combustible and LP Gas";

(C) Underwriters Laboratories of Canada Guide ULC-107, "Glass Fiber Reinforced Plastic Pipe and Fittings for Flammable Liquids"; and

(D) Underwriters Laboratories of Canada Standard CAN 4-S633-M81, "Flexible Underground Hose Connectors."]

(2) The piping is constructed of steel and cathodically protected in the following manner:

(i) The piping is coated with a suitable dielectric material;

(ii) Field-installed Cathodic protection systems are designed by a corrosion expert;

(iii) Impressed current systems are designed to allow determination of current operating status as required in 280.31(c); and

(iv) Cathodic protection systems are operated and maintained in accordance with 280.31 or guidelines established by the implementing agency; or

[Note: The following codes and standards may be used to comply with paragraph (b) (2) of this section:

(A) National Fire Protection Association Standard 30, "Flammable and Combustible Liquids Code";

(B) American Petroleum Institute Publication 1615, "Installation of Underground Petroleum Storage Systems";

(C) American Petroleum Institute Publication 1632, "Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems"; and

(D) National Association of Corrosion Engineers Standard RP-01-69, "Control of External Corrosion on Submerged Metallic Piping Systems."]

(3) The piping is constructed of metal without additional corrosion protection measures provided that:

(i) The piping is installed at a site that is determined by a corrosion expert to not be corrosive enough to cause it to have a release due to corrosion during its operating life; and

(ii) Owners and operators maintain records that demonstrate compliance with the requirements of paragraph (b) (3) (i) of this section for the remaining life of the piping; or

[Note: National Fire Protection Association Standard 30, "Flammable and Combustible Liquids Code"; and National Association of Corrosion Engineers Standard RP-01-69, "Control of External Corrosion on Submerged Metallic Piping Systems," may be used to comply with paragraph (b) (3) of this section.]

(4) The piping construction and corrosion protection are determined by the implementing agency to be designed to prevent the release or threatened release of any stored regulated substance in a manner that is no less protective of human health and the environment than the requirements in paragraphs (b) (1) through (3) of this section.

(c) Spill and overfill prevention equipment.

(1) Except as provided in paragraph (c) (2) of this section, to prevent spilling and overfilling associated with product transfer to the UST system, owners and operators must use the following spill and overfill prevention equipment:

(i) Spill prevention equipment that will prevent release of product to the environment when the transfer hose is detached from the fill pipe (for example, a spill catchment basin); and

(ii) Overfill prevention equipment that will:

(A) Automatically shut off flow into the tank when the tank is no more than 95 percent full; or

(B) Alert the transfer operator when the tank is no more than 90 percent full by restricting the flow into the tank or triggering a high-level alarm; or

(C) Restrict flow 30 minutes prior to overfilling, alert the operator with a high level alarm one minute before overfilling, or automatically shut off flow into the tank so that none of the fittings located on top of the tank are exposed to product due to overfilling.

(2) Owners and operators are not required to use the spill and overfill prevention equipment specified in paragraph (c) (1) of this section if:

(i) Alternative equipment is used that is determined by the implementing agency to be no less protective of human health and the environment than the equipment specified in paragraph (c) (1) (i) or (ii) of this section; or

(ii) The UST system is filled by transfers of no more than 25 gallons at one time.

(d) **Installation.** All tanks and piping must be properly installed in accordance with a code of practice developed by a nationally recognized association or independent testing laboratory and in accordance with the manufacturer's instructions.

[Note: Tank and piping system installation practices and procedures described in the following codes may be used to comply with the requirements of paragraph (d) of this section:

(i) American Petroleum Institute Publication 1615, "Installation of Underground Petroleum Storage System"; or

(ii) Petroleum Equipment Institute Publication RP100, "Recommended Practices for Installation of Underground Liquid Storage Systems"; or

(iii) American National Standards Institute Standard B31.3, "Petroleum Refinery Piping," and American National Standards Institute Standard B31.4 "Liquid Petroleum Transportation Piping System."]

(e) **Certification of installation.** All owners and operators must ensure that one or more of the following methods of certification, testing, or inspection is used to demonstrate compliance with paragraph (d) of this section by providing a certification of compliance on the UST notification form in accordance with § 280.22.

- (1) The installer has been certified by the tank and piping manufacturers; or
- (2) The installer has been certified or licensed by the implementing agency; or
- (3) The installation has been inspected and certified by a registered professional engineer with education and experience in UST system installation; or
- (4) The installation has been inspected and approved by the implementing agency; or
- (5) All work listed in the manufacturer's installation checklists has been completed; or
- (6) The owner and operator have complied with another method for ensuring compliance with paragraph (d) of this section that is determined by the implementing agency to be no less protective of human health and the environment.

Section 280.21 Upgrading of existing UST systems.

(a) **Alternatives allowed.** Not later than December 22, 1998, all existing UST systems must comply with one of the following requirements:

- (1) New UST system performance standards under § 280.20;
 - (2) The upgrading requirements in sections (b) through (d) of this section; or
 - (3) Closure requirements under Subpart G of this Part, including applicable requirements for corrective action under Subpart F.
- (b) **Tank upgrading requirements.** Steel tanks must be upgraded to meet one of the following requirements in accordance with a code of practice developed by a nationally recognized association or independent testing laboratory:
- (1) **Interior lining.** A tank may be upgraded by internal lining if:
 - (i) The lining is installed in accordance with the requirements § 280.33, and
 - (ii) Within 10 years after lining, and every 5 years thereafter, the lined tank is internally inspected and found to be structurally sound with the lining still performing in accordance with original design specifications.
 - (2) **Cathodic protection.** A tank may be upgraded by Cathodic protection if the Cathodic protection system meets the requirements of § 280.20 (a) (2) (ii), (iii), and (iv) and the integrity of the tank is ensured using one of the following methods:
 - (i) The tank is internally inspected and assessed to ensure that the tank is structurally sound and free of corrosion holes prior to installing the Cathodic protection system; or
 - (ii) The tank has been installed for less than 10 years and is monitored monthly for releases in accordance with § 280.43 (d) through (h); or
 - (iii) The tank has been installed for less than 10 years and is assessed for corrosion holes by conducting two (2) tightness tests that meet the requirements of § 280.43 (c). The first tightness test must be conducted prior to installing the Cathodic protection system. The second tightness test must be conducted between three (3) and six (6) months following the first operation of the Cathodic protection system; or

(iv) The tank is assessed for corrosion holes by a method that is determined by the implementing agency to prevent releases in a manner that is no less protective of human health and the environment than paragraphs (b) (2) (i) through (iii) of this section.

(3) Internal lining combined with Cathodic protection. A tank may be upgraded by both internal lining and Cathodic protection if:

- (i) The lining is installed in accordance with the requirements of § 280.33; and
- (ii) The Cathodic protection system meets the requirements of § 280.20 (a) (2) (ii), (iii), and (iv).
[Note: The following codes and standards may be used to comply with this section:

(A) American Petroleum Institute Publication 1631, "Recommended Practice for the Interior Lining of Existing Steel Underground Storage Tanks";

(B) National Leak Prevention Association Standard 631, "Spill Prevention, Minimum 10 Year Life Extension of Existing Steel Underground Tanks by Lining Without the Addition of Cathodic Protection";

(C) National Association of Corrosion Engineers Standard RP-02-85, "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems"; and

(D) American Petroleum Institute Publication 1632, "Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems."]

(c) Piping upgrading requirements. Metal piping that routinely contains regulated substances and is in contact with the ground must be cathodically protected in accordance with a code of practice developed by a nationally recognized association or independent testing laboratory and must meet the requirements of § 280.20 (b) (2) (ii), (iii), and (iv).

[Note: The codes and standards listed in the note following § 280.20 (b) (2) may be used to comply with this requirement.]

(d) Spill and overfill prevention equipment. To prevent spilling and overfilling associated with product transfer to the UST system, all existing UST systems must comply with new UST system spill and overfill prevention equipment requirements specified in § 280.20 (c).

Section 280.22 Notification requirements.

(a) Any owner who brings an underground storage tank system into use after May 8, 1986, must within 30 days of bringing such tank into use, submit, in the form prescribed in Appendix I of this Part, a notice of existence of such tank system to the state or local agency or department designated in Appendix II of this Part to receive such notice.

[Note: Owners and operators of UST systems that were in the ground on or after May 8, 1986, unless taken out of operation on or before January 1, 1974, were required to notify the designated state or local agency in accordance with the Hazardous and Solid Waste Amendments of 1984, Public Law 98-616, on a form published by EPA on November 8, 1985 (50 FR 46602) unless notice was given pursuant to § 103 (c) of CERCLA. Owners and operators who have not complied with the notification requirements may use portions I through VI of the notification form contained in Appendix I of this Part.]

(b) In states where state law, regulations, or procedures require owners to use forms that differ from those set forth in Appendix I of this Part to fulfill the requirements of this section, the state forms may be submitted in lieu of the forms set forth in Appendix I of this Part. If a state requires that its form be used in lieu of the form presented in this regulation, such form must meet the requirements of § 9002.

(c) Owners required to submit notices under paragraph (a) of this section must provide notices to the appropriate agencies or departments identified in Appendix II of this Part for each tank they own. Owners may provide notice for several tanks using one notification form, but owners who own tanks located at

more than one place of operation must file a separate notification form for each separate place of operation.

(d) Notices required to be submitted under paragraph (a) of this section must provide all of the information in Sections I through VI of the prescribed form (or appropriate state form) for each tank for which notice must be given. Notices for tanks installed after December 22, 1988 must also provide all of the information in Section VII of the prescribed form (or appropriate state form) for each tank for which notice must be given.

(e) All owners and operators of new UST systems must certify in the notification form compliance with the following requirements:

(1) Installation of tanks and piping under § 280.20 (e);

(2) Cathodic protection of steel tanks and piping under § 280.20 (a) and (b);

(3) Financial responsibility under Subpart H of this Part; and

(4) Release detection under §§ 280.41 and 280.42.

(f) All owners and operators of new UST systems must ensure that the installer certifies in the notification form that the methods used to install the tanks and piping complies with the requirements in § 280.20 (d).

(g) Beginning October 24, 1988, any person who sells a tank intended to be used as an underground storage tank must notify the purchaser of such tank of the owner's notification obligations under paragraph (a) of this section. The form provided in Appendix III of this part may be used to comply with this requirement.

Subpart C--General Operating Requirements

Section 280.30 Spill and overfill control.

(a) Owners and operators must ensure that releases due to spilling or overfilling do not occur. The owner and operator must ensure that the volume available in the tank is greater than the volume of product to be transferred to the tank before the transfer is made and that the transfer operation is monitored constantly to prevent overfilling and spilling.

[Note: The transfer procedures described in National Fire Protection Association Publication 385 may be used to comply with paragraph (a) of this section. Further guidance on spill and overfill prevention appears in American Petroleum Institute Publication 1621, "Recommended Practice for Bulk Liquid Stock Control at Retail Outlets," and National Fire Protection Association Standard 30, "Flammable and Combustible Liquids Code."]

(b) The owner and operator must report, investigate, and clean up any spills and overfills in accordance with § 280.53.

Section 280.31 Operation and maintenance of corrosion protection.

All owners and operators of steel UST systems with corrosion protection must comply with the following requirements to ensure that releases due to corrosion are prevented for as long as the UST system is used to store regulated substances:

(a) All corrosion protection systems must be operated and maintained to continuously provide corrosion protection to the metal components of that portion of the tank and piping that routinely contain regulated substances and are in contact with the ground.

(b) All UST systems equipped with Cathodic protection systems must be inspected for proper operation by a qualified Cathodic protection tester in accordance with the following requirements:

(1) **Frequency.** All Cathodic protection systems must be tested within 6 months of installation and at least every 3 years thereafter or according to another reasonable time frame established by the implementing agency; and

(2) **Inspection criteria.** The criteria that are used to determine that Cathodic protection is adequate as required by this section must be in accordance with a code of practice developed by a nationally recognized association.

[Note: National Association of Corrosion Engineers Standard RP-02-85, "Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems," may be used to comply with paragraph (b) (2) of this section.]

(c) UST systems with impressed current Cathodic protection systems must also be inspected every 60 days to ensure the equipment is running properly.

(d) For UST systems using Cathodic protection, records of the operation of the Cathodic protection must be maintained (in accordance with § 280.34) to demonstrate compliance with the performance standards in this section. These records must provide the following:

(1) The results of the last three inspections required in paragraph (c) of this section; and

(2) The results of testing from the last two inspections required in paragraph (b) of this section.

Section 280.32 Compatibility.

Owners and operators must use an UST system made of or lined with materials that are compatible with the substance stored in the UST system.

[Note: Owners and operators storing alcohol blends may use the following codes to comply with the requirements of this section:

(A) American Petroleum Institute Publication 1626, "Storing and Handling Ethanol and Gasoline-Ethanol Blends at Distribution Terminals and Service Stations"; and

(B) American Petroleum Institute Publication 1627, "Storage and Handling of Gasoline-Methanol/Cosolvent Blends at Distribution Terminals and Service Stations."]

Section 280.33 Repairs allowed.

Owners and operators of UST systems must ensure that repairs will prevent releases due to structural failure or corrosion as long as the UST system is used to store regulated substances. The repairs must meet the following requirements:

(a) Repairs to UST systems must be properly conducted in accordance with a code of practice developed by a nationally recognized association or an independent testing laboratory.

[Note: The following codes and standards may be used to comply with paragraph (a) of this section: National Fire Protection Association Standard 30, "Flammable and Combustible Liquids Code"; American Petroleum Institute Publication 2200, "Repairing Crude Oil, Liquified Petroleum Gas, and Product Pipelines"; American Petroleum Institute Publication 1631, "Recommended Practice for the Interior Lining of Existing Steel Underground Storage Tanks"; and National Leak Prevention Association Standard 631, "Spill Prevention, Minimum 10 Year Life Extension of Existing Steel Underground Tanks by Lining Without the Addition of Cathodic Protection."]

(b) Repairs to fiberglass-reinforced plastic tanks may be made by the manufacturer's authorized representatives or in accordance with a code of practice developed by a nationally recognized association or an independent testing laboratory.

(c) Metal pipe sections and fittings that have released product as a result of corrosion or other damage must be replaced. Fiberglass pipes and fittings may be repaired in accordance with the manufacturer's specifications.

(d) Repaired tanks and piping must be tightness tested in accordance with § 280.43 (c) and § 280.44 (b) within 30 days following the date of the completion of the repair except as provided in paragraphs (d) (1) through (3), of this section:

(1) The repaired tank is internally inspected in accordance with a code of practice developed by a nationally recognized association or an independent testing laboratory; or

(2) The repaired portion of the UST system is monitored monthly for releases in accordance with a method specified in § 280.43 (d) through (h); or

(3) Another test method is used that is determined by the implementing agency to be no less protective of human health and the environment than those listed above.

(e) Within 6 months following the repair of any cathodically protected UST system, the Cathodic protection system must be tested in accordance with § 280.31 (b) and (c) to ensure that it is operating properly.

(f) UST system owners and operators must maintain records of each repair for the remaining operating life of the UST system that demonstrate compliance with the requirements of this section.

Section 280.34 Reporting and recordkeeping.

Owners and operators of UST systems must cooperate fully with inspections, monitoring and testing conducted by the implementing agency, as well as requests for document submission, testing, and monitoring by the owner or operator pursuant to § 9005 of Subtitle I of the Resource Conservation and Recovery Act, as amended.

(a) **Reporting.** Owners and operators must submit the following information to the implementing agency:

(1) Notification for all UST systems (§ 280.22), which includes certification of installation for new UST systems (§ 280.20 (e));

(2) Reports of all releases including suspected releases (§ 280.50), spills and overfills (§ 280.53), and confirmed releases (§ 280.61);

(3) Corrective actions planned or taken including initial abatement measures (§ 280.62), initial site characterization (§ 280.63), free product removal (§ 280.64), investigation of soil and groundwater cleanup (§ 280.65), and corrective action plan (§ 280.66); and

(4) A notification before permanent closure or change-in-service (§ 280.71).

(b) **Recordkeeping.** Owners and operators must maintain the following information:

(1) A corrosion expert's analysis of site corrosion potential if corrosion protection equipment is not used (§ 280.20 (a) (4); § 280.20 (b) (3)).

(2) Documentation of operation of corrosion protection equipment (§ 280.31);

(3) Documentation of UST system repairs (§ 280.33 (f));

(4) Recent compliance with release detection requirements (§ 280.45); and

(5) Results of the site investigation conducted at permanent closure (§ 280.74).

(c) **Availability and Maintenance of Records.** Owners and operators must keep the records required either:

(1) At the UST site and immediately available for inspection by the implementing agency; or

(2) At a readily available alternative site and be provided for inspection to the implementing agency upon request.

(3) In the case of permanent closure records required under 280.74, owners and operators are also provided with the additional alternative of mailing closure records to the implementing agency if they cannot be kept at the site or an alternative site as indicated above.

(Note: The recordkeeping and reporting requirements listed in this section have been approved by the Office of Management and Budget and have been assigned OMB Control No. 2050-0068.)

Subpart D--Release Detection

Section 280.40 General requirements for all UST systems.

(a) Owners and operators of new and existing UST systems must provide a method, or combination of methods, of release detection that:

(1) Can detect a release from any portion of the tank and the connected underground piping that routinely contains product;

(2) Is installed, calibrated, operated, and maintained in accordance with the manufacturer's instructions, including routine maintenance and service checks for operability or running condition; and

(3) Meets the performance requirements in § 280.43 or § 280.44, with any performance claims and their manner of determination described in writing by the equipment manufacturer or installer. In addition, methods used after the date shown in the following table corresponding with the specified method except for methods permanently installed prior to that date, must be capable of detecting the leak rate or quantity specified for that method in the corresponding section of the rule (also shown in the table) with a probability of detection (Pd) of 0.95 and a probability of false alarm (Pfa) of 0.05.

Method	Section	Date after which Pd/Pfa must be demonstrated
Manual Tank Gauging.	280.43 (b)	December 22, 1990.

Tank Tightness Testing.	280.43 (c)	December 22, 1990.
Automatic Tank Gauging.	280.43 (d)	December 22, 1991.
Automatic Line Leak Detectors.	280.44 (a)	September 22, 1991.
Line Tightness Testing.	280.44 (b)	December 22, 1990.

(b) When a release detection method operated in accordance with the performance standards in § 280.43 and § 280.44 indicates a release may have occurred, owners and operators must notify the implementing agency in accordance with Subpart E.

(c) Owners and operators of all UST systems must comply with the release detection requirements of this Subpart by December 22 of the year listed in the following table:

Schedule for Phase-in of Release Detection					
Year System Was Installed	1989	1990	1991	1992	1993
Before 1965 or date unknown	RD	P	-	-	-
1965 -1969	-	P/RD	-	-	-
1970-1974	-	P	RD	-	-
1975-1979	-	P	-	RD	-
1980-1988	-	P	-	-	RD
New tanks (after December 22)	Immediately upon installation				

P = Must begin release detection for all pressurized piping in accordance with § 280.41 (b) (1) and § 280.42 (b) (4).

RD = Must begin release detection for tanks and suction piping in accordance with § 280.41 (a), § 280.41 (b) (2), and § 280.42.

(d) Any existing UST system that cannot apply a method of release detection that complies with the requirements of this Subpart must complete the closure procedures in Subpart G by the date on which release detection is required for that UST system under paragraph (c) of this section.

Section 280.41 Requirements for petroleum UST systems.

Owners and operators of petroleum UST systems must provide release detection for tanks and piping as follows:

(a) **Tanks.** Tanks must be monitored at least every 30 days for releases using one of the methods listed in § 280.43 (d)-(h) except that:

(1) UST systems that meet the performance standards in § 280.20 or § 280.21, and the monthly inventory control requirements in § 280.43 (a) or (b), may use tank tightness testing (conducted in accordance with § 280.43 (c)) at least every 5 years until December 22, 1998, or until 10 years after the tank is installed or upgraded under § 280.21 (b), whichever is later;

(2) UST systems that do not meet the performance standards in § 280.20 or § 280.21 may use monthly inventory controls (conducted in accordance with § 280.43 (a) or (b)) and annual tank tightness testing (conducted in accordance with § 280.43 (c)) until December 22, 1998 when the tank must be upgraded under § 280.21 or permanently closed under § 280.71; and

(3) Tanks with capacity of 550 gallons or less may use weekly tank gauging (conducted in accordance with § 280.43 (b)).

(b) **Piping.** Underground piping that routinely contains regulated substances must be monitored for releases in a manner that meets one of the following requirements:

(1) **Pressurized piping.** Underground piping that conveys regulated substances under pressure must:

- (i) Be equipped with an automatic line leak detector conducted in accordance with § 280.44 (a); and

- (ii) Have an annual line tightness test conducted in accordance with § 280.44 (b) or have monthly monitoring conducted in accordance with § 280.44 (c).

(2) **Suction piping.** Underground piping that conveys regulated substances under suction must either have a line tightness test conducted at least every 3 years and in accordance with § 280.44 (b), or use a monthly monitoring method conduct in accordance with § 280.44 (c). No release detection is required for suction piping that is designed and constructed to meet the following standards:

- (i) The below-grade piping operates at less than atmospheric pressure;

- (ii) The below-grade piping is sloped so that the contents of the pipe will drain back into the storage tank if the suction is released;

- (iii) Only one check valve is included in each suction line;

- (iv) The check valve is located directly below and as close as practical to the suction pump; and

- (v) A method is provided that allows compliance with paragraphs (b) (2) (ii)-(iv) of this section to be readily determined.

Section 280.42 Requirements for hazardous substance UST systems.

Owners and operators of hazardous substance UST systems must provide release detection that meets the following requirements:

(a) Release detection at existing UST systems must meet the requirements for petroleum UST systems in § 280.41. By December 22, 1998, all existing hazardous substance UST systems must meet the release detection requirements for new systems in paragraph (b) of this section.

(b) Release detection at new hazardous substance UST systems must meet the following requirements:

- (1) Secondary containment systems must be designed, constructed and installed to:

- (i) Contain regulated substances released from the tank system until they are detected and removed;

- (ii) Prevent the release of regulated substances to the environment at any time during the operational life of the UST system; and

- (iii) Be checked for evidence of a release at least every 30 days.

[Note: The provisions of 40 CFR 265.193, Containment and Detection of Releases, may be used to comply with these requirements.]

(2) Double-walled tanks must be designed, constructed, and installed to:

- (i) Contain a release from any portion of the inner tank within the outer wall; and

- (ii) Detect the failure of the inner wall.

(3) External liners (including vaults) must be designed, constructed, and installed to:

- (i) Contain 100 percent of the capacity of the largest tank within its boundary;

- (ii) Prevent the interference of precipitation or groundwater intrusion with the ability to contain or detect a release of regulated substances; and

(iii) Surround the tank completely (i.e., it is capable of preventing lateral as well as vertical migration of regulated substances).

(4) Underground piping must be equipped with secondary containment that satisfies the requirements of paragraph (b) (1) of this section (e.g., trench liners, jacketing of double-walled pipe). In addition, underground piping that conveys regulated substances under pressure must be equipped with an automatic line leak detector in accordance with § 280.44 (a).

(5) Other methods of release detection may be used if owners and operators:

(i) Demonstrate to the implementing agency that an alternate method can detect a release of the stored substance as effectively as any of the methods allowed in § 280.43 (b)-(h) can detect a release of petroleum;

(ii) Provide information to the implementing agency on effective corrective action technologies, health risks, and chemical and physical properties of the stored substance, and the characteristics of the UST site; and,

(iii) Obtain approval from the implementing agency to use the alternate release detection method before the installation and operation of the new UST system.

Section 280.43 Methods of release detection for tanks.

Each method of release detection for tanks used to meet the requirements of § 280.41 must be conducted in accordance with the following:

(a) **Inventory control.** Product inventory control (or another test of equivalent performance) must be conducted monthly to detect a release of at least 1.0 percent of flow-through plus 130 gallons on a monthly basis in the following manner:

(1) Inventory volume measurements for regulated substance inputs, withdrawals, and the amount still remaining in the tank are recorded each operating day;

(2) The equipment used is capable of measuring the level of product over the full range of the tank's height to the nearest one-eighth of an inch;

(3) The regulated substance inputs are reconciled with delivery receipts by measurement of the tank inventory volume before and after delivery;

(4) Deliveries are made through a drop tube that extends to within one foot of the tank bottom;

(5) Product dispensing is metered and recorded within the local standards for meter calibration or an accuracy of 6 cubic inches for every 5 gallons of product withdrawn; and

(6) The measurement of any water level in the bottom of the tank is made to the nearest one-eighth of an inch at least once a month.

[Note: Practices described in the American Petroleum Institute Publication 1621, "Recommended Practice for Bulk Liquid Stock Control at Retail Outlets," may be used, where applicable, as guidance in meeting the requirements of this paragraph.]

(b) **Manual tank gauging.** Manual tank gauging must meet the following requirements:

(1) Tank liquid level measurements are taken at the beginning and ending of a period of at least 36 hours during which no liquid is added to or removed from the tank;

(2) Level measurements are based on an average of two consecutive stick readings at both the beginning and ending of the period;

(3) The equipment used is capable of measuring the level of product over the full range of the tank's

height to the nearest one-eighth of an inch;

(4) A leak is suspected and subject to the requirements of Subpart E if the variation between beginning and ending measurements exceeds the weekly or monthly standards in the following table:

Nominal Tank Capacity	Weekly Standard (one test)	Monthly Standard (average of four tests)
550 gallons or less	10 gallons	5 gallons
551-1,000 gallons	13 gallons	7 gallons
1,001-2,000 gallons	26 gallons	13 gallons

(5) Only tanks of 550 gallons or less nominal capacity may use this as the sole method of release detection. Tanks of 551 to 2,000 gallons may use the method in place of manual inventory control in § 280.43 (a). Tanks of greater than 2,000 gallons nominal capacity may not use this method to meet the requirements of this subpart.

c) **Tank tightness testing.** Tank tightness testing (or another test of equivalent performance) must be capable of detecting a 0.1 gallon per hour leak rate from any portion of the tank that routinely contains product while accounting for the effects of thermal expansion or contraction of the product, vapor pockets, tank deformation, evaporation or condensation, and the location of the water table.

(d) **Automatic tank gauging.** Equipment for automatic tank gauging that tests for the loss of product and conducts inventory control must meet the following requirements:

(1) The automatic product level monitor test can detect a 0.2 gallon per hour leak rate from any portion of the tank that routinely contains product; and

(2) Inventory control (or another test of equivalent performance) is conducted in accordance with the requirements of § 280.43 (a).

(e) **Vapor monitoring.** Testing or monitoring for vapors within the soil gas of the excavation zone must meet the following requirements:

(1) The materials used as backfill are sufficiently porous (e.g., gravel, sand, crushed rock) to readily allow diffusion of vapors from releases into the excavation area;

(2) The stored regulated substance, or a tracer compound placed in the tank system, is sufficiently volatile (e.g., gasoline) to result in a vapor level that is detectable by the monitoring devices located in the excavation zone in the event of a release from the tank;

(3) The measurement of vapors by the monitoring device is not rendered inoperative by the groundwater, rainfall, or soil moisture or other known interferences so that a release could go undetected for more than 30 days;

(4) The level of background contamination in the excavation zone will not interfere with the method used to detect releases from the tank;

(5) The vapor monitors are designed and operated to detect any significant increase in concentration above background of the regulated substance stored in the tank system, a component or components of that substance, or a tracer compound placed in the tank system;

(6) In the UST excavation zone, the site is assessed to ensure compliance with the requirements in paragraphs (e) (1)-(4) of this section and to establish the number and positioning of monitoring wells that will detect releases within the excavation zone from any portion of the tank that routinely contains product; and

(7) Monitoring wells are clearly marked and secured to avoid unauthorized access and tampering.

(f) **Groundwater monitoring.** Testing or monitoring for liquids on the groundwater must meet the following requirements:

- (1) The regulated substance stored is immiscible in water and has a specific gravity of less than one;
- (2) Groundwater is never more than 20 feet from the ground surface and the hydraulic conductivity of the soil(s) between the UST system and the monitoring wells or devices is not less than 0.01 cm/sec (e.g., the soil should consist of gravels, coarse to medium sands, coarse silts or other permeable materials);
- (3) The slotted portion of the monitoring well casing must be designed to prevent migration of natural soils or filter pack into the well and to allow entry of regulated substance on the water table into the well under both high and low groundwater conditions;
- (4) Monitoring wells shall be sealed from the ground surface to the top of the filter pack;
- (5) Monitoring wells or devices intercept the excavation zone or are as close to it as is technically feasible;
- (6) The continuous monitoring devices or manual methods used can detect the presence of at least one-eighth of an inch of free product on top of the groundwater in the monitoring wells;
- (7) Within and immediately below the UST system excavation zone, the site is assessed to ensure compliance with the requirements in paragraphs (f) (1)-(5) of this section and to establish the number and positioning of monitoring wells or devices that will detect releases from any portion of the tank that routinely contains product; and
- (8) Monitoring wells are clearly marked and secured to avoid unauthorized access and tampering.

(g) **Interstitial monitoring.** Interstitial monitoring between the UST system and a secondary barrier immediately around or beneath it may be used, but only if the system is designed, constructed and installed to detect a leak from any portion of the tank that routinely contains product and also meets one of the following requirements:

- (1) For double-walled UST systems, the sampling or testing method can detect a release through the inner wall in any portion of the tank that routinely contains product;

[Note: The provisions outlined in the Steel Tank Institute's "Standard for Dual Wall Underground Storage Tanks" may be used as guidance for aspects of the design and construction of underground steel double-walled tanks.]

(2) For UST systems with a secondary barrier within the excavation zone, the sampling or testing method used can detect a release between the UST system and the secondary barrier;

- (i) The secondary barrier around or beneath the UST system consists of artificially constructed material that is sufficiently thick and impermeable (at least 10^{-6} cm/sec for the regulated substance stored) to direct a release to the monitoring point and permit its detection;

(ii) The barrier is compatible with the regulated substance stored so that a release from the UST system will not cause a deterioration of the barrier allowing a release to pass through undetected;

- (iii) For cathodically protected tanks, the secondary barrier must be installed so that it does not interfere with the proper operation of the Cathodic protection system;

(iv) The groundwater, soil moisture, or rainfall will not render the testing or sampling method used inoperative so that a release could go undetected for more than 30 days;

(v) The site is assessed to ensure that the secondary barrier is always above the groundwater and not in a 25-year flood plain, unless the barrier and monitoring designs are for use under such conditions; and,

(vi) Monitoring wells are clearly marked and secured to avoid unauthorized access and tampering.

(3) For tanks with an internally fitted liner, an automated device can detect a release between the inner wall of the tank and the liner, and the liner is compatible with the substance stored.

(h) **Other methods.** Any other type of release detection method, or combination of methods, can be used if:

(1) It can detect a 0.2 gallon per hour leak rate or a release of 150 gallons within a month with a probability of detection of 0.95 and a probability of false alarm of 0.05; or

(2) The implementing agency may approve another method if the owner and operator can demonstrate that the method can detect a release as effectively as any of the methods allowed in paragraphs (c)-(h) of this section. In comparing methods, the implementing agency shall consider the size of release that the method can detect and the frequency and reliability with which it can be detected. If the method is approved, the owner and operator must comply with any conditions imposed by the implementing agency on its use to ensure the protection of human health and the environment.

Section 280.44 Methods of release detection for piping.

Each method of release detection for piping used to meet the requirements of § 280.41 must be conducted in accordance with the following:

(a) **Automatic line leak detectors.** Methods which alert the operator to the presence of a leak by restricting or shutting off the flow of regulated substances through piping or triggering an audible or visual alarm may be used only if they detect leaks of 3 gallons per hour at 10 pounds per square inch line pressure within 1 hour. An annual test of the operation of the leak detector must be conducted in accordance with the manufacturer's requirements.

(b) **Line tightness testing.** A periodic test of piping may be conducted only if it can detect a 0.1 gallon per hour leak rate at one and one-half times the operating pressure.

(c) **Applicable tank methods.** Any of the methods in § 280.43 (e)-(h) may be used if they are designed to detect a release from any portion of the underground piping that routinely contains regulated substances.

Section 280.45 Release detection recordkeeping.

All UST system owners and operators must maintain records in accordance with § 280.34 demonstrating compliance with all applicable requirements of this Subpart. These records must include the following:

(a) All written performance claims pertaining to any release detection system used, and the manner in which these claims have been justified or tested by the equipment manufacturer or installer, must be maintained for 5 years, or for another reasonable period of time determined by the implementing agency, from the date of installation;

(b) The results of any sampling, testing, or monitoring must be maintained for at least 1 year, or for another reasonable period of time determined by the implementing agency, except that the results of tank tightness testing conducted in accordance with § 280.43 (c) must be retained until the next test is conducted; and

(c) Written documentation of all calibration, maintenance, and repair of release detection equipment permanently located on-site must be maintained for at least one year after the servicing work is completed, or for another reasonable time period determined by the implementing agency. Any schedules

of required calibration and maintenance provided by the release detection equipment manufacturer must be retained for 5 years from the date of installation.

Subpart E--Release Reporting, Investigation, and Confirmation

Section 280.50 Reporting of suspected releases.

Owners and operators of UST systems must report to the implementing agency within 24 hours, or another reasonable time period specified by the implementing agency, and follow the procedures in § 280.52 for any of the following conditions:

- (a) The discovery by owners and operators or others of released regulated substances at the UST site or in the surrounding area (such as the presence of free product or vapors in soils, basements, sewer and utility lines, and nearby surface water).
- (b) Unusual operating conditions observed by owners and operators (such as the erratic behavior of product dispensing equipment, the sudden loss of product from the UST system, or an unexplained presence of water in the tank), unless system equipment is found to be defective but not leaking, and is immediately repaired or replaced; and,
- (c) Monitoring results from a release detection method required under § 280.41 and § 280.42 that indicate a release may have occurred unless:
 - (1) The monitoring device is found to be defective, and is immediately repaired, recalibrated or replaced, and additional monitoring does not confirm the initial result; or
 - (2) In the case of inventory control, a second month of data does not confirm the initial result.

Section 280.51 Investigation due to off-site impacts.

When required by the implementing agency, owners and operators of UST systems must follow the procedures in § 280.52 to determine if the UST system is the source of off-site impacts. These impacts include the discovery of regulated substances (such as the presence of free product or vapors in soils, basements, sewer and utility lines, and nearby surface and drinking waters) that has been observed by the implementing agency or brought to its attention by another party.

Section 280.52 Release investigation and confirmation steps.

Unless corrective action is initiated in accordance with Subpart F, owners and operators must immediately investigate and confirm all suspected releases of regulated substances requiring reporting under § 280.50 within 7 days, or another reasonable time period specified by the implementing agency, using either the following steps or another procedure approved by the implementing agency:

- (a) **System test.** Owners and operators must conduct tests (according to the requirements for tightness testing in § 280.43 (c) and § 280.44 (b)) that determine whether a leak exists in that portion of the tank that routinely contains product, or the attached delivery piping, or both.
 - (1) Owners and operators must repair, replace or upgrade the UST system, and begin corrective action in accordance with Subpart F if the test results for the system, tank, or delivery piping indicate that a leak exists.
 - (2) Further investigation is not required if the test results for the system, tank, and delivery piping do not indicate that a leak exists and if environmental contamination is not the basis for suspecting a release.
 - (3) Owners and operators must conduct a site check as described in paragraph (b) of this section if the test results for the system, tank, and delivery piping do not indicate that a leak exists but environmental contamination is the basis for suspecting a release.
- (b) **Site check.** Owners and operators must measure for the presence of a release where contamination is most likely to be present at the UST site. In selecting sample types, sample locations, and measurement methods, owners and operators must consider the nature of the stored substance, the type of initial alarm

or cause for suspicion, the type of backfill, the depth of groundwater, and other factors appropriate for identifying the presence and source of the release.

(1) If the test results for the excavation zone or the UST site indicate that a release has occurred, owners and operators must begin corrective action in accordance with Subpart F;

(2) If the test results for the excavation zone or the UST site do not indicate that a release has occurred, further investigation is not required.

Section 280.53 Reporting and cleanup of spills and overfills.

(a) Owners and operators of UST systems must contain and immediately clean up a spill or overfill and report to the implementing agency within 24 hours, or another reasonable time period specified by the implementing agency, and begin corrective action in accordance with Subpart F in the following cases:

(1) Spill or overfill of petroleum that results in a release to the environment that exceeds 25 gallons or another reasonable amount specified by the implementing agency, or that causes a sheen on nearby surface water; and

(2) Spill or overfill of a hazardous substance that results in a release to the environment that equals or exceeds its reportable quantity under CERCLA (40 CFR 302).

(b) Owners and operators of UST systems must contain and immediately clean up a spill or overfill of petroleum that is less than 25 gallons or another reasonable amount specified by the implementing agency, and a spill or overfill of a hazardous substance that is less than the reportable quantity. If cleanup cannot be accomplished within 24 hours, or another reasonable time period established by the implementing agency, owners and operators must immediately notify the implementing agency.

[Note: A release of a hazardous substance equal to or in excess of its reportable quantity must also be reported immediately (rather than within 24 hours) to the National Response Center under sections 102 and 103 of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (40 CFR 302.6) and to appropriate state and local authorities under Title III of the Superfund Amendments and Reauthorization Act of 1986 (40 CFR 355.40).]

Subpart F--Release Response and Corrective Action for UST Systems Containing Petroleum or Hazardous Substances

Section 280.60 General.

Owners and operators of petroleum or hazardous substance UST systems must, in response to a confirmed release from the UST system, comply with the requirements of this subpart except for USTs excluded under § 280.10 (b) and UST systems subject to RCRA Subtitle C corrective action requirements under § 3004 (u) of the Resource Conservation and Recovery Act, as amended.

Section 280.61 Initial response.

Upon confirmation of a release in accordance with § 280.52 or after a release from the UST system is identified in any other manner, owners and operators must perform the following initial response actions within 24 hours of a release or within another reasonable period of time determined by the implementing agency:

- (a) Report the release to the implementing agency (e.g., by telephone or electronic mail);
- (b) Take immediate action to prevent any further release of the regulated substance into the environment; and
- (c) Identify and mitigate fire, explosion, and vapor hazards.

Section 280.62 Initial abatement measures and site check.

- (a) Unless directed to do otherwise by the implementing agency, owners and operators must perform the following abatement measures:
- (1) Remove as much of the regulated substance from the UST system as is necessary to prevent further release to the environment;
- (2) Visually inspect any aboveground releases or exposed belowground releases and prevent further migration of the released substance into surrounding soils and groundwater;
- (3) Continue to monitor and mitigate any additional fire and safety hazards posed by vapors or free product that have migrated from the UST excavation zone and entered into subsurface structures (such as sewers or basements);
- (4) Remedy hazards posed by contaminated soils that are excavated or exposed as a result of release confirmation, site investigation, abatement, or corrective action activities. If these remedies include treatment or disposal of soils, the owner and operator must comply with applicable state and local requirements;
- (5) Measure for the presence of a release where contamination is most likely to be present at the UST site, unless the presence and source of the release have been confirmed in accordance with the site check required by § 280.52 (b) or the closure site assessment of § 280.72 (a). In selecting sample types, sample locations, and measurement methods, the owner and operator must consider the nature of the stored substance, the type of backfill, depth to groundwater and other factors as appropriate for identifying the presence and source of the release; and
- (6) Investigate to determine the possible presence of free product, and begin free product removal as soon as practicable and in accordance with § 280.64.
- (b) Within 20 days after release confirmation, or within another reasonable period of time determined by the implementing agency, owners and operators must submit a report to the implementing agency summarizing the initial abatement steps taken under paragraph (a) of this section and any resulting information or data.

Section 280.63 Initial site characterization.

- (a) Unless directed to do otherwise by the implementing agency, owners and operators must assemble information about the site and the nature of the release, including information gained while confirming the release or completing the initial abatement measures in § 280.60 and § 280.61. This information must include, but is not necessarily limited to the following:
- (1) Data on the nature and estimated quantity of release;
- (2) Data from available sources and/or site investigations concerning the following factors: surrounding populations, water quality, use and approximate locations of wells potentially affected by the release, subsurface soil conditions, locations of subsurface sewers, climatological conditions, and land use;
- (3) Results of the site check required under § 280.62 (a) (5); and
- (4) Results of the free product investigations required under § 280.62 (a) (6), to be used by owners and operators to determine whether free product must be recovered under § 280.64.
- (b) Within 45 days of release confirmation or another reasonable period of time determined by the implementing agency, owners and operators must submit the information collected in compliance with paragraph (a) of this section to the implementing agency in a manner that demonstrates its applicability and technical adequacy, or in a format and according to the schedule required by the implementing agency.

Section 280.64 Free product removal.

At sites where investigations under § 280.62 (a) (6) indicate the presence of free product, owners and operators must remove free product to the maximum extent practicable as determined by the implementing agency while continuing, as necessary, any actions initiated under § 280.61 through § 280.63, or preparing for actions required under § 280.65 through § 280.66. In meeting the requirements of this section, owners and operators must:

- (a) Conduct free product removal in a manner that minimizes the spread of contamination into previously uncontaminated zones by using recovery and disposal techniques appropriate to the hydrogeologic conditions at the site, and that properly treats, discharges or disposes of recovery byproducts in compliance with applicable local, state and federal regulations;
- (b) Use abatement of free product migration as a minimum objective for the design of the free product removal system;
- (c) Handle any flammable products in a safe and competent manner to prevent fires or explosions; and
- (d) Unless directed to do otherwise by the implementing agency, prepare and submit to the implementing agency, within 45 days after confirming a release, a free product removal report that provides at least the following information:
 - (1) The name of the person(s) responsible for implementing the free product removal measures;
 - (2) The estimated quantity, type, and thickness of free product observed or measured in wells, boreholes, and excavations;
 - (3) The type of free product recovery system used;
 - (4) Whether any discharge will take place on-site or off-site during the recovery operation and where this discharge will be located;
 - (5) The type of treatment applied to, and the effluent quality expected from, any discharge;
 - (6) The steps that have been or are being taken to obtain necessary permits for any discharge; and
 - (7) The disposition of the recovered free product.

Section 280.65 Investigations for soil and groundwater cleanup.

(a) In order to determine the full extent and location of soils contaminated by the release and the presence and concentrations of dissolved product contamination in the groundwater, owners and operators must conduct investigations of the release, the release site, and the surrounding area possibly affected by the release if any of the following conditions exist:

- (1) There is evidence that groundwater wells have been affected by the release (e.g., as found during release confirmation or previous corrective action measures);
- (2) Free product is found to need recovery in compliance with § 280.64;
- (3) There is evidence that contaminated soils may be in contact with groundwater (e.g., as found during conduct of the initial response measures or investigations required under § 280.60 through § 280.64); and
- (4) The implementing agency requests an investigation, based on the potential effects of contaminated soil or groundwater on nearby surface water and groundwater resources.

(b) Owners and operators must submit the information collected under paragraph (a) of this section as soon as practicable or in accordance with a schedule established by the implementing agency.

Section 280.66 Corrective action plan.

(a) At any point after reviewing the information submitted in compliance with § 280.61 through § 280.63, the implementing agency may require owners and operators to submit additional information or to develop and submit a corrective action plan for responding to contaminated soils and groundwater. If a plan is required, owners and operators must submit the plan according to a schedule and format established by the implementing agency. Alternatively, owners and operators may, after fulfilling the requirements of § 280.61 through § 280.63, choose to submit a corrective action plan for responding to contaminated soil and groundwater. In either case, owners and operators are responsible for submitting a plan that provides for adequate protection of human health and the environment as determined by the implementing agency, and must modify their plan as necessary to meet this standard.

(b) The implementing agency will approve the corrective action plan only after ensuring that implementation of the plan will adequately protect human health, safety, and the environment. In making this determination, the implementing agency should consider the following factors as appropriate:

(1) The physical and chemical characteristics of the regulated substance, including its toxicity, persistence, and potential for migration;

(2) The hydrogeologic characteristics of the facility and the surrounding area;

(3) The proximity, quality, and current and future uses of nearby surface water and groundwater;

(4) The potential effects of residual contamination on nearby surface water and groundwater;

(5) An exposure assessment; and

(6) Any information assembled in compliance with this subpart.

(c) Upon approval of the corrective action plan or as directed by the implementing agency, owners and operators must implement the plan, including modifications to the plan made by the implementing agency. They must monitor, evaluate, and report the results of implementing the plan in accordance with a schedule and in a format established by the implementing agency.

(d) Owners and operators may, in the interest of minimizing environmental contamination and promoting more effective cleanup, begin cleanup of soil and groundwater before the corrective action plan is approved provided that they:

(1) Notify the implementing agency of their intention to begin cleanup;

(2) Comply with any conditions imposed by the implementing agency, including halting cleanup or mitigating adverse consequences from cleanup activities; and

(3) Incorporate these self-initiated cleanup measures in the corrective action plan that is submitted to the implementing agency for approval.

Section 280.67 Public participation.

(a) For each confirmed release that requires a corrective action plan, the implementing agency must provide notice to the public by means designed to reach those members of the public directly affected by the release and the planned corrective action. This notice may include, but is not limited to, public notice in local newspapers, block advertisements, public service announcements, publication in a state register, letters to individual households, or personal contacts by field staff.

- (b) The implementing agency must ensure that site release information and decisions concerning the corrective action plan are made available to the public for inspection upon request.
 - (c) Before approving a corrective action plan, the implementing agency may hold a public meeting to consider comments on the proposed corrective action plan if there is sufficient public interest, or for any other reason.
 - (d) The implementing agency must give public notice that complies with paragraph (a) of this section if implementation of an approved corrective action plan does not achieve the established cleanup levels in the plan and termination of that plan is under consideration by the implementing agency.
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Subpart G--Out-of-Service UST Systems and Closure

Section 280.70 Temporary closure.

- (a) When an UST system is temporarily closed, owners and operators must continue operation and maintenance of corrosion protection in accordance with § 280.31, and any release detection in accordance with Subpart D. Subparts E and F must be complied with if a release is suspected or confirmed. However, release detection is not required as long as the UST system is empty. The UST system is empty when all materials have been removed using commonly employed practices so that no more than 2.5 centimeters (one inch) of residue, or 0.3 percent by weight of the total capacity of the UST system, remain in the system.
- (b) When an UST system is temporarily closed for 3 months or more, owners and operators must also comply with the following requirements:
- (1) Leave vent lines open and functioning; and
 - (2) Cap and secure all other lines, pumps, manways, and ancillary equipment.
- (c) When an UST system is temporarily closed for more than 12 months, owners and operators must permanently close the UST system if it does not meet either performance standards in § 280.20 for new UST systems or the upgrading requirements in § 280.21, *except that* the spill and overfill equipment requirements do not have to be met. Owners and operators must permanently close the substandard UST systems at the end of this 12-month period in accordance with §§ 280.71-280.74, *unless* the implementing agency provides an extension of the 12-month temporary closure period. Owners and operators must complete a site assessment in accordance with § 280.72 before such an extension can be applied for.

Section 280.71 Permanent closure and changes-in-service.

- (a) At least 30 days before beginning either permanent closure or a change-in-service under paragraphs (b) and (c) of this section, or within another reasonable time period determined by the implementing agency, owners and operators must notify the implementing agency of their intent to permanently close or make the change-in-service, *unless* such action is in response to corrective action. The required assessment of the excavation zone under § 280.72 must be performed after notifying the implementing agency but before completion of the permanent closure or a change-in-service.
- (b) To permanently close a tank, owners and operators must empty and clean it by removing all liquids and accumulated sludges. All tanks taken out of service permanently must also be either removed from the ground or filled it with an inert solid material.
- (c) Continued use of an UST system to store a non-regulated substance is considered a change-in-service. Before a change-in-service, owners and operators must empty and clean the tank by removing all liquid and accumulated sludge and conduct a site assessment in accordance with § 280.72.

[Note: The following cleaning and closure procedures may be used to comply with this section:

- (A) American Petroleum Institute Recommended Practice 1604, "Removal and Disposal of Used Underground Petroleum Storage Tanks";
- (B) American Petroleum Institute Publication 2015, "Cleaning Petroleum Storage Tanks";
- (C) American Petroleum Institute Recommended Practice 1631, "Interior Lining of Underground Storage Tanks," may be used as guidance for compliance with this section; and
- (D) The National Institute for Occupational Safety and Health "Criteria for a Recommended Standard...Working in Confined Space" may be used as guidance for conducting safe closure procedures at some hazardous substance tanks.]

Section 280.72 Assessing the site at closure or change-in-service.

(a) Before permanent closure or a change-in-service is completed, owners and operators must measure for the presence of a release where contamination is most likely to be present at the UST site. In selecting sample types, sample locations, and measurement methods, owners and operators must consider the method of closure, the nature of the stored substance, the type of backfill, the depth to groundwater, and other factors appropriate for identifying the presence of a release. The requirements of this section are satisfied if one of the external release detection methods allowed in § 280.43 (e) and (f) is operating in accordance with the requirements in § 280.43 at the time of closure, and indicates no release has occurred.

(b) If contaminated soils, contaminated groundwater, or free product as a liquid or vapor is discovered under paragraph (a) of this section, or by any other manner, owners and operators must begin corrective action in accordance with Subpart F.

Section 280.73 Applicability to previously closed UST systems.

When directed by the implementing agency, the owner and operator of an UST system permanently closed before December 22, 1988 must assess the excavation zone and close the UST system in accordance with this Subpart if releases from the UST may, in the judgment of the implementing agency, pose a current or potential threat to human health and the environment.

Section 280.74 Closure records.

Owners and operators must maintain records in accordance with § 280.34 that are capable of demonstrating compliance with closure requirements under this Subpart. The results of the excavation zone assessment required in § 280.72 must be maintained for at least 3 years after completion of permanent closure or change-in-service in one of the following ways:

- (a) By the owners and operators who took the UST system out of service;
- (b) By the current owners and operators of the UST system site; or
- (c) By mailing these records to the implementing agency if they cannot be maintained at the closed facility.

Appendix I--Notification for Underground Storage Tanks (Form)

This form has been revised--<http://www.epa.gov/swerust1/fedlaws/ustform>

Appendix II--List of Agencies

his list has been updated--<http://www.epa.gov/swerust1/states/statcon1.htm>.

Appendix III--Statement for Shipping Tickets and Invoices

Note.--A Federal law (the Resource Conservation and Recovery Act (RCRA), as amended (Pub. L. 98-616)) requires owners of certain underground storage tanks to notify designated State or local agencies by May 8, 1986, of the existence of their tanks. Notifications for tanks brought into use after May 8, 1986, must be made within 30 days. Consult EPA's regulations, issued on November 8, 1985 (40 CFR Part 280) to determine if you are affected by this law.

§280.74 Closure records.

Owners and operators must maintain records in accordance with §280.34 that are capable of demonstrating compliance with closure requirements under this subpart. The results of the excavation zone assessment required in §280.72 must be maintained for at least 3 years after completion of permanent closure or change-in-service in one of the following ways:

- (a) By the owners and operators who took the UST system out of service;
- (b) By the current owners and operators of the UST system site; or
- (c) By mailing these records to the implementing agency if they cannot be maintained at the closed facility.



Appendix II to Part 280 -- List of Agencies Designated To Receive Notifications

Alabama (EPA Form), Alabama Department of Environmental Management, Groundwater Section/Water Division, 1751 Congressman W.L. Dickinson Drive, Montgomery, Alabama 36130, 205/271-7823

Alaska (EPA Form), Department of Environmental Conservation, Box 0, Juneau, Alaska 99811-1800, 970/465-2653

American Samoa (EPA Form), Executive Secretary, Environmental Quality Commission, Office of the Governor, American Samoan Government, Pago Pago, American Samoa 96799; Attention: UST Notification

Arizona (EPA Form), Attention: UST Coordinator, Arizona Department of Environmental Quality, Environmental Health Services, 2005 N. Central, Phoenix, Arizona 85004

Arkansas (EPA Form), Arkansas Department of Pollution Control and Ecology, P.O. Box 9583, Little Rock, Arkansas 72219, 501/562-7444

California (State Form), Executive Director, State Water Resources Control Board, P.O. Box 100, Sacramento, California 95801, 916/445-1533

Colorado (EPA Form), Section Chief, Colorado Department of Health, Waste Management Division, Underground Tank Program, 4210 East 11th Avenue, Denver, Colorado 80220, 303/320-8333

Connecticut (State Form), Hazardous Materials Management Unit, Department of Environmental Protection, State Office Building, 165 Capitol Avenue, Hartford, Connecticut 06106

Delaware (State Form), Division of Air and Waste Management, Department of Natural Resources and Environmental Control, P.O. Box 1401, 89 Kings Highway, Dover, Delaware 19903, 302/726-5409

District of Columbia (EPA Form), Attention: UST Notification Form, Department of Consumer and Regulatory Affairs, Pesticides and Hazardous Waste Management Branch, Room 114, 5010 Overlook Avenue SW., Washington, DC 20032

Florida (State Form), Florida Department of Environmental Regulation, Solid Waste Section, Twin Towers Office Building, 2600 Blair Stone Road, Tallahassee, Florida 32399, 904/487-4398

Georgia (EPA Form), Georgia Department of Natural Resources, Environmental Protection Division, Underground Storage Tank Program, 3420 Norman Berry Drive, 7th Floor, Hapeville, Georgia 30354, 404/656-7404

Guam (State Form), Administrator, Guam Environmental Protection Agency, P.O. Box 2999, Agana, Guam 96910, Overseas Operator (Commercial call 646-8863)

Hawaii (EPA Form), Administrator, Hazardous Waste Program, 645 Halekauwila Street, Honolulu, Hawaii 96813, 808/548-2270

Idaho (EPA Form), Underground Storage Tank Coordinator, Water Quality Bureau, Division of Environmental Quality, Idaho Department of Health and Welfare, 450 W. State Street, Boise, Idaho 83720, 208/334-4251

Illinois (EPA Form), Underground Storage Tank Coordinator, Division of Fire Prevention, Office of State Fire Marshal, 3150 Executive Park Drive, Springfield, Illinois 62703-4599

Indiana (EPA Form), Underground Storage Tank Program, Office of Environmental Response, Indiana Department of Environmental Management, 105 South Meridian Street, Indianapolis, Indiana 46225

Iowa (State Form), UST Coordinator, Iowa Department of Natural Resources, Henry A. Wallace Building, 900 East Grand, Des Moines, Iowa 50219, 512/281-8135

Kansas (EPA Form), Kansas Department of Health and Environment, Forbes Field, Building 740, Topeka, Kansas 66620, 913/296-1594

Kentucky (State Form), Department of Environmental Protection, Hazardous Waste Branch, Fort Boone Plaza, Building #2, 18 Reilly Road, Frankfort, Kentucky 40601, 501/564-6716

Louisiana (State Form), Secretary, Louisiana Department of Environmental Quality, P.O. Box 44066, Baton Rouge, Louisiana 70804, 501/342-1265

Maine (State Form), Attention: Underground Tanks Program, Bureau of Oil and Hazardous Material Control, Department of Environmental Protection, State House -- Station 17, Augusta, Maine 04333

Maryland (EPA Form), Science and Health Advisory Group, Office of Environmental Programs, 201 West Preston Street, Baltimore, Maryland 21201

Massachusetts (EPA Form), UST Registry, Department of Public Safety, 1010 Commonwealth Avenue, Boston, Massachusetts 02215, 617/566-4500

Michigan (EPA Form), Michigan Department of State Police, Fire Marshal Division, General Office Building, 7150 Harris Drive, Lansing, Michigan 48913

Minnesota (State Form), Underground Storage Tank Program, Division of Solid and Hazardous Wastes, Minnesota Pollution Control Agency, 520 West Lafayette Road, St. Paul, Minnesota 55155

Mississippi (State Form), Department of Natural Resources, Bureau of Pollution Control, Underground Storage Tank Section, P.O. Box 10385, Jackson, Mississippi 39209, 601/961-5171

Missouri (EPA Form), UST Coordinator, Missouri Department of Natural Resources, P.O. Box 176, Jefferson City, Missouri 65102, 314/751-7428

Montana (EPA Form), Solid and Hazardous Waste Bureau, Department of Health and Environmental Science, Cogswell Bldg., Room B-201, Helena, Montana 59620

Nebraska (EPA Form), Nebraska State Fire Marshal, P.O. Box 94677, Lincoln, Nebraska 68509-4677, 402/471-9465

Nevada (EPA Form), Attention: UST Coordinator, Division of Environmental Protection, Department of Conservation and Natural Resources, Capitol Complex 201 S. Fall Street, Carson City, Nevada 89710, 800/992-0900, Ext. 4670, 702/885-4670

New Hampshire (EPA Form), NH Dept. of Environmental Services, Water Supply and Pollution Control Division, Hazen Drive, P.O. Box 95, Concord, New Hampshire 03301, Attention: UST Registration

New Jersey (State Form), Underground Storage Tank Coordinator, Department of Environmental Protection, Division of Water Resources (CN-029), Trenton, New Jersey 08625, 609/292-0424

New Mexico (EPA Form), New Mexico Environmental Improvement Division, Groundwater/Hazardous Waste Bureau, P.O. Box 968, Santa Fe, New Mexico 37504, 505/827-2933

New York (EPA Form), Bulk Storage Section, Division of Water, Department of Environmental Conservation, 50 Wolf Road, Room 326, Albany, New York 12233-0001, 518/457-4351

North Carolina (EPA Form), Division of Environmental Management, Groundwater Operations Branch, Department of Natural Resources and Community Development, P.O. Box 27687, Raleigh, North Carolina 27611, 919/733-3221

North Dakota (State Form), Division of Hazardous Management and Special Studies, North Dakota Department of Health, Box 5520, Bismarck, North Dakota 58502-5520

Northern Mariana Islands (EPA Form), Chief, Division of Environmental Quality, P.O. Box 1304, Commonwealth of Northern Mariana Islands, Saipan, CM 96950, Cable Address: Gov. NMI Saipan, Overseas Operator: 6984

Ohio (State Form), State Fire Marshal's Office, Department of Commerce, 8895 E. Main Street, Reynoldsburg, Ohio 43068, State Hotline: 800/282-1927

Oklahoma (EPA Form), Underground Storage Tank Program, Oklahoma Corporation Comm., Jim Thorpe Building, Oklahoma City, Oklahoma 73105

Oregon (State Form), Underground Storage Tank Program, Hazardous and Solid Waste Division, Department of Environmental Quality, 811 S.W. Sixth Avenue, Portland, Oregon 98204, 503/229-5788

Pennsylvania (EPA Form), PA Department of Environmental Resources, Bureau of Water Quality Management, Groundwater Unit, 9th Floor Fulton Building, P.O. Box 2063, Harrisburg, Pennsylvania 17120

Puerto Rico (EPA Form), Director, Water Quality Control Area, Environmental Quality Board, Commonwealth of Puerto Rico, Santurce, Puerto Rico, 809/725-0717

Rhode Island (EPA Form), UST Registration, Department of Environmental Management, 83 Park Street, Providence, Rhode Island 02903, 401/277-2234

South Carolina (State Form), Groundwater Protection Division, South Carolina Department of Health and Environmental Control, 2600 Bull Street, Columbia, South Carolina 29201, 803/758-5213

South Dakota (EPA Form), Office of Water Quality, Department of Water and Natural Resources, Joe Foss Building, Pierre, South Dakota 57501,

Tennessee (EPA Form), Tennessee Department of Health and Environment, Division of Superfund Underground Storage Tank Section, 150 Ninth Avenue, North, Nashville, Tennessee 37219-5404, 615/741-0690

Texas (EPA Form), Underground Storage Tank Program, Texas Water Commission, P.O. Box 13087, Austin, Texas 78711

Utah (EPA Form), Division of Environmental Health, P.O. Box 45500, Salt Lake City, Utah 84145-0500
Vermont (State Form), Underground Storage Tank Program, Vermont AEC/Waste Management Division, State Office Building, Montpelier, Vermont 05602, 802/828-3395

Virginia (EPA Form), Virginia Water Control Board, P.O. Box 11143, Richmond, Virginia 23230-1143, 804/257-6685

Virgin Islands (EPA Form), 205(J) Coordinator, Division of Natural Resources Management, 14 F Building 111, Watergut Homes, Christiansted, St. Croix, Virgin Islands 00820

Washington (State Form), Underground Storage Tank Notification, Solid and Hazardous Waste Program, Department of Ecology, M/S PV-11, Olympia, Washington 98504-8711, 206/459-6316

West Virginia (EPA Form), Attention: UST Notification, Solid and Hazardous Waste, Groundwater Branch, West Virginia Department of Natural Resources, 1201 Greenbriar Street, Charleston, West Virginia 25311

Wisconsin (State Form), Bureau of Petroleum Inspection, P.O. Box 7969, Madison, Wisconsin 53707, 608/266-7605

Wyoming (EPA Form), Water Quality Division, Department of Environmental Quality, Herschler Building, 4th Floor West, 122 West 25th Street, Cheyenne, Wyoming 82002, 307/777-7781.



Glossary

A

Absolute Pressure: The pressure above zone absolute, i.e. the sum of atmospheric and gauge pressure. In vacuum related work it is usually expressed in millimeters of mercury. (mmHg).

Aerodynamics: The study of the flow of gases. The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.

Aeronautics: The mathematics and mechanics of flying objects, in particular airplanes.

Air Break: A physical separation which may be a low inlet into the indirect waste receptor from the fixture, or device that is indirectly connected. You will most likely find an air break on waste fixtures or on non-potable lines. You should never allow an air break on an ice machine.

Air Gap Separation: A physical separation space that is present between the discharge vessel and the receiving vessel, for an example, a kitchen faucet.

Altitude-Control Valve: If an overflow occurs on a storage tank, the operator should first check the altitude-control valve. Altitude-Control Valve is designed to, 1. Prevent overflows from the storage tank or reservoir, or 2. Maintain a constant water level as long as water pressure in the distribution system is adequate.

Angular Motion Formulas: Angular velocity can be expressed as (angular velocity = constant):

$$\omega = \theta / t \quad (2a)$$

where

ω = angular velocity (rad/s)

θ = angular displacement (rad)

t = time (s)

Angular velocity can be expressed as (angular acceleration = constant):

$$\omega = \omega_0 + \alpha t \quad (2b)$$

where

ω_0 = angular velocity at time zero (rad/s)

α = angular acceleration (rad/s²)

Angular displacement can be expressed as (angular acceleration = constant):

$$\theta = \omega_0 t + 1/2 \alpha t^2 \quad (2c)$$

Combining 2a and 2c:

$$\omega = (\omega_0^2 + 2 \alpha \theta)^{1/2}$$

Angular acceleration can be expressed as:

$$\alpha = d\omega / dt = d^2\theta / dt^2 \quad (2d)$$

where

$d\theta$ = change of angular displacement (rad)

dt = change in time (s)

Atmospheric Pressure: Pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute, 1 bar = 14.5psi.)

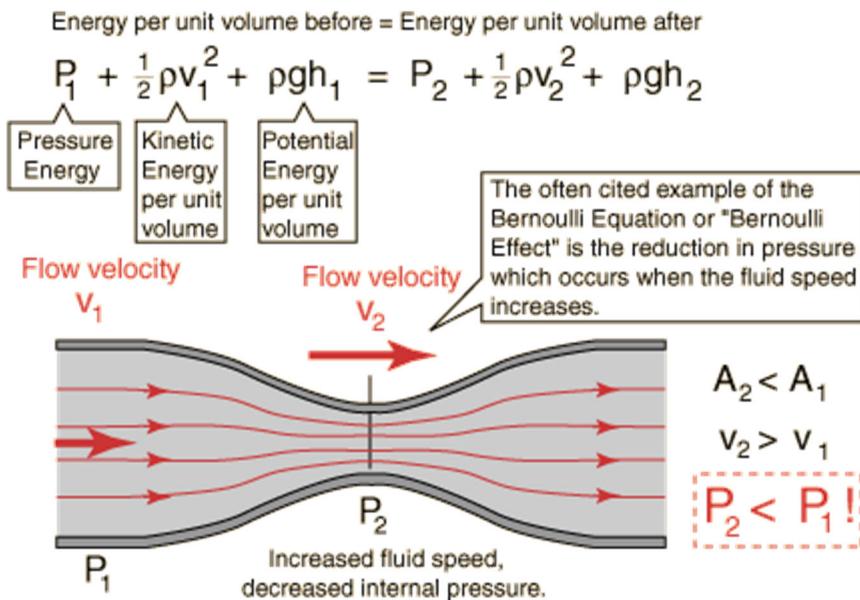
B

Backflow Prevention: To stop or prevent the occurrence of, the unnatural act of reversing the normal direction of the flow of liquid, gases, or solid substances back in to the public potable (drinking) water supply. See Cross-connection control.

Backflow: To reverse the natural and normal directional flow of a liquid, gases, or solid substances back in to the public potable (drinking) water supply. This is normally an undesirable effect.

Backsiphonage: A liquid substance that is carried over a higher point. It is the method by which the liquid substance may be forced by excess pressure over or into a higher point. Is a condition in which the pressure in the distribution system is less than atmospheric pressure. In other words, something is "sucked" into the system because the main is under a vacuum.

Bernoulli's Equation: Describes the behavior of moving fluids along a streamline. The Bernoulli Equation can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids. The qualitative behavior that is usually labeled with the term "**Bernoulli effect**" is the lowering of fluid pressure in regions where the flow velocity is increased. This lowering of pressure in a constriction of a flow path may seem counterintuitive, but seems less so when you consider pressure to be energy density. In the high velocity flow through the constriction, kinetic energy must increase at the expense of pressure energy.



A special form of the Euler's equation derived along a fluid flow streamline is often called the **Bernoulli Equation**.

$$\frac{\partial}{\partial s} \left(\frac{v^2}{2} + \frac{p}{\rho} + g \cdot h \right) = 0 \quad (1)$$

where

v = flow speed

p = pressure

ρ = density

g = gravity

h = height

$$\frac{v^2}{2} + \frac{p}{\rho} + g \cdot h = \text{Constant} \quad (2)$$

$$\frac{v^2}{2 \cdot g} + \frac{p}{\gamma} + h = \text{Constant} \quad (3)$$

where

$$\gamma = \rho \cdot g$$

$$\frac{\rho \cdot v^2}{2} + p = \text{Constant} \quad (4)$$

$$\frac{\rho \cdot v^2}{2} = p_d \quad (5)$$

$$\frac{\rho \cdot v_1^2}{2} + p_1 = \frac{\rho \cdot v_2^2}{2} + p_2 = \text{Constant} \quad (6)$$

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For steady state incompressible flow the Euler equation becomes (1). If we integrate (1) along the streamline it becomes (2). (2) can further be modified to (3) by dividing by gravity.

Head of Flow: Equation (3) is often referred to as the **head** because all elements have the unit of length.

Bernoulli's Equation Continued:

Dynamic Pressure

(2) and (3) are two forms of the Bernoulli Equation for steady state incompressible flow. If we assume that the gravitational body force is negligible, (3) can be written as (4). Both elements in the equation have the unit of pressure and it's common to refer the flow velocity component as the **dynamic pressure** of the fluid flow (5).

Since energy is conserved along the streamline, (4) can be expressed as (6). Using the equation we see that increasing the velocity of the flow will reduce the pressure, decreasing the velocity will increase the pressure.

This phenomena can be observed in a **venturi meter** where the pressure is reduced in the constriction area and regained after. It can also be observed in a **pitot tube** where the **stagnation** pressure is measured. The stagnation pressure is where the velocity component is zero.

Bernoulli's Equation Continued:

Pressurized Tank

If the tanks are pressurized so that product of gravity and height ($g h$) is much less than the pressure difference divided by the density, (e4) can be transformed to (e6).

The velocity out from the tanks depends mostly on the pressure difference.

Example - outlet velocity from a pressurized tank

The outlet velocity of a pressurized tank where

$$p_1 = 0.2 \text{ MN/m}^2, p_2 = 0.1 \text{ MN/m}^2 A_2/A_1 = 0.01, h = 10 \text{ m}$$

can be calculated as

$$V_2 = [(2/(1-(0.01)^2)) ((0.2 - 0.1) \times 10^6 / 1 \times 10^3 + 9.81 \times 10)]^{1/2} = \underline{19.9 \text{ m/s}}$$

Coefficient of Discharge - Friction Coefficient

Due to friction the real velocity will be somewhat lower than this theoretical example. If we introduce a **friction coefficient** c (coefficient of discharge), (e5) can be expressed as (e5b). The coefficient of discharge can be determined experimentally. For a sharp edged opening it may be as low as 0.6. For smooth orifices it may be between 0.95 and 1.

Bingham Plastic Fluids: Bingham Plastic Fluids have a yield value which must be exceeded before it will start to flow like a fluid. From that point the viscosity will decrease with increase of agitation. Toothpaste, mayonnaise and tomato catsup are examples of such products.

Boundary Layer: The layer of fluid in the immediate vicinity of a bounding surface.

Bulk Modulus and Fluid Elasticity: An introduction to and a definition of the Bulk Modulus Elasticity commonly used to characterize the compressibility of fluids.

The Bulk Modulus Elasticity can be expressed as

$$E = -dp / (dV / V) \quad (1)$$

where

E = bulk modulus elasticity

dp = differential change in pressure on the object

dV = differential change in volume of the object

V = initial volume of the object

The Bulk Modulus Elasticity can be alternatively expressed as

$$E = -dp / (dp / \rho) \quad (2)$$

where

dp = differential change in density of the object

ρ = initial density of the object

An increase in the pressure will decrease the volume (1). A decrease in the volume will increase the density (2).

- The SI unit of the bulk modulus elasticity is N/m² (Pa)
- The imperial (BG) unit is lb_f/in² (psi)
- 1 lb_f/in² (psi) = 6.894 × 10³ N/m² (Pa)

A large Bulk Modulus indicates a relatively incompressible fluid.

Bulk Modulus for some common fluids can be found in the table below:

Bulk Modulus - E	Imperial Units - BG (psi, lb/in ²) x 10 ⁵	SI Units (Pa, N/m ²) x 10 ⁹
Carbon Tetrachloride	1.91	1.31
Ethyl Alcohol	1.54	1.06
Gasoline	1.9	1.3
Glycerin	6.56	4.52
Mercury	4.14	2.85
SAE 30 Oil	2.2	1.5
Seawater	3.39	2.35
Water	3.12	2.15

C

Capillarity: (or capillary action) The ability of a narrow tube to draw a liquid upwards against the force of gravity.

The height of liquid in a tube due to capillarity can be expressed as

$$h = 2 \sigma \cos\theta / (\rho g r) \quad (1)$$

where

h = height of liquid (ft, m)

σ = surface tension (lb/ft, N/m)

θ = contact angle

ρ = density of liquid (lb/ft³, kg/m³)

g = acceleration due to gravity (32.174 ft/s², 9.81 m/s²)

r = radius of tube (ft, m)

Cauchy Number: A dimensionless value useful for analyzing fluid flow dynamics problems where compressibility is a significant factor.

The Cauchy Number is the ratio between inertial and the compressibility force in a flow and can be expressed as

$$C = \rho v^2 / E \quad (1)$$

where

ρ = density (kg/m³)

v = flow velocity (m/s)

E = bulk modulus elasticity (N/m²)

The bulk modulus elasticity has the dimension pressure and is commonly used to characterize the compressibility of a fluid.

The Cauchy Number is the square root of the Mach Number

$$M^2 = Ca \quad (3)$$

where

C = Mach Number

Cavitation: Under the wrong condition, cavitation will reduce the components life time dramatically. Cavitation may occur when the local static pressure in a fluid reach a level below the vapor pressure of the liquid at the actual temperature. According to the Bernoulli Equation this may happen when the fluid accelerates in a control valve or around a pump impeller. The vaporization itself does not cause the damage - the damage happens when the vapor almost immediately collapses after evaporation when the velocity is decreased and pressure increased. Cavitation means that cavities are forming in the liquid that we are pumping. When these cavities form at the suction of the pump several things happen all at once: We experience a loss in capacity. We can no longer build the same head (pressure). The efficiency drops. The cavities or bubbles will collapse when they pass into the higher regions of pressure causing noise, vibration, and damage to many of the components. The cavities form for five basic reasons and it is common practice to lump all of them into the general classification of cavitation.

This is an error because we will learn that to correct each of these conditions we must understand why they occur and how to fix them. Here they are in no particular order: Vaporization, Air ingestion, Internal recirculation, Flow turbulence and finally the Vane Passing Syndrome.

Avoiding Cavitation

Cavitation can in general be avoided by:

- increasing the distance between the actual local static pressure in the fluid - and the vapor pressure of the fluid at the actual temperature

This can be done by:

- reengineering components initiating high speed velocities and low static pressures
- increasing the total or local static pressure in the system
- reducing the temperature of the fluid

Reengineering of Components Initiating High Speed Velocity and Low Static Pressure

Cavitation and damage can be avoided by using special components designed for the actual rough conditions.

- Conditions such as huge pressure drops can - with limitations - be handled by Multi Stage Control Valves
- Difficult pumping conditions - with fluid temperatures close to the vaporization temperature - can be handled with a special pump - working after another principle than the centrifugal pump.

Cavitation Continued: Increasing the Total or Local Pressure in the System

By increasing the total or local pressure in the system, the distance between the static pressure and the vaporization pressure is increased and vaporization and cavitation may be avoided.

The ratio between static pressure and the vaporization pressure, an indication of the possibility of vaporization, is often expressed by the Cavitation Number. Unfortunately it may not always be possible to increase the total static pressure due to system classifications or other limitations. Local static pressure in the component may then be increased by lowering the component in the system. Control valves and pumps should in general be positioned in the lowest part of the system to maximize the static head. This is common for boiler feeding pumps receiving hot condensate (water close to 100 °C) from a condensate receiver.

Cavitation Continued: Reducing the Temperature of the Fluid

The vaporization pressure is highly dependent on the fluid temperature. Water, our most common fluid, is an example:

Temperature (°C)	Vapor Pressure (kN/m ²)
0	0.6
5	0.9
10	1.2
15	1.7
20	2.3
25	3.2
30	4.3
35	5.6
40	7.7
45	9.6
50	12.5
55	15.7
60	20
65	25
70	32.1
75	38.6
80	47.5
85	57.8
90	70
95	84.5
100	101.33

As we can see - the possibility of evaporation and cavitation increases dramatically with the water temperature.

Cavitation can be avoided by locating the components in the coldest part of the system. For example, it is common to locate the pumps in heating systems at the "cold" return lines. The situation is the same for control valves. Where it is possible they should be located on the cold side of heat exchangers.

Cavitations Number: A "special edition" of the dimensionless Euler Number.

The Cavitations Number is useful for analyzing fluid flow dynamics problems where cavitations may occur. The Cavitations Number can be expressed as

$$Ca = (p_r - p_v) / 1/2 \rho v^2 \quad (1)$$

where

Ca = Cavitations number

p_r = reference pressure

(Pa)

p_v = vapor pressure of the fluid (Pa)

ρ = density of the fluid (kg/m^3)

v = velocity of fluid (m/s)

Centrifugal Pump: A pump consisting of an impeller fixed on a rotating shaft and enclosed in a casing, having an inlet and a discharge connection. The rotating impeller creates pressure in the liquid by the velocity derived from centrifugal force.

Chezy Formula: Conduits flow and mean velocity. The Chezy formula can be used to calculate mean flow velocity in conduits and is expressed as

$$v = c (R S)^{1/2} \quad (1)$$

where

v = mean velocity (m/s, ft/s)

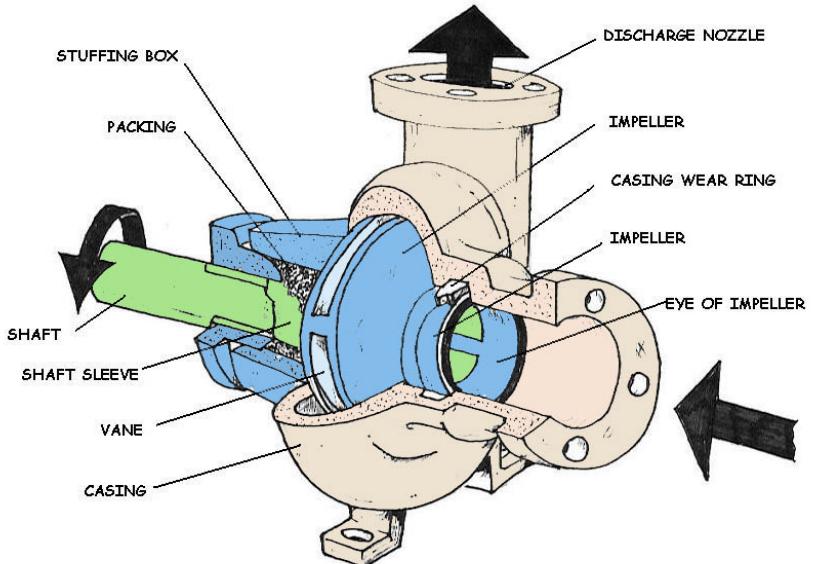
c = the Chezy roughness and conduit coefficient

R = hydraulic radius of the conduit (m, ft)

S = slope of the conduit (m/m, ft/ft)

In general the Chezy coefficient - c - is a function of the flow Reynolds Number - Re - and the relative roughness - ϵ/R - of the channel.

ϵ is the characteristic height of the roughness elements on the channel boundary.



Coanda Effect: The tendency of a stream of fluid to stay attached to a convex surface, rather than follow a straight line in its original direction.

Colebrook Equation: The friction coefficients used to calculate pressure loss (or major loss) in ducts, tubes and pipes can be calculated with the Colebrook equation.

$$1 / \lambda^{1/2} = -2 \log \left(\frac{2.51}{Re \lambda^{1/2}} + \frac{k}{d_h} / 3.72 \right) \quad (1)$$

where

λ = D'Arcy-Weisbach friction coefficient

Re = Reynolds Number

k = roughness of duct, pipe or tube surface (m, ft)

d_h = hydraulic diameter (m, ft)

The Colebrook equation is only valid at turbulent flow conditions.

Note that the friction coefficient is involved on both sides of the equation and that the equation must be solved by iteration.

The Colebrook equation is generic and can be used to calculate the friction coefficients in different kinds of fluid flows - air ventilation ducts, pipes and tubes with water or oil, compressed air and much more.

Common Pressure Measuring Devices: The Strain Gauge is a common measuring device used for a variety of changes such as head. As the pressure in the system changes, the diaphragm expands which changes the length of the wire attached. This change of length of the wire changes the Resistance of the wire, which is then converted to head. Float mechanisms, diaphragm elements, bubbler tubes, and direct electronic sensors are common types of level sensors.

Compressible Flow: We know that fluids are classified as Incompressible and Compressible fluids. Incompressible fluids do not undergo significant changes in density as they flow. In general, liquids are incompressible; water being an excellent example. In contrast compressible fluids do undergo density changes.

Gases are generally compressible; air being the most common compressible fluid we can find. Compressibility of gases leads to many interesting features such as shocks, which are absent for incompressible fluids. Gas dynamics is the discipline that studies the flow of compressible fluids and forms an important branch of Fluid Mechanics. In this book we give a broad introduction to the basics of compressible fluid flow.

In a compressible flow the compressibility of the fluid must be taken into account. The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of **Gas Mixtures** - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and **Universal Gas Constant** - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

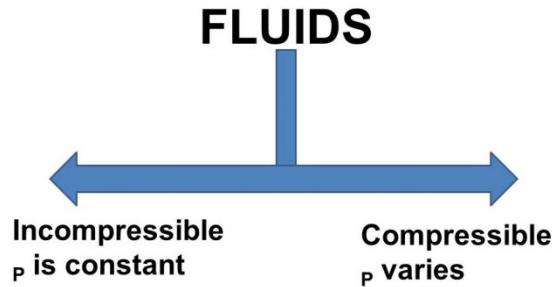
Compression and Expansion of Gases: If the compression or expansion takes place under constant temperature conditions - the process is called **isothermal**. The isothermal process can on the basis of the Ideal Gas Law be expressed as:

$$p / \rho = \text{constant} \quad (1)$$

where

p = absolute pressure

ρ = density



Confined Space Entry: Entry into a confined space requires that all entrants wear a harness and safety line. If an operator is working inside a storage tank and suddenly faints or has a serious problem, there should be two people outside standing by to remove the injured operator.

Conservation Laws: The conservation laws states that particular measurable properties of an isolated physical system does not change as the system evolves: Conservation of energy (including mass). Fluid Mechanics and Conservation of Mass - The law of conservation of mass states that mass can neither be created or destroyed.

Contaminant: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known or anticipated to occur in public water systems.

Contamination: To make something bad; to pollute or infect something. To reduce the quality of the potable (drinking) water and create an actual hazard to the water supply by poisoning or through spread of diseases.

Corrosion: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.

Cross-Contamination: The mixing of two unlike qualities of water. For example, the mixing of good water with a polluting substance like a chemical.

D

Darcy-Weisbach Equation: The **pressure loss** (or major loss) in a pipe, tube or duct can be expressed with the D'Arcy-Weisbach equation:

$$\Delta p = \lambda (l / d_h) (\rho v^2 / 2) (1)$$

where

Δp = pressure loss (Pa , N/m^2 , lb/ft^2)

λ = D'Arcy-Weisbach friction coefficient

l = length of duct or pipe (m , ft)

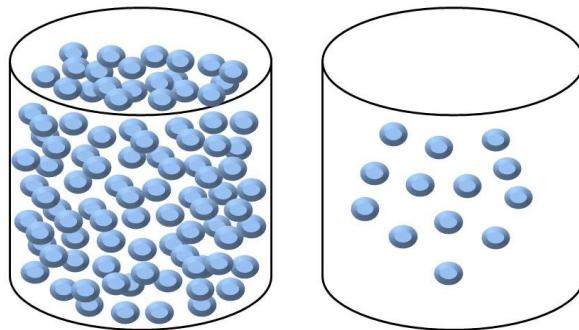
d_h = hydraulic diameter (m , ft)

ρ = density (kg/m^3 , lb/ft^3)

Note! Be aware that there are two alternative friction coefficients present in the literature. One is 1/4 of the other and (1) must be multiplied with four to achieve the correct result. This is important to verify when selecting friction coefficients from Moody diagrams.

Density: Is a physical property of matter, as each element and compound has a unique density associated with it.

Density defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume. For example: A rock is obviously more dense than a crumpled piece of paper of the same size. A Styrofoam cup is less dense than a ceramic cup. Density may also refer to how closely "packed" or "crowded" the material appears to be - again refer to the Styrofoam vs. ceramic cup. Take a look at the two boxes below.



Each box has the same volume. **If each ball has the same mass, which box would weigh more? Why?**

The box that has more balls has more mass per unit of volume. This property of matter is called density. The density of a material helps to distinguish it from other materials. Since mass is usually expressed in grams and volume in cubic centimeters, density is expressed in grams/cubic centimeter. We can calculate density using the formula:

Density= Mass/Volume

The density can be expressed as

$$\rho = m / V = 1 / v_g (1)$$

where

$$\begin{aligned}\rho &= \text{density } (\text{kg/m}^3) \\ m &= \text{mass } (\text{kg}) \\ V &= \text{volume } (\text{m}^3) \\ v_g &= \text{specific volume } (\text{m}^3/\text{kg})\end{aligned}$$

The SI units for density are kg/m³. The imperial (BG) units are lb/ft³ (slugs/ft³). While people often use pounds per cubic foot as a measure of density in the U.S., pounds are really a measure of force, not mass. Slugs are the correct measure of mass. You can multiply slugs by 32.2 for a rough value in pounds. The higher the density, the tighter the particles are packed inside the substance. Density is a physical property constant at a given temperature and density can help to identify a substance.

Example - Use the Density to Identify the Material:

An unknown liquid substance has a mass of 18.5 g and occupies a volume of 23.4 ml. (milliliter).

The density can be calculated as

$$\begin{aligned}\rho &= [18.5 \text{ (g)} / 1000 \text{ (g/kg)}] / [23.4 \text{ (ml)} / 1000 \text{ (ml/l)} 1000 \text{ (l/m}^3\text{)}] \\ &= 18.5 10^{-3} \text{ (kg)} / 23.4 10^{-6} \text{ (m}^3\text{)} \\ &= \underline{\underline{790 \text{ kg/m}^3}}\end{aligned}$$

If we look up densities of some common substances, we can find that ethyl alcohol, or ethanol, has a density of 790 kg/m³. Our unknown liquid may likely be ethyl alcohol!

Example - Use Density to Calculate the Mass of a Volume

The density of titanium is 4507 kg/m³. Calculate the mass of 0.17 m³ titanium!

$$\begin{aligned}m &= 0.17 \text{ (m}^3\text{)} 4507 \text{ (kg/m}^3\text{)} \\ &= \underline{\underline{766.2 \text{ kg}}}\end{aligned}$$

Dilatant Fluids: Shear Thickening Fluids or Dilatant Fluids increase their viscosity with agitation. Some of these liquids can become almost solid within a pump or pipe line. With agitation, cream becomes butter and Candy compounds, clay slurries and similar heavily filled liquids do the same thing.

Disinfect: To kill and inhibit growth of harmful bacterial and viruses in drinking water.

Disinfection: The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.

Distribution System Water Quality: Can be adversely affected by improperly constructed or poorly located blowoffs of vacuum/air relief valves. Air relief valves in the distribution system lines must be placed in locations that cannot be flooded. This is to prevent water contamination. The common customer complaint of Milky Water or Entrained Air is sometimes solved by the installation of air relief valves. The venting of air is not a major concern when checking water levels in a storage tank. If the vent line on a ground level storage tank is closed or clogged up, a vacuum will develop in the tank may happen to the tank when the water level begins to lower.

Drag Coefficient: Used to express the drag of an object in moving fluid. Any object moving through a fluid will experience a drag - the net force in direction of flow due to the pressure and shear stress forces on the surface of the object.

The drag force can be expressed as:

$$F_d = c_d / 2 \rho v^2 A \quad (1)$$

where

F_d = drag force (N)

c_d = drag coefficient

ρ = density of fluid

v = flow velocity

A = characteristic frontal area of the body

The drag coefficient is a function of several parameters as shape of the body, Reynolds Number for the flow, Froude number, Mach Number and Roughness of the Surface.

The characteristic frontal area - A - depends on the body.

Dynamic or Absolute Viscosity: The viscosity of a fluid is an important property in the analysis of liquid behavior and fluid motion near solid boundaries. The viscosity of a fluid is its resistance to shear or flow and is a measure of the adhesive/cohesive or frictional properties of a fluid. The resistance is caused by intermolecular friction exerted when layers of fluids attempts to slide by another.

Dynamic Pressure: Dynamic pressure is the component of fluid pressure that represents a fluids kinetic energy. The dynamic pressure is a defined property of a moving flow of gas or liquid and can be expressed as

$$p_d = 1/2 \rho v^2 \quad (1)$$

where

p_d = dynamic pressure (Pa)

ρ = density of fluid (kg/m^3)

v = velocity (m/s)

Dynamic, Absolute and Kinematic Viscosity: The viscosity of a fluid is an important property in the analysis of liquid behavior and fluid motion near solid boundaries. The viscosity is the fluid resistance to shear or flow and is a measure of the adhesive/cohesive or frictional fluid property. The resistance is caused by intermolecular friction exerted when layers of fluids attempts to slide by another.

Viscosity is a measure of a fluid's resistance to flow.

The knowledge of viscosity is needed for proper design of required temperatures for storage, pumping or injection of fluids.

Common used units for viscosity are

- CentiPoises (cp) = CentiStokes (cSt) × Density
- SSU¹ = Centistokes (cSt) × 4.55
- Degree Engler¹ × 7.45 = Centistokes (cSt)
- Seconds Redwood¹ × 0.2469 = Centistokes (cSt)

¹centistokes greater than 50

There are two related measures of fluid viscosity - known as **dynamic (or absolute)** and **kinematic** viscosity.

Dynamic (absolute) Viscosity: The tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid. The shearing stress between the layers of non-turbulent fluid moving in straight parallel lines can be defined for a Newtonian fluid as:

The dynamic or absolute viscosity can be expressed like

$$\tau = \mu \frac{dc}{dy} \quad (1)$$

where

τ = shearing stress

μ = dynamic viscosity

Equation (1) is known as the **Newton's Law of Friction**.

In the SI system the dynamic viscosity units are **N s/m², Pa s** or **kg/m s** where

- $1 \text{ Pa s} = 1 \text{ N s/m}^2 = 1 \text{ kg/m s}$

The dynamic viscosity is also often expressed in the metric CGS (centimeter-gram-second) system as **g/cm.s, dyne.s/cm² or poise (p)** where

- $1 \text{ poise} = \text{dyne s/cm}^2 = \text{g/cm s} = 1/10 \text{ Pa s}$

For practical use the Poise is too large and its usual divided by 100 into the smaller unit called the **centipoise (cP)** where

- $1 \text{ p} = 100 \text{ cP}$

Water at 68.4°F (20.2°C) has an absolute viscosity of one - 1 - centipoise.

E

E. Coli, Escherichia coli: A bacterium commonly found in the human intestine. For water quality analyses purposes, it is considered an indicator organism. These are considered evidence of water contamination. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves.

Elevation Head: The energy possessed per unit weight of a fluid because of its elevation. 1 foot of water will produce .433 pounds of pressure head.

Energy: The ability to do work. Energy can exist in one of several forms, such as heat, light, mechanical, electrical, or chemical. Energy can be transferred to different forms. It also can exist in one of two states, either potential or kinetic.

Energy and Hydraulic Grade Line: The hydraulic grade and the energy line are graphical forms of the Bernoulli equation. For steady, in viscous, incompressible flow the total energy remains constant along a stream line as expressed through the Bernoulli

Equation:

$$p + 1/2 \rho v^2 + \gamma h = \text{constant along a streamline} \quad (1)$$

where

p = static pressure (relative to the moving fluid)

ρ = density

γ = specific weight

v = flow velocity

g = acceleration of gravity

h = elevation height

Each term of this equation has the dimension force per unit area - psi, lb/ft² or N/m².

The Head

By dividing each term with the specific weight - $\gamma = \rho g$ - (1) can be transformed to express the "head":

$$p / \gamma + v^2 / 2 g + h = \text{constant along a streamline} = H \quad (2)$$

where

H = the total head

Each term of this equation has the dimension length - ft, m.

The Total Head

(2) states that the sum of **pressure head** - p / γ -, **velocity head** - $v^2 / 2 g$ - and **elevation head** - h - is constant along the stream line. This constant can be called **the total head** - H -.

The total head in a flow can be measured by the stagnation pressure using a pitot tube.

Energy and Hydraulic Grade Line Continued:

The Piezometric Head

The sum of pressure head - p / γ - and elevation head - h - is called **the piezometric head**. The piezometric head in a flow can be measured through a flat opening parallel to the flow.

Energy and Hydraulic Grade Line Continued:

The Energy Line

The Energy Line is a line that represents the total head available to the fluid and can be expressed as:

$$EL = H = p / \gamma + v^2 / 2 g + h = \text{constant along a streamline} \quad (3)$$

where

EL = Energy Line

For a fluid flow without any losses due to friction (major losses) or components (minor losses) the energy line would be at a constant level. In the practical world the energy line decreases along the flow due to the losses.

A turbine in the flow will reduce the energy line and a pump or fan will increase the energy line.

The Hydraulic Grade Line

The Hydraulic Grade Line is a line that represent the total head available to the fluid minus the velocity head and can be expressed as:

$$HGL = p / \gamma + h \quad (4)$$

where

HGL = Hydraulic Grade Line

The hydraulic grade line lies one velocity head below the energy line.

Entrance Length and Developed Flow: Fluids need some length to develop the velocity profile after entering the pipe or after passing through components such as bends, valves, pumps, and turbines or similar.

The Entrance Length: The entrance length can be expressed with the dimensionless Entrance Length Number:

$$El = l_e / d \quad (1)$$

where

El = Entrance Length Number

l_e = length to fully developed velocity profile

d = tube or duct diameter

The Entrance Length Number for Laminar Flow

The Entrance length number correlation with the Reynolds Number for laminar flow can be expressed as:

$$El_{laminar} = 0.06 Re \quad (2)$$

where

Re = Reynolds Number

The Entrance Length Number for Turbulent Flow

The Entrance length number correlation with the Reynolds Number for turbulent flow can be expressed as:

$$El_{turbulent} = 4.4 Re^{1/6} \quad (3)$$

Entropy in Compressible Gas Flow:

Calculating entropy in compressible gas flow Entropy change in compressible gas flow can be expressed as

$$ds = c_v \ln(T_2 / T_1) + R \ln(p_1 / p_2) \quad (1)$$

or

$$ds = c_p \ln(T_2 / T_1) - R \ln(p_2 / p_1) \quad (2)$$

where

ds = entropy change

c_v = specific heat capacity at a constant volume process

c_p = specific heat capacity at a constant pressure process

T = absolute temperature

R = individual gas constant

ρ = density of gas

p = absolute pressure

Equation of Continuity: The Law of Conservation of Mass states that mass can be neither created nor destroyed. Using the Mass Conservation Law on a **steady flow** process - flow where the flow rate doesn't change over time - through a control volume where the stored mass in the control volume doesn't change - implements that inflow equals outflow. This statement is called **the Equation of Continuity**. Common application where **the Equation of Continuity** can be used are pipes, tubes and ducts with flowing fluids and gases, rivers, overall processes as power plants, diaries, logistics in general, roads, computer networks and semiconductor technology and more.

The Equation of Continuity and can be expressed as:

$$m = \rho_{i1} v_{i1} A_{i1} + \rho_{i2} v_{i2} A_{i2} + \dots + \rho_{in} v_{in} A_{in} \\ = \rho_{o1} v_{o1} A_{o1} + \rho_{o2} v_{o2} A_{o2} + \dots + \rho_{om} v_{om} A_{om} \quad (1)$$

where

m = mass flow rate (kg/s)

ρ = density (kg/m^3)

v = speed (m/s)

A = area (m^2)

With uniform density equation (1) can be modified to

$$q = v_{i1} A_{i1} + v_{i2} A_{i2} + \dots + v_{in} A_{in} \\ = v_{o1} A_{o1} + v_{o2} A_{o2} + \dots + v_{om} A_{om} \quad (2)$$

where

q = flow rate (m^3/s)

$\rho_{i1} = \rho_{i2} = \dots = \rho_{in} = \rho_{o1} = \rho_{o2} = \dots = \rho_{om}$

Example - Equation of Continuity

10 m^3/h of water flows through a pipe of 100 mm inside diameter. The pipe is reduced to an inside dimension of 80 mm. Using equation (2) the velocity in the 100 mm pipe can be calculated as

$$(10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) = v_{100} (3.14 \times 0.1 \text{ (m)} \times 0.1 \text{ (m)} / 4) \\ \text{or}$$

$$v_{100} = (10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) / (3.14 \times 0.1 \text{ (m)} \times 0.1 \text{ (m)} / 4) \\ = \underline{0.35 \text{ m/s}}$$

Using equation (2) the velocity in the 80 mm pipe can be calculated

$$(10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) = v_{80} (3.14 \times 0.08 \text{ (m)} \times 0.08 \text{ (m)} / 4) \\ \text{or}$$

$$v_{100} = (10 \text{ m}^3/\text{h})(1 / 3600 \text{ h/s}) / (3.14 \times 0.08 \text{ (m)} \times 0.08 \text{ (m)} / 4) \\ = \underline{0.55 \text{ m/s}}$$

Equation of Mechanical Energy: The Energy Equation is a statement of the first law of thermodynamics. The energy equation involves energy, heat transfer and work. With certain limitations the mechanical energy equation can be compared to the Bernoulli Equation and transferred to the Mechanical Energy Equation in Terms of Energy per Unit Mass.

The mechanical energy equation for a **pump or a fan** can be written in terms of **energy per unit mass**:

$$p_{in} / \rho + v_{in}^2 / 2 + g h_{in} + w_{shaft} = p_{out} / \rho + v_{out}^2 / 2 + g h_{out} + w_{loss} \quad (1)$$

where

p = static pressure

ρ = density

v = flow velocity

g = acceleration of gravity

h = elevation height

w_{shaft} = net shaft energy inn per unit mass for a pump, fan or similar

w_{loss} = loss due to friction

The energy equation is often used for incompressible flow problems and is called **the Mechanical Energy Equation or the Extended Bernoulli Equation.**

The mechanical energy equation for a **turbine** can be written as:

$$p_{in} / \rho + v_{in}^2 / 2 + g h_{in} = p_{out} / \rho + v_{out}^2 / 2 + g h_{out} + w_{shaft} + w_{loss} \quad (2)$$

where

w_{shaft} = net shaft energy out per unit mass for a turbine or similar

Equation (1) and (2) dimensions are

energy per unit mass ($ft^2/s^2 = ft \text{ lb/slug}$ or $m^2/s^2 = N \text{ m/kg}$)

Efficiency

According to (1) a larger amount of loss - w_{loss} - result in more shaft work required for the same rise of output energy. The efficiency of a **pump or fan process** can be expressed as:

$$\eta = (w_{shaft} - w_{loss}) / w_{shaft} \quad (3)$$

The efficiency of a **turbine process** can be expressed as:

$$\eta = w_{shaft} / (w_{shaft} + w_{loss}) \quad (4)$$

The Mechanical Energy Equation in Terms of Energy per Unit Volume

The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit volume** by multiplying (1) with fluid density - ρ :

$$p_{in} + \rho v_{in}^2 / 2 + \gamma h_{in} + \rho w_{shaft} = p_{out} + \rho v_{out}^2 / 2 + \gamma h_{out} + w_{loss} \quad (5)$$

where

$\gamma = \rho g$ = specific weight

The dimensions of equation (5) are

energy per unit volume ($ft.\text{lb}/ft^3 = \text{lb}/ft^2$ or $N.m/m^3 = N/m^2$)

The Mechanical Energy Equation in Terms of Energy per Unit Weight involves Heads

The mechanical energy equation for a **pump or a fan** (1) can also be written in terms of **energy per unit weight** by dividing with gravity - g :

$$p_{in} / \gamma + v_{in}^2 / 2 g + h_{in} + h_{shaft} = p_{out} / \gamma + v_{out}^2 / 2 g + h_{out} + h_{loss} \quad (6)$$

where

$\gamma = \rho g$ = specific weight

$h_{shaft} = W_{shaft} / g$ = net shaft energy head inn per unit mass for a pump, fan or similar

$h_{loss} = W_{loss} / g$ = loss head due to friction

The dimensions of equation (6) are

energy per unit weight (ft.lb/lb = ft or N.m/N = m)

Head is the energy per unit weight.

h_{shaft} can also be expressed as:

$h_{shaft} = W_{shaft} / g = W_{shaft} / m g = W_{shaft} / \gamma Q$ (7)

where

W_{shaft} = shaft power

m = mass flow rate

Q = volume flow rate

Example - Pumping Water

Water is pumped from an open tank at level zero to an open tank at level 10 ft. The pump adds four horsepowers to the water when pumping 2 ft³/s.

Since $v_{in} = v_{out} = 0$, $p_{in} = p_{out} = 0$ and $h_{in} = 0$ - equation (6) can be modified to:

$$h_{shaft} = h_{out} + h_{loss}$$

or

$$h_{loss} = h_{shaft} - h_{out} \quad (8)$$

Equation (7) gives:

$$h_{shaft} = W_{shaft} / \gamma Q = (4 \text{ hp})(550 \text{ ft.lb/s/hp}) / (62.4 \text{ lb/ft}^3)(2 \text{ ft}^3/\text{s}) = 17.6 \text{ ft}$$

- specific weight of water 62.4 lb/ft³
- 1 hp (English horse power) = 550 ft. lb/s

Combined with (8):

$$h_{loss} = (17.6 \text{ ft}) - (10 \text{ ft}) = 7.6 \text{ ft}$$

The pump efficiency can be calculated from (3) modified for head:

$$\eta = ((17.6 \text{ ft}) - (7.6 \text{ ft})) / (17.6 \text{ ft}) = 0.58$$

Equations in Fluid Mechanics: Common fluid mechanics equations - Bernoulli, conservation of energy, conservation of mass, pressure, Navier-Stokes, ideal gas law, Euler equations, Laplace equations, Darcy-Weisbach Equation and the following:

The Bernoulli Equation

- The Bernoulli Equation - A statement of the conservation of energy in a form useful for solving problems involving fluids. For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point.

Conservation laws

- The conservation laws states that particular measurable properties of an isolated physical system does not change as the system evolves.
- Conservation of energy (including mass)
- Fluid Mechanics and Conservation of Mass - The law of conservation of mass states that mass can neither be created nor destroyed.

- The Continuity Equation - The Continuity Equation is a statement that mass is conserved.

Darcy-Weisbach Equation

- Pressure Loss and Head Loss due to Friction in Ducts and Tubes - Major loss - head loss or pressure loss - due to friction in pipes and ducts.

Euler Equations

- In fluid dynamics, the Euler equations govern the motion of a compressible, inviscid fluid. They correspond to the Navier-Stokes equations with zero viscosity, although they are usually written in the form shown here because this emphasizes the fact that they directly represent conservation of mass, momentum, and energy.

Laplace's Equation

- The Laplace Equation describes the behavior of gravitational, electric, and fluid potentials.

Ideal Gas Law

- The Ideal Gas Law - For a perfect or ideal gas, the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.
- Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density.
- The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Navier-Stokes Equations

- The motion of a non-turbulent, Newtonian fluid is governed by the Navier-Stokes equations. The equation can be used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

Mechanical Energy Equation

- The Mechanical Energy Equation - The mechanical energy equation in Terms of Energy per Unit Mass, in Terms of Energy per Unit Volume and in Terms of Energy per Unit Weight involves Heads.

Pressure

- Static Pressure and Pressure Head in a Fluid - Pressure and pressure head in a static fluid.

Euler Equations: In fluid dynamics, the Euler equations govern the motion of a compressible, inviscid fluid. They correspond to the Navier-Stokes equations with zero viscosity, although they are usually written in the form shown here because this emphasizes the fact that they directly represent conservation of mass, momentum, and energy.

Euler Number: The Euler numbers, also called the secant numbers or zig numbers, are defined for $|x| < \pi/2$ by

$$\operatorname{sech} x - 1 \equiv -\frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} - \frac{E_3^* x^6}{6!} + \dots$$

$$\sec x - 1 \equiv \frac{E_1^* x^2}{2!} + \frac{E_2^* x^4}{4!} + \frac{E_3^* x^6}{6!} + \dots$$

where $\operatorname{sech}(z)$ is the hyperbolic secant and \sec is the secant. Euler numbers give the number of odd alternating permutations and are related to Genocchi numbers. The base e of the natural logarithm is sometimes known as Euler's number. A different sort of Euler number, the Euler number of a finite complex K , is defined by

$$\chi(K) = \sum (-1)^p \operatorname{rank}(C_p(K)).$$

This Euler number is a topological invariant. To confuse matters further, the Euler characteristic is sometimes also called the "Euler number," and numbers produced by the prime-generating polynomial $n^2 - n + 41$ are sometimes called "Euler numbers" (Flannery and Flannery 2000, p. 47).

F

Fecal Coliform: A group of bacteria that may indicate the presence of human or animal fecal matter in water.

Filtration: A series of processes that physically remove particles from water.

Flood Rim: The point of an object where the water would run over the edge of something and begin to cause a flood. See Air Break.

Fluids: A fluid is defined as a substance that continually deforms (flows) under an applied shear stress regardless of the magnitude of the applied stress. It is a subset of the phases of matter and includes liquids, gases, plasmas and, to some extent, plastic solids. Fluids are also divided into liquids and gases. Liquids form a free surface (that is, a surface not created by their container) while gases do not.

The distinction between solids and fluids is not so obvious. The distinction is made by evaluating the viscosity of the matter: for example silly putty can be considered either a solid or a fluid, depending on the time period over which it is observed. Fluids share the properties of not resisting deformation and the ability to flow (also described as their ability to take on the shape of their containers).

These properties are typically a function of their inability to support a shear stress in static equilibrium. While in a solid, stress is a function of strain, in a fluid, stress is a function of rate of strain. A consequence of this behavior is Pascal's law which entails the important role of pressure in characterizing a fluid's state. Based on how the stress depends on the rate of strain and its derivatives, fluids can be characterized as: Newtonian fluids: where stress is directly proportional

to rate of strain, and Non-Newtonian fluids : where stress is proportional to rate of strain, its higher powers and derivatives (basically everything other than Newtonian fluid).

The behavior of fluids can be described by a set of partial differential equations, which are based on the conservation of mass, linear and angular momentum (Navier-Stokes equations) and energy. The study of fluids is fluid mechanics, which is subdivided into fluid dynamics and fluid statics depending on whether the fluid is in motion or not. Fluid **Related Information:** The Bernoulli Equation - A statement of the conservation of energy in a form useful for solving problems involving fluids. For a non-viscous, incompressible fluid in steady flow, the sum of pressure, potential and kinetic energies per unit volume is constant at any point. Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.

Friction Head: The head required to overcome the friction at the interior surface of a conductor and between fluid particles in motion. It varies with flow, size, type and conditions of conductors and fittings, and the fluid characteristics.

G

Gas: A gas is one of the four major phases of matter (after solid and liquid, and followed by plasma) that subsequently appear as solid material when they are subjected to increasingly higher temperatures. Thus, as energy in the form of heat is added, a solid (e.g., ice) will first melt to become a liquid (e.g., water), which will then boil or evaporate to become a gas (e.g., water vapor). In some circumstances, a solid (e.g., "dry ice") can directly turn into a gas: this is called sublimation. If the gas is further heated, its atoms or molecules can become (wholly or partially) ionized, turning the gas into a plasma. Relater Gas Information: The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law. Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Gauge Pressure: Pressure differential above or below ambient atmospheric pressure.

H

Hazardous Atmosphere: An atmosphere which by reason of being explosive, flammable, poisonous, corrosive, oxidizing, irritating, oxygen deficient, toxic, or otherwise harmful, may cause death, illness, or injury.

Hazen-Williams Factor: Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes.

Hazen-Williams Equation - Calculating Friction Head Loss in Water Pipes

Friction head loss (ft H₂O per 100 ft pipe) in water pipes can be obtained by using the empirical Hazen-Williams equation. The Darcy-Weisbach equation with the Moody diagram are considered to be the most accurate model for estimating frictional head loss in steady pipe flow. Since the approach requires a not so efficient trial and error solution, an alternative empirical head loss calculation that does not require the trial and error solutions, as the Hazen-Williams equation, may be preferred:

$$f = 0.2083 (100/c)^{1.852} q^{1.852} / d_h^{4.8655} \quad (1)$$

where

f = friction head loss in feet of water per 100 feet of pipe ($\text{ft}_{\text{h2o}}/100 \text{ ft pipe}$)

c = Hazen-Williams roughness constant

q = volume flow (gal/min)

d_h = inside hydraulic diameter (inches)

Note that the Hazen-Williams formula is empirical and lacks physical basis. Be aware that the roughness constants are based on "normal" condition with approximately 1 m/s (3 ft/sec).

The Hazen-Williams formula is not the only empirical formula available. Manning's formula is common for gravity driven flows in open channels.

The flow velocity may be calculated as:

$$v = 0.4087 q / d_h^2$$

where

v = flow velocity (ft/s)

The Hazen-Williams formula can be assumed to be relatively accurate for piping systems where the Reynolds Number is above 10^5 (turbulent flow).

- 1 ft (foot) = 0.3048 m
- 1 in (inch) = 25.4 mm
- 1 gal (US)/min = $6.30888 \times 10^{-5} \text{ m}^3/\text{s} = 0.0227 \text{ m}^3/\text{h} = 0.0631 \text{ dm}^3(\text{liter})/\text{s} = 2.228 \times 10^{-3} \text{ ft}^3/\text{s} = 0.1337 \text{ ft}^3/\text{min} = 0.8327 \text{ Imperial gal (UK)/min}$

Note! The Hazen-Williams formula gives accurate head loss due to friction for fluids with kinematic viscosity of approximately 1.1 cSt. More about fluids and kinematic viscosity.

The results for the formula are acceptable for cold water at 60° F (15.6° C) with kinematic viscosity 1.13 cSt. For hot water with a lower kinematic viscosity (0.55 cSt at 130° F (54.4° C)) the error will be significant. Since the Hazen Williams method is only valid for water flowing at ordinary temperatures between 40 to 75° F, the Darcy Weisbach method should be used for other liquids or gases.

Head: The height of a column or body of fluid above a given point expressed in linear units. Head is often used to indicate gauge pressure. Pressure is equal to the height times the density of the liquid. The measure of the pressure of water expressed in feet of height of water. 1 psi = 2.31 feet of water. There are various types of heads of water depending upon what is being measured. Static (water at rest) and Residual (water at flow conditions).

Hydraulics: Hydraulics is a branch of science and engineering concerned with the use of liquids to perform mechanical tasks.

Hydrodynamics: Hydrodynamics is the fluid dynamics applied to liquids, such as water, alcohol, and oil.

|

Ideal Gas: The Ideal Gas Law - For a perfect or ideal gas the change in density is directly related to the change in temperature and pressure as expressed in the Ideal Gas Law.
Properties of Gas Mixtures - Special care must be taken for gas mixtures when using the ideal gas law, calculating the mass, the individual gas constant or the density. The Individual and Universal Gas Constant - The Individual and Universal Gas Constant is common in fluid mechanics and thermodynamics.

Isentropic Compression/Expansion Process: If the compression or expansion takes place under constant volume conditions - the process is called **isentropic**. The isentropic process on the basis of the Ideal Gas Law can be expressed as:

$$p / \rho^k = \text{constant} \quad (2)$$

where

$k = c_p / c_v$ - the ratio of specific heats - the ratio of specific heat at constant pressure - c_p - to the specific heat at constant volume - c_v

Irrigation: Water that is especially furnished to help provide and sustain the life of growing plants. It comes from ditches. It is sometimes treated with herbicides and pesticides to prevent the growth of weeds and the development of bugs in a lawn and a garden.

K

Kinematic Viscosity: The ratio of absolute or dynamic viscosity to density - a quantity in which no force is involved. Kinematic viscosity can be obtained by dividing the absolute viscosity of a fluid with its mass density as

$$\nu = \mu / \rho \quad (2)$$

where

ν = kinematic viscosity

μ = absolute or dynamic viscosity

ρ = density

In the SI-system the theoretical unit is m^2/s or commonly used **Stoke (St)** where

- $1 \text{ St} = 10^{-4} \text{ m}^2/\text{s}$

Since the Stoke is an unpractical large unit, it is usual divided by 100 to give the unit called **Centistokes (cSt)** where

$$1 \text{ St} = 100 \text{ cSt}$$

$$1 \text{ cSt} = 10^{-6} \text{ m}^2/\text{s}$$

Since the specific gravity of water at 68.4°F (20.2°C) is almost one - 1, the kinematic viscosity of water at 68.4°F is for all practical purposes 1.0 cSt.

Kinetic Energy: The ability of an object to do work by virtue of its motion. The energy terms that are used to describe the operation of a pump are pressure and head.

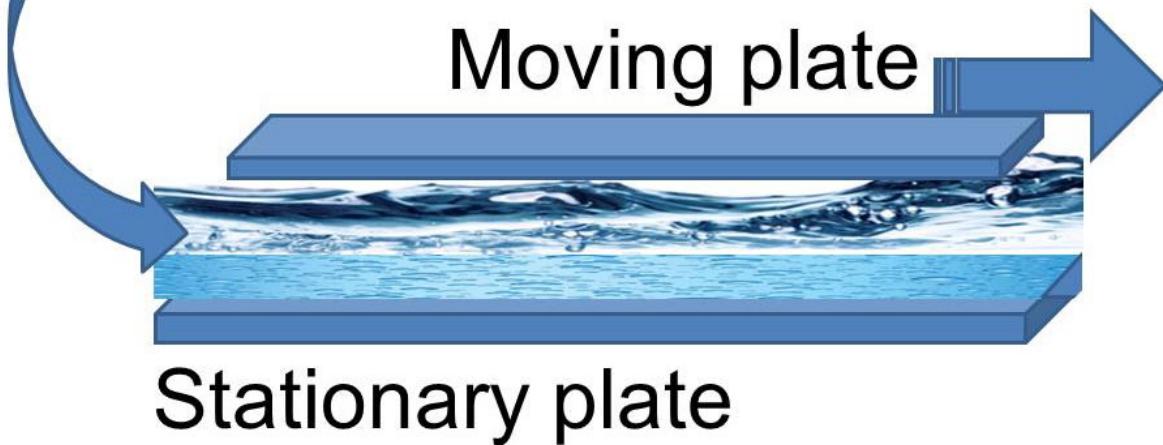
Knudsen Number: Used by modelers who wish to express a non-dimensionless speed.

L

Laminar Flow: The resistance to flow in a liquid can be characterized in terms of the viscosity

of the fluid if the flow is smooth. In the case of a moving plate in a liquid, it is found that there is a layer or lamina which moves with the plate, and a layer which is essentially stationary if it is next to a stationary plate. There is a gradient of velocity as you move from the stationary to the moving plate, and the liquid tends to move in layers with successively higher speed. This is called laminar flow, or sometimes "streamlined" flow. Viscous resistance to flow can be modeled for laminar flow, but if the lamina break up into turbulence, it is very difficult to characterize the fluid flow.

Lamina of flow with higher velocities



The common application of laminar flow would be in the smooth flow of a viscous liquid through a tube or pipe. In that case, the velocity of flow varies from zero at the walls to a maximum along the centerline of the vessel. The flow profile of laminar flow in a tube can be calculated by dividing the flow into thin cylindrical elements and applying the viscous force to them. Laminar, Transitional or Turbulent Flow? - It is important to know if the fluid flow is laminar, transitional or turbulent when calculating heat transfer or pressure and head loss.

Laplace's Equation: Describes the behavior of gravitational, electric, and fluid potentials.

The scalar form of Laplace's equation is the partial differential equation

$$\nabla^2 \psi = 0, \quad (1)$$

where ∇^2 is the Laplacian.

Note that the operator ∇^2 is commonly written as Δ by mathematicians (Krantz 1999, p. 16).

Laplace's equation is a special case of the Helmholtz differential equation

$$\nabla^2 \psi + k^2 \psi = 0 \quad (2)$$

with $k = 0$, or Poisson's equation

$$\nabla^2 \psi = -4\pi\rho \quad (3)$$

with $\rho = 0$.

The vector Laplace's equation is given by

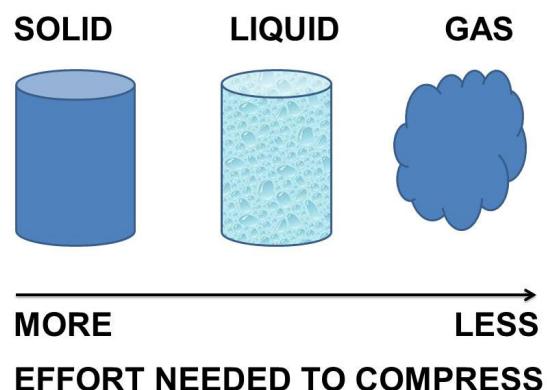
$$\nabla^2 \mathbf{F} = 0. \quad (4)$$

A function ψ which satisfies Laplace's equation is said to be harmonic. A solution to Laplace's equation has the property that the average value over a spherical surface is equal to the value at the center of the sphere (Gauss's harmonic function theorem). Solutions have no local maxima or minima. Because Laplace's equation is linear, the superposition of any two solutions is also a solution.

Lift (Force): Lift consists of the sum of all the aerodynamic forces normal to the direction of the external airflow.

Liquids: An in-between state of matter. They can be found in between the solid and gas states. They don't have to be made up of the same compounds. If you have a variety of materials in a liquid, it is called a solution. One characteristic of a liquid is that it will fill up the shape of a container. If you pour some water in a cup, it will fill up the bottom of the cup first and then fill the rest. The water will also take the shape of the cup. It fills the bottom first because of **gravity**. The top part of a liquid will usually have a flat surface. That flat surface is because of gravity too. Putting an ice cube (solid) into a cup will leave you with a cube in the middle of the cup; the shape won't change until the ice becomes a liquid.

Another trait of liquids is that they are difficult to compress. When you compress something, you take a certain amount and force it into a smaller space. Solids are very difficult to compress and gases are very easy. Liquids are in the middle but tend to be difficult. When you compress something, you force the atoms closer together. When pressure goes up, substances are compressed. Liquids already have their atoms close together, so they are hard to compress. Many shock absorbers in cars compress liquids in tubes.



A special force keeps liquids together. Solids are stuck together and you have to force them apart. Gases bounce everywhere and they try to spread themselves out. Liquids actually want to stick together. There will always be the occasional evaporation where extra energy gets a molecule excited and the molecule leaves the system. Overall, liquids have **cohesive** (sticky) forces at work that hold the molecules together. Related Liquid Information: Equations in Fluid Mechanics - Continuity, Euler, Bernoulli, Dynamic and Total Pressure

M

Mach Number: When an object travels through a medium, then its Mach number is the ratio of the object's speed to the speed of sound in that medium.

Magnetic Flow Meter: Inspection of magnetic flow meter instrumentation should include checking for corrosion or insulation deterioration.

Manning Formula for Gravity Flow: Manning's equation can be used to calculate cross-sectional average velocity flow in open channels

$$v = k_n/n R^{2/3} S^{1/2} \quad (1)$$

where

v = cross-sectional average velocity (ft/s, m/s)

k_n = 1.486 for English units and k_n = 1.0 for SI units

A = cross sectional area of flow (ft^2 , m^2)

n = Manning coefficient of roughness

R = hydraulic radius (ft, m)

S = slope of pipe (ft/ft, m/m)

The volume flow in the channel can be calculated as

$$q = A v = A k_n/n R^{2/3} S^{1/2} \quad (2)$$

where

q = volume flow (ft^3/s , m^3/s)

A = cross-sectional area of flow (ft^2 , m^2)

Maximum Contamination Levels or (MCLs): The maximum allowable level of a contaminant that federal or state regulations allow in a public water system. If the MCL is exceeded, the water system must treat the water so that it meets the MCL. Or provide adequate backflow protection.

Mechanical Seal: A mechanical device used to control leakage from the stuffing box of a pump. Usually made of two flat surfaces, one of which rotates on the shaft. The two flat surfaces are of such tolerances as to prevent the passage of water between them.

Mg/L: milligrams per liter

ML: milliliter

N

Navier-Stokes Equations: The motion of a non-turbulent, Newtonian fluid is governed by the Navier-Stokes equation. The equation can be used to model turbulent flow, where the fluid parameters are interpreted as time-averaged values.

Newtonian Fluid: Newtonian fluid (named for Isaac Newton) is a fluid that flows like water—its shear stress is linearly proportional to the velocity gradient in the direction perpendicular to the plane of shear. The constant of proportionality is known as the viscosity. Water is Newtonian, because it continues to exemplify fluid properties no matter how fast it is stirred or mixed.

Contrast this with a non-Newtonian fluid, in which stirring can leave a "hole" behind (that gradually fills up over time - this behavior is seen in materials such as pudding, or to a less rigorous extent, sand), or cause the fluid to become thinner, the drop in viscosity causing it to flow more (this is seen in non-drip paints). For a Newtonian fluid, the viscosity, by definition, depends only on temperature and pressure (and also the chemical composition of the fluid if the fluid is not a pure substance), not on the forces acting upon it. If the fluid is incompressible and viscosity is constant across the fluid, the equation governing the shear stress. Related Newtonian Information: A Fluid is Newtonian if viscosity is constant applied to shear force. Dynamic, Absolute and Kinematic Viscosity - An introduction to dynamic, absolute and kinematic viscosity and how to convert between CentiStokes (cSt), CentiPoises (cP), Saybolt Universal Seconds (SSU) and degree Engler.

Newton's Third Law: Newton's third law describes the forces acting on objects interacting with each other. Newton's third law can be expressed as

- *"If one object exerts a force F on another object, then the second object exerts an equal but opposite force F on the first object"*

Force is a convenient abstraction to represent mentally the pushing and pulling interaction between objects.

It is common to express forces as vectors with magnitude, direction and point of application. The net effect of two or more forces acting on the same point is the vector sum of the forces.

Non-Newtonian Fluid: Non-Newtonian fluid viscosity changes with the applied shear force.

O

Oxidizing: The process of breaking down organic wastes into simpler elemental forms or by products. Also used to separate combined chlorine and convert it into free chlorine.

P

Pascal's Law: A pressure applied to a confined fluid at rest is transmitted with equal intensity throughout the fluid.

Pathogens: Disease-causing pathogens; waterborne pathogens. A pathogen is a bacterium, virus or parasite that causes or is capable of causing disease. Pathogens may contaminate water and cause waterborne disease.

pCi/L- picocuries per liter: A curie is the amount of radiation released by a set amount of a certain compound. A picocurie is one quadrillionth of a curie.

pH: A measure of the acidity of water. The pH scale runs from 0 to 14 with 7 being the mid-point

or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity. pH (Power of Hydroxyl Ion Activity).

Pipeline Appurtenances: Pressure reducers, bends, valves, regulators (which are a type of valve), etc.

Peak Demand: The maximum momentary load placed on a water treatment plant, pumping station or distribution system is the Peak Demand.

Pipe Velocities: For calculating fluid pipe velocity.

Imperial units

A fluids flow velocity in pipes can be calculated with Imperial or American units as

$$v = 0.4085 q / d^2 \quad (1)$$

where

v = velocity (ft/s)

q = volume flow (US gal. /min)

d = pipe inside diameter (inches)

SI units

A fluids flow velocity in pipes can be calculated with SI units as

$$v = 1.274 q / d^2 \quad (2)$$

where

v = velocity (m/s)

q = volume flow (m^3/s)

d = pipe inside diameter (m)

Pollution: To make something unclean or impure. Some states will have a definition of pollution that relates to non-health related water problems, like taste and odors. See Contaminated.

Positive Flow Report-back Signal: When a pump receives a signal to start, a light will typically be illuminated on the control panel indicating that the pump is running. In order to be sure that the pump is actually pumping water, a Positive flow report-back signal should be installed on the control panel.

Potable: Good water which is safe for drinking or cooking purposes. Non-Potable: A liquid or water that is not approved for drinking.

Potential Energy: The energy that a body has by virtue of its position or state enabling it to do work.

PPM: Abbreviation for parts per million.

Prandtl Number: The Prandtl Number is a dimensionless number approximating the ratio of momentum diffusivity and thermal diffusivity and can be expressed as

$$Pr = v / \alpha \quad (1)$$

where

Pr = Prandtl's number

ν = kinematic viscosity (Pa s)
 α = thermal diffusivity (W/m K)

The Prandtl number can alternatively be expressed as

$$Pr = \mu c_p / k \quad (2)$$

where

μ = absolute or dynamic viscosity (kg/m s , cP)

c_p = specific heat capacity (J/kg K , $\text{Btu/(lb }^{\circ}\text{F)}$)

k = thermal conductivity (W/m K , $\text{Btu/(h ft}^2\text{ }^{\circ}\text{F/ft)}$)

The Prandtl Number is often used in heat transfer and free and forced convection calculations.

Pressure: An introduction to pressure - the definition and presentation of common units as psi and Pa and the relationship between them.

The pressure in a fluid is defined as

"the normal force per unit area exerted on an imaginary or real plane surface in a fluid or a gas"

The equation for pressure can be expressed as:

$$p = F / A \quad (1)$$

where

p = pressure [lb/in^2 (psi) or lb/ft^2 (psf), N/m^2 or kg/ms^2 (Pa)]

F = force [¹⁾, N]

A = area [in^2 or ft^2 , m^2]

¹⁾ In the English Engineering System special care must be taken for the force unit. The basic unit for mass is the pound mass (lb_m) and the unit for the force is the pound (lb) or pound force (lb_f).

Absolute Pressure

The **absolute pressure** - p_a - is measured relative to the *absolute zero pressure* - the pressure that would occur at absolute vacuum.

Gauge Pressure

A **gauge** is often used to measure the pressure difference between a system and the surrounding atmosphere. This pressure is often called the **gauge pressure** and can be expressed as

$$p_g = p_a - p_o \quad (2)$$

where

p_g = gauge pressure

p_o = atmospheric pressure

Atmospheric Pressure

The atmospheric pressure is the pressure in the surrounding air. It varies with temperature and altitude above sea level.

Standard Atmospheric Pressure

The **Standard Atmospheric Pressure** (atm) is used as a reference for gas densities and volumes. The Standard Atmospheric Pressure is defined at sea-level at 273°K (0°C) and is **1.01325 bar** or **101325 Pa** (absolute). The temperature of 293°K (20°C) is also used.

In imperial units the Standard Atmospheric Pressure is 14.696 psi.

- $1 \text{ atm} = 1.01325 \text{ bar} = 101.3 \text{ kPa} = 14.696 \text{ psi (lb/in}^2\text{)} = 760 \text{ mmHg} = 10.33 \text{ mH}_2\text{O} = 760 \text{ torr}$
 $= 29.92 \text{ in Hg} = 1013 \text{ mbar} = 1.0332 \text{ kg/cm}^2 = 33.90 \text{ ftH}_2\text{O}$

Pressure Head: The height to which liquid can be raised by a given pressure.

Pressure Regulation Valves: Control water pressure and operate by restricting flows. They are used to deliver water from a high pressure to a low-pressure system. The pressure downstream from the valve regulates the amount of flow. Usually, these valves are of the globe design and have a spring-loaded diaphragm that sets the size of the opening.

Pressure Units: Since 1 Pa is a small pressure unit, the unit hectopascal (hPa) is widely used, especially in meteorology. The unit kilopascal (kPa) is commonly used designing technical applications like HVAC systems, piping systems and similar.

- $1 \text{ hectopascal} = 100 \text{ pascal} = 1 \text{ millibar}$
- $1 \text{ kilopascal} = 1000 \text{ pascal}$

Some Pressure Levels

- 10 Pa - The pressure at a depth of 1 mm of water
- 1 kPa - Approximately the pressure exerted by a 10 g mass on a 1 cm² area
- 10 kPa - The pressure at a depth of 1 m of water, or
the drop in air pressure when going from sea level to 1000 m elevation
- 10 MPa - A "high pressure" washer forces the water out of the nozzles at this pressure
- 10 GPa - This pressure forms diamonds

Some Alternative Units of Pressure

- 1 bar - 100,000 Pa
- 1 millibar - 100 Pa
- 1 atmosphere - 101,325 Pa
- 1 mm Hg - 133 Pa
- 1 inch Hg - 3,386 Pa

A **torr** (torr) is named after Torricelli and is the pressure produced by a column of mercury 1 mm high equals to 1/760th of an atmosphere. 1 atm = 760 torr = 14.696 psi

Pounds per square inch (psi) was common in U.K. but has now been replaced in almost every country except in the U.S. by the SI units. The Normal atmospheric pressure is 14.696 psi, meaning that a column of air on one square inch in area rising from the Earth's atmosphere to space weighs 14.696 pounds.

The **bar** (bar) is common in the industry. One bar is 100,000 Pa, and for most practical purposes can be approximated to one atmosphere even if

$$1 \text{ Bar} = 0.9869 \text{ atm}$$

There are 1,000 **millibar** (mbar) in one bar, a unit common in meteorology.

$$1 \text{ millibar} = 0.001 \text{ bar} = 0.750 \text{ torr} = 100 \text{ Pa}$$

Q

R

Residual Disinfection/Protection: A required level of disinfectant that remains in treated water to ensure disinfection protection and prevent recontamination throughout the distribution system (i.e., pipes).

Reynolds Number: The Reynolds number is used to determine whether a flow is laminar or turbulent. The Reynolds Number is a non-dimensional parameter defined by the ratio of dynamic pressure (ρu^2) and shearing stress ($\mu u / L$) - and can be expressed as

$$\begin{aligned} Re &= (\rho u^2) / (\mu u / L) \\ &= \rho u L / \mu \\ &= u L / v \quad (1) \end{aligned}$$

where

Re = Reynolds Number (non-dimensional)

ρ = density (kg/m^3 , lb_m/ft^3)

u = velocity (m/s , ft/s)

μ = dynamic viscosity (Ns/m^2 , $\text{lb}_m/\text{s ft}$)

L = characteristic length (m , ft)

v = kinematic viscosity (m^2/s , ft^2/s)

Richardson Number: A dimensionless number that expresses the ratio of potential to kinetic energy.

S

Sanitizer: A chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.

Saybolt Universal Seconds (or SUS, SSU): Saybolt Universal Seconds (or SUS) is used to measure viscosity. The efflux time is Saybolt Universal Seconds (SUS) required for 60 milliliters of a petroleum product to flow through the calibrated orifice of a Saybolt Universal viscometer, under carefully controlled temperature and as prescribed by test method ASTM D 88. This method has largely been replaced by the kinematic viscosity method. Saybolt Universal Seconds is also called the SSU number (Seconds Saybolt Universal) or SSF number (Saybolt Seconds Furol).

Kinematic viscosity versus dynamic or absolute viscosity can be expressed as

$$v = 4.63 \mu / SG \quad (3)$$

where

v = kinematic viscosity (SSU)

μ = dynamic or absolute viscosity (cP)

Scale: Crust of calcium carbonate, the result of unbalanced pool water. Hard insoluble minerals deposited (usually calcium bicarbonate) which forms on pool and spa surfaces and clog filters, heaters and pumps. Scale is caused by high calcium hardness and/or high pH. You will often find major scale deposits inside a backflow prevention assembly.

Shock: Also known as superchlorination or break point chlorination. Ridding a pool of organic waste through oxidization by the addition of significant quantities of a halogen.

Shock Wave: A shock wave is a strong pressure wave produced by explosions or other phenomena that create violent changes in pressure.

Solder: A fusible alloy used to join metallic parts. Solder for potable water pipes shall be lead-free.

Sound Barrier: The sound barrier is the apparent physical boundary stopping large objects from becoming supersonic.

Specific Gravity: The Specific Gravity - SG - is a dimensionless unit defined as the ratio of density of the material to the density of water at a specified temperature. Specific Gravity can be expressed as

$$SG = \rho / \rho_{H_2O} \quad (3)$$

where

ρ = specific gravity

ρ = density of fluid or substance (kg/m^3)

ρ_{H_2O} = density of water (kg/m^3)

It is common to use the density of water at 4°C (39°F) as a reference - at this point the density of water is at the highest. Since Specific Weight is dimensionless it has the same value in the metric SI system as in the imperial English system (BG). At the reference point the Specific Gravity has same numerically value as density.

Example - Specific Gravity

If the density of iron is 7850 kg/m^3 , 7.85 grams per cubic millimeter, 7.85 kilograms per liter, or 7.85 metric tons per cubic meter - the specific gravity of iron is:

$$SG = 7850 \text{ kg/m}^3 / 1000 \text{ kg/m}^3$$

$$= \underline{7.85}$$

(the density of water is 1000 kg/m^3)

Specific Weight: Specific Weight is defined as weight per unit volume. Weight is a **force**.

- Mass and Weight - the difference! - What is weight and what is mass? An explanation of the difference between weight and mass.

Specific Weight can be expressed as

$$\gamma = \rho g \quad (2)$$

where

γ = specific weight (kN/m^3)

g = acceleration of gravity (m/s^2)

The SI-units of specific weight are kN/m^3 . The imperial units are lb/ft^3 . The local acceleration g is under normal conditions 9.807 m/s^2 in SI-units and 32.174 ft/s^2 in imperial units.

Example - Specific Weight Water

Specific weight for water at 60 °F is 62.4 lb/ft³ in imperial units and 9.80 kN/m³ in SI-units.

Example - Specific Weight Some other Materials

Product	Specific Weight - γ	
	Imperial Units (lb/ft ³)	SI Units (kN/m ³)
Ethyl Alcohol	49.3	7.74
Gasoline	42.5	6.67
Glycerin	78.6	12.4
Mercury	847	133
SAE 20 Oil	57	8.95
Seawater	64	10.1
Water	62.4	9.80

Static Head: The height of a column or body of fluid above a given point

Static Pressure: The pressure in a fluid at rest.

Static Pressure and Pressure Head in Fluids: The pressure indicates the normal force per unit area at a given point acting on a given plane. Since there is no shearing stresses present in a fluid at rest - the pressure in a fluid is independent of direction.

For fluids - liquids or gases - at rest the pressure gradient in the vertical direction depends only on the specific weight of the fluid.

How pressure changes with elevation can be expressed as

$$dp = -\gamma dz \quad (1)$$

where

dp = change in pressure

dz = change in height

γ = specific weight

The pressure gradient in vertical direction is negative - the pressure decrease upwards.

Specific Weight: Specific Weight can be expressed as:

$$\gamma = \rho g \quad (2)$$

where

γ = specific weight

g = acceleration of gravity

In general the specific weight - γ - is constant for fluids. For gases the specific weight - γ - varies with the elevation.

Static Pressure in a Fluid: For an incompressible fluid - as a liquid - the pressure difference between two elevations can be expressed as:

$$p_2 - p_1 = -\gamma(z_2 - z_1) \quad (3)$$

where

p_2 = pressure at level 2

p_1 = pressure at level 1

z_2 = level 2

z_1 = level 1

(3) can be transformed to:

$$p_1 - p_2 = \gamma(z_2 - z_1) \quad (4)$$

or

$$p_1 - p_2 = \gamma h \quad (5)$$

where

$h = z_2 - z_1$ difference in elevation - the depth down from location z_2 .

or

$$p_1 = \gamma h + p_2 \quad (6)$$

Static Pressure and Pressure Head in Fluids Continued:

The Pressure Head

(6) can be transformed to:

$$h = (p_2 - p_1) / \gamma \quad (6)$$

h express **the pressure head** - the height of a column of fluid of specific weight - γ - required to give a pressure difference of $(p_2 - p_1)$.

Example - Pressure Head

A pressure difference of 5 psi (lbf/in^2) is equivalent to

$$5 \text{ (\text{lbf/in}^2)} 12 \text{ (\text{in}/\text{ft})} 12 \text{ (\text{in}/\text{ft})} / 62.4 \text{ (\text{lb}/\text{ft}^3)} = 11.6 \text{ ft of water}$$

$$5 \text{ (\text{lbf/in}^2)} 12 \text{ (\text{in}/\text{ft})} 12 \text{ (\text{in}/\text{ft})} / 847 \text{ (\text{lb}/\text{ft}^3)} = 0.85 \text{ ft of mercury}$$

when specific weight of water is 62.4 (lb/ft^3) and specific weight of mercury is 847 (lb/ft^3).

Streamline - Stream Function: A streamline is the path that an imaginary particle would follow if it was embedded in the flow.

Strouhal Number: A quantity describing oscillating flow mechanisms. The Strouhal Number is a dimensionless value useful for analyzing oscillating, unsteady fluid flow dynamics problems.

The Strouhal Number can be expressed as

$$St = \omega l / v \quad (1)$$

where

St = Strouhal Number

ω = oscillation frequency

l = characteristic length

v = flow velocity

The Strouhal Number represents a measure of the ratio of inertial forces due to the unsteadiness of the flow or local acceleration to the inertial forces due to changes in velocity from one point to another in the flow field.

The vortices observed behind a stone in a river, or measured behind the obstruction in a vortex flow meter, illustrate these principles.

Stuffing Box: That portion of the pump which houses the packing or mechanical seal.

Submerged: To cover with water or liquid substance.

Supersonic Flow: Flow with speed above the speed of sound, 1,225 km/h at sea level, is said to be supersonic.

Surface Tension: Surface tension is a force within the surface layer of a liquid that causes the layer to behave as an elastic sheet. The cohesive forces between liquid molecules are responsible for the phenomenon known as surface tension. The molecules at the surface do not have other like molecules on all sides of them and consequently they cohere more strongly to those directly associated with them on the surface. This forms a surface "film" which makes it more difficult to move an object through the surface than to move it when it is completely submerged. Surface tension is typically measured in dynes/cm, the force in dynes required to break a film of length 1 cm. Equivalently, it can be stated as surface energy in ergs per square centimeter. Water at 20°C has a surface tension of 72.8 dynes/cm compared to 22.3 for ethyl alcohol and 465 for mercury.

Surface tension is typically measured in *dynes/cm* or *N/m*.

Liquid	Surface Tension	
	N/m	dynes/cm
Ethyl Alcohol	0.0223	22.3
Mercury	0.465	465
Water 20°C	0.0728	72.75
Water 100°C	0.0599	58.9

Surface tension is the energy required to stretch a unit change of a surface area. Surface tension will form a drop of liquid to a sphere since the sphere offers the smallest area for a definite volume.

Surface tension can be defined as

$$\sigma = F_s / l \quad (1)$$

where

σ = surface tension (*N/m*)

F_s = stretching force (*N*)

l = unit length (*m*)

Alternative Units

Alternatively, surface tension is typically measured in dynes/cm, which is

- the force in dynes required to break a film of length 1 cm
- or as surface energy J/m^2 or alternatively ergs per square centimeter.
- 1 dynes/cm = 0.001 N/m = 0.0000685 lb_f/ft = 0.571 10^{-5} lb_f/in = 0.0022 poundal/ft = 0.00018 poundal/in = 1.0 mN/m = 0.001 J/m² = 1.0 erg/cm² = 0.00010197 kgf/m

Common Imperial units used are lb/ft and lb/in.

Water surface tension at different temperatures can be taken from the table below:

Temperature	Surface Tension
-------------	-----------------

(°C)	- σ - (N/m)
0	0.0757
10	0.0742
20	0.0728
30	0.0712
40	0.0696
50	0.0679
60	0.0662
70	0.0644
80	0.0626
90	0.0608
100	0.0588

Surface Tension of some common Fluids

- benzene : 0.0289 (N/m)
- diethyl ether : 0.0728 (N/m)
- carbon tetrachloride : 0.027 (N/m)
- chloroform : 0.0271 (N/m)
- ethanol : 0.0221 (N/m)
- ethylene glycol : 0.0477 (N/m)
- glycerol : 0.064 (N/m)
- mercury : 0.425 (N/m)
- methanol : 0.0227 (N/m)
- propanol : 0.0237 (N/m)
- toluene : 0.0284 (N/m)
- water at 20°C : 0.0729 (N/m)

Surge Tanks: Surge tanks can be used to control Water Hammer. A limitation of hydropneumatic tanks is that they do not provide much storage to meet peak demands during power outages and you have very limited time to do repairs on equipment.

T

Telemetering Systems: The following are common pressure sensing devices: Helical Sensor, Bourdon Tube, and Bellows Sensor. The most frequent problem that affects a liquid pressure-sensing device is air accumulation at the sensor. A diaphragm element being used as a level sensor would be used in conjunction with a pressure sensor. Devices must often transmit more than one signal. You can use several types of systems including: Polling, Scanning and Multiplexing. Transmitting equipment requires installation where temperature will not exceed 130 degrees F.

Thixotropic Fluids: Shear Thinning Fluids or Thixotropic Fluids reduce their viscosity as agitation or pressure is increased at a constant temperature. Ketchup and mayonnaise are examples of thixotropic materials. They appear thick or viscous but are possible to pump quite easily.

Transonic: Flow with speed at velocities just below and above the speed of sound is said to be transonic.

Turbidity: A measure of the cloudiness of water caused by suspended particles.

U

U-Tube Manometer: Pressure measuring devices using liquid columns in vertical or inclined tubes are called manometers. One of the most common is the water filled u-tube manometer used to measure pressure difference in pitot or orifices located in the airflow in air handling or ventilation systems.

V

Valve: A device that opens and closes to regulate the flow of liquids. Faucets, hose bibs, and Ball are examples of valves.

Vane: That portion of an impeller which throws the water toward the volute.

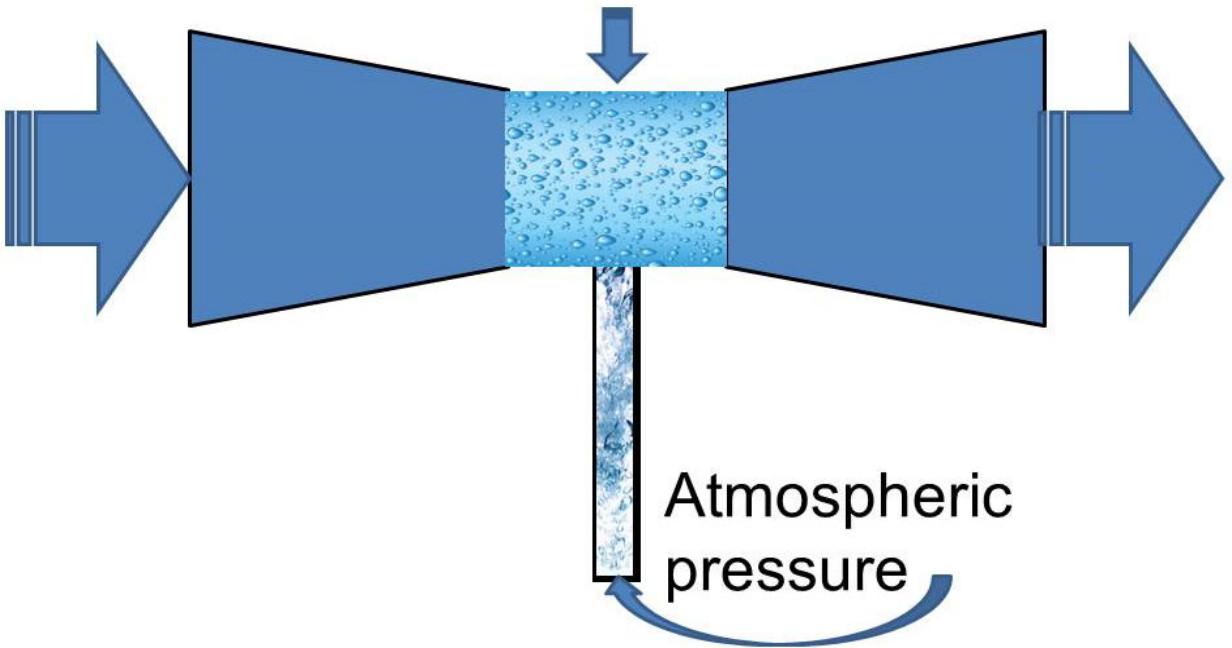
Vapor Pressure: For a particular substance at any given temperature there is a pressure at which the vapor of that substance is in equilibrium with its liquid or solid forms.

Velocity Head: The vertical distance a liquid must fall to acquire the velocity with which it flows through the piping system. For a given quantity of flow, the velocity head will vary indirectly as the pipe diameter varies.

Venturi: A system for speeding the flow of the fluid, by constricting it in a cone-shaped tube. Venturi are used to measure the speed of a fluid, by measuring the pressure changes from one point to another along the venturi. A venturi can also be used to inject a liquid or a gas into another liquid. A pump forces the liquid flow through a tube connected to:

- A venturi to increase the speed of the fluid (restriction of the pipe diameter)
- A short piece of tube connected to the gas source
- A second venturi that decrease the speed of the fluid (the pipe diameter increase again)
- After the first venturi the pressure in the pipe is lower, so the gas is sucked in the pipe. Then the mixture enters the second venturi and slow down. At the end of the system a mixture of gas and liquid appears and the pressure rise again to its normal level in the pipe.
- This technique is used for ozone injection in water.

Velocity increases – Pressure drops



The newest injector design causes complete mixing of injected materials (air, ozone or chemicals), eliminating the need for other in-line mixers. Venturi injectors have no moving parts and are maintenance free. They operate effectively over a wide range of pressures (from 1 to 250 psi) and require only a minimum pressure difference to initiate the vacuum at the suction part. Venturis are often built in thermoplastics (PVC, PE, PVDF), stainless steel or other metals.

The cavitation effect at the injection chamber provides an instantaneous mixing, creating thousands of very tiny bubbles of gas in the liquid. The small bubbles provide increased gas exposure to the liquid surface area, increasing the effectiveness of the process (i.e. ozonation).

Vibration: A force that is present on construction sites and must be considered. The vibrations caused by backhoes, dump trucks, compactors and traffic on job sites can be substantial.

Viscosity: Informally, viscosity is the quantity that describes a fluid's resistance to flow. Fluids resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them. Formally, viscosity (represented by the symbol η "eta") is the ratio of the shearing stress (F/A) to the velocity gradient ($\Delta v_x/\Delta z$ or dv_x/dz) in a fluid.

$$\eta = \left(\frac{F}{A} \right) \div \left(\frac{\Delta v_x}{\Delta z} \right) \quad \text{or} \quad \eta = \left(\frac{F}{A} \right) \div \left(\frac{dv_x}{dz} \right)$$

The more usual form of this relationship, called Newton's equation, states that the resulting shear of a fluid is directly proportional to the force applied and inversely proportional to its viscosity. The similarity to Newton's second law of motion ($F = ma$) should be apparent.

$$\frac{F}{A} = \eta \frac{\Delta v_x}{\Delta z} \quad \text{or} \quad \frac{F}{A} = \eta \frac{dv_x}{dz}$$

$$\Downarrow \qquad \qquad \Downarrow$$

$$F = m \frac{\Delta v}{\Delta t} \quad \text{or} \quad F = m \frac{dv}{dt}$$

The SI unit of viscosity is the pascal second [Pa·s], which has no special name. Despite its self-proclaimed title as an international system, the International System of Units has had very little international impact on viscosity. The pascal second is rarely used in scientific and technical publications today. The most common unit of viscosity is the dyne second per square centimeter [dyne·s/cm²], which is given the name poise [P] after the French physiologist Jean Louis Poiseuille (1799-1869). Ten poise equal one pascal second [Pa·s] making the centipoise [cP] and millipascal second [mPa·s] identical.

$$\begin{aligned} 1 \text{ pascal second} &= 10 \text{ poise} = 1,000 \text{ millipascal second} \\ 1 \text{ centipoise} &= 1 \text{ millipascal second} \end{aligned}$$

There are actually two quantities that are called viscosity. The quantity defined above is sometimes called dynamic viscosity, absolute viscosity, or simple viscosity to distinguish it from the other quantity, but is usually just called viscosity. The other quantity called kinematic viscosity (represented by the symbol ν "nu") is the ratio of the viscosity of a fluid to its density.

$$\nu = \frac{\eta}{\rho}$$

Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity. It is frequently measured using a device called a capillary viscometer -- basically a graduated can with a narrow tube at the bottom. When two fluids of equal volume are placed in identical capillary viscometers and allowed to flow under the influence of gravity, a viscous fluid takes longer than a less viscous fluid to flow through the tube. Capillary viscometers are discussed in more detail later in this section. The SI unit of kinematic viscosity is the square meter per second [m²/s], which has no special name. This unit is so large that it is rarely used. A more common unit of kinematic viscosity is the square centimeter per second [cm²/s], which is given the name stoke [St] after the English scientist George Stoke. This unit is also a bit too large and so the most common unit is probably the square millimeter per second [mm²/s] or centistoke [cSt].

Viscosity and Reference Temperatures: The viscosity of a fluid is highly temperature dependent and for either dynamic or kinematic viscosity to be meaningful, the **reference temperature** must be quoted. In ISO 8217 the reference temperature for a residual fluid is 100°C. For a distillate fluid the reference temperature is 40°C.

- For a liquid - the kinematic viscosity will **decrease** with higher temperature.
- For a gas - the kinematic viscosity will **increase** with higher temperature.

Volute: The spiral-shaped casing surrounding a pump impeller that collects the liquid discharged by the impeller.

Vorticity: Vorticity is defined as the circulation per unit area at a point in the flow field.

Vortex: A vortex is a whirlpool in the water.

W

Water Freezing: The effects of water freezing in storage tanks can be minimized by alternating water levels in the tank.

Water Storage Facility Inspection: During an inspection of your water storage facility, you should inspect the Cathodic protection system including checking the anode's condition and the connections. The concentration of polyphosphates that is used for corrosion control in storage tanks is typically 5 mg/L or less. External corrosion of steel water storage facilities can be reduced with Zinc or aluminum coatings. All storage facilities should be regularly sampled to determine the quality of water that enters and leaves the facility. One tool or piece of measuring equipment is the Jackson turbidimeter, which is a method to measure cloudiness in water.

Wave Drag: Wave drag refers to a sudden and very powerful drag that appears on aircrafts flying at high-subsonic speeds.

Water Purveyor: The individuals or organization responsible to help provide, supply, and furnish quality water to a community.

Water Works: All of the pipes, pumps, reservoirs, dams and buildings that make up a water system.

Waterborne Diseases: A disease, caused by a virus, bacterium, protozoan, or other microorganism, capable of being transmitted by water (e.g., typhoid fever, cholera, amoebic dysentery, gastroenteritis).

Weber Number: A dimensionless value useful for analyzing fluid flows where there is an interface between two different fluids. Since the Weber Number represents an index of the inertial force to the surface tension force acting on a fluid element, it can be useful analyzing thin films flows and the formation of droplets and bubbles.

Appendices and Charts

Density of Common Liquids

The density of some common liquids can be found in the table below:

Liquid	Temperature - t - (°C)	Density - ρ - (kg/m³)
Acetic Acid	25	1049
Acetone	25	785
Acetonitrile	20	782
Alcohol, ethyl	25	785
Alcohol, methyl	25	787
Alcohol, propyl	25	780
Ammonia (aqua)	25	823
Aniline	25	1019
Automobile oils	15	880 - 940
Beer (varies)	10	1010
Benzene	25	874
Benzyl	15	1230
Brine	15	1230
Bromine	25	3120
Butyric Acid	20	959
Butane	25	599
n-Butyl Acetate	20	880
n-Butyl Alcohol	20	810
n-Butylchloride	20	886
Caproic acid	25	921
Carbolic acid	15	956
Carbon disulfide	25	1261
Carbon tetrachloride	25	1584
Carene	25	857
Castor oil	25	956
Chloride	25	1560
Chlorobenzene	20	1106
Chloroform	20	1489
Chloroform	25	1465
Citric acid	25	1660
Coconut oil	15	924
Cotton seed oil	15	926
Cresol	25	1024
Creosote	15	1067
Crude oil, 48° API	60°F	790
Crude oil, 40° API	60°F	825
Crude oil, 35.6° API	60°F	847
Crude oil, 32.6° API	60°F	862

Crude oil, California	60°F	915
Crude oil, Mexican	60°F	973
Crude oil, Texas	60°F	873
Cumene	25	860
Cyclohexane	20	779
Cyclopentane	20	745
Decane	25	726
Diesel fuel oil 20 to 60	15	820 - 950
Diethyl ether	20	714
o-Dichlorobenzene	20	1306
Dichloromethane	20	1326
Diethylene glycol	15	1120
Dichloromethane	20	1326
Dimethyl Acetamide	20	942
N,N-Dimethylformamide	20	949
Dimethyl Sulfoxide	20	1100
Dodecane	25	755
Ethane	-89	570
Ether	25	73
Ethylamine	16	681
Ethyl Acetate	20	901
Ethyl Alcohol	20	789
Ethyl Ether	20	713
Ethylene Dichloride	20	1253
Ethylene glycol	25	1097
Fluorine refrigerant R-12	25	1311
Formaldehyde	45	812
Formic acid 10%oncentration	20	1025
Formic acid 80%oncentration	20	1221
Freon - 11	21	1490
Freon - 21	21	1370
Fuel oil	60°F	890
Furan	25	1416
Furfural	25	1155
Gasoline, natural	60°F	711
Gasoline, Vehicle	60°F	737
Gas oils	60°F	890
Glucose	60°F	1350 - 1440
Glycerin	25	1259
Glycerol	25	1126
Heptane	25	676
Hexane	25	655
Hexanol	25	811
Hexene	25	671

Hydrazine	25	795
Iodine	25	4927
Ionene	25	932
Isobutyl Alcohol	20	802
Iso-Octane	20	692
Isopropyl Alcohol	20	785
Isopropyl Myristate	20	853
Kerosene	60°F	817
Linolenic Acid	25	897
Linseed oil	25	929
Methane	-164	465
Methanol	20	791
Methyl Isoamyl Ketone	20	888
Methyl Isobutyl Ketone	20	801
Methyl n-Propyl Ketone	20	808
Methyl t-Butyl Ether	20	741
N-Methylpyrrolidone	20	1030
Methyl Ethyl Ketone	20	805
Milk	15	1020 - 1050
Naphtha	15	665
Naphtha, wood	25	960
Naphthalene	25	820
Ocimene	25	798
Octane	15	918
Olive oil	20	800 - 920
Oxygen (liquid)	-183	1140
Palmitic Acid	25	851
Pentane	20	626
Pentane	25	625
Petroleum Ether	20	640
Petrol, natural	60°F	711
Petrol, Vehicle	60°F	737
Phenol	25	1072
Phosgene	0	1378
Phytadiene	25	823
Pinene	25	857
Propane	-40	583
Propane, R-290	25	494
Propanol	25	804
Propylene carbonate	20	1201
Propylene	25	514
Propylene glycol	25	965
Pyridine	25	979
Pyrrole	25	966

Rape seed oil	20	920
Resorcinol	25	1269
Rosin oil	15	980
Sea water	25	1025
Silane	25	718
Silicone oil		760
Sodium Hydroxide (caustic soda)	15	1250
Sorbaldehyde	25	895
Soya bean oil	15	924 - 928
Stearic Acid	25	891
Sulfuric Acid 95%onc.	20	1839
Sugar solution 68 brix	15	1338
Sunflower oil	20	920
Styrene	25	903
Terpinene	25	847
Tetrahydrofuran	20	888
Toluene	20	867
Toluene	25	862
Triethylamine	20	728
Trifluoroacetic Acid	20	1489
Turpentine	25	868
Water - pure	4	1000
Water - sea	77°F	1022
Whale oil	15	925
o-Xylene	20	880

1 kg/m³ = 0.001 g/cm³ = 0.0005780 oz/in³ = 0.16036 oz/gal (Imperial) = 0.1335 oz/gal (U.S.) = 0.0624 lb/ft³ = 0.000036127 lb/in³ = 1.6856 lb/yd³ = 0.010022 lb/gal (Imperial) = 0.008345 lb/gal (U.S) = 0.0007525 ton/yd³

Dynamic or Absolute Viscosity Units Converting Table

The table below can be used to convert between common dynamic or absolute viscosity units.

Multiply by	Convert to				
Convert from	Poiseuille (Pa s)	Poise (dyne s / cm ² = g / cm s)	centiPoise	kg / m h	kg _f s / m ²
Poiseuille (Pa s)	1	10	10 ³	3.63 10 ³	0.102
Poise (dyne s / cm ² = g / cm s)	0.1	1	100	360	0.0102
centiPoise	0.001	0.01	1	3.6	0.00012
kg / m h	2.78 10 ⁻⁴	0.00278	0.0278	1	2.83 10 ⁻⁵
kg _f s / m ²	9.81	98.1	9.81 10 ³	3.53 10 ⁴	1
lb _f s / inch ²	6.89 10 ³	6.89 10 ⁴	6.89 10 ⁶	2.48 10 ⁷	703
lb _f s / ft ²	47.9	479	4.79 10 ⁴	1.72 10 ⁵	0.0488
lb _f h / ft ²	1.72 10 ⁵	1.72 10 ⁶	1.72 10 ⁸	6.21 10 ⁸	1.76 10 ⁴
lb / ft s	1.49	14.9	1.49 10 ³	5.36 10 ³	0.152
lb / ft h	4.13 10 ⁻⁴	0.00413	0.413	1.49	4.22 10 ⁻⁵
Multiply by	Convert to				
Convert from	lb _f s / inch ²	lb _f s / ft ²	lb _f h / ft ²	lb / ft s	lb / ft h
Poiseuille (Pa s)	1.45 10 ⁻⁴	0.0209	5.8 10 ⁻⁶	0.672	2.42 10 ³
Poise (dyne s / cm ² = g / cm s)	1.45 10 ⁻⁵	0.00209	5.8 10 ⁻⁷	0.0672	242
centiPoise	1.45 10 ⁻⁷	2.9 10 ⁻⁵	5.8 10 ⁻⁹	0.000672	2.42
kg / m h	4.03 10 ⁻⁸	5.8 10 ⁻⁶	1.61 10 ⁻⁹	0.000187	0.672
kg _f s / m ²	0.00142	20.5	5.69 10 ⁻⁵	6.59	2.37 10 ⁴
lb _f s / inch ²	1	144	0.04	4.63 10 ³	1.67 10 ⁷
lb _f s / ft ²	0.00694	1	0.000278	32.2	1.16 10 ⁵
lb _f h / ft ²	25	3.6 10 ³	1	1.16 10 ⁵	4.17 10 ⁸
lb / ft s	0.000216	0.0311	8.63 10 ⁻⁶	1	3.6 10 ³
lb / ft h	6 10 ⁻⁸	1.16 10 ⁵	2.4 10 ⁻⁹	0.000278	1

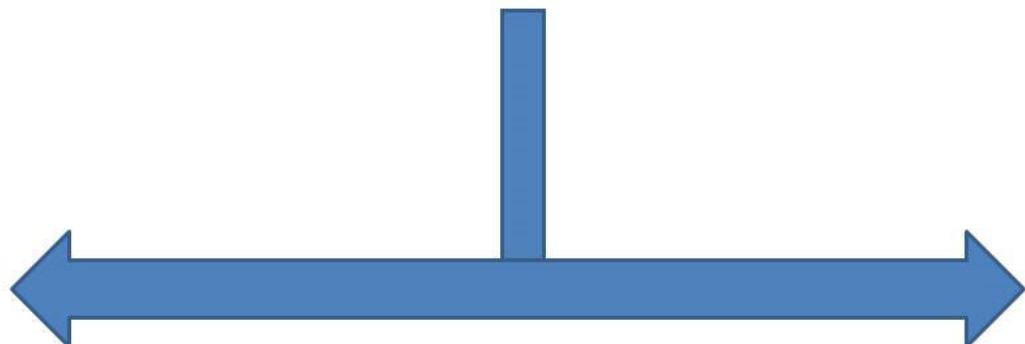
Friction Loss Chart

The table below can be used to indicate the friction loss - feet of liquid per 100 feet of pipe - in standard schedule 40 steel pipes.

Pipe Size (inches)	Flow Rate		Kinematic Viscosity - SSU					
	(gpm)	(l/s)	31 (Water)	100 (~Cream)	200 (~Vegetable oil)	400 (~SAE 10 oil)	800 (~Tomato juice)	1500 (~SAE 30 oil)
1/2	3	0.19	10.0	25.7	54.4	108.0	218.0	411.0
3/4	3	0.19	2.5	8.5	17.5	35.5	71.0	131.0
	5	0.32	6.3	14.1	29.3	59.0	117.0	219.0
1	3	0.19	0.8	3.2	6.6	13.4	26.6	50.0
	5	0.32	1.9	5.3	11.0	22.4	44.0	83.0
	10	0.63	6.9	11.2	22.4	45.0	89.0	165.0
	15	0.95	14.6	26.0	34.0	67.0	137.0	
	20	1.26	25.1	46	46.0	90.0	180.0	
1 1/4	5	0.32	0.5	1.8	3.7	7.6	14.8	26.0
	10	0.63	1.8	3.6	7.5	14.9	30.0	55.0
	15	0.95	3.7	6.4	11.3	22.4	45.0	84.0
1 1/2	10	0.63	0.8	1.9	4.2	8.1	16.5	31.0
	15	0.95	1.7	2.8	6.2	12.4	25.0	46.0
	20	1.26	2.9	5.3	8.1	16.2	33.0	61.0
	30	1.9	6.3	11.6	12.2	24.3	50.0	91.0
	40	2.5	10.8	19.6	20.8	32.0	65.0	121.0
2	20	1.26	0.9	1.5	3.0	6.0	11.9	22.4
	30	1.9	1.8	3.2	4.4	9.0	17.8	33.0
	40	2.5	3.1	5.8	5.8	11.8	24.0	44.0
	60	3.8	6.6	11.6	13.4	17.8	36.0	67.0
	80	5.0	1.6	3.0	3.2	4.8	9.7	18.3
2 1/2	30	1.9	0.8	1.4	2.2	4.4	8.8	16.6
	40	2.5	1.3	2.5	3.0	5.8	11.8	22.2
	60	3.8	2.7	5.1	5.5	8.8	17.8	34.0
	80	5.0	4.7	8.3	9.7	11.8	24.0	44.0
	100	6.3	7.1	12.2	14.1	14.8	29.0	55.0
3	60	3.8	0.9	1.8	1.8	3.7	7.3	13.8
	100	6.3	2.4	4.4	5.1	6.2	12.1	23.0
	125	7.9	3.6	6.5	7.8	8.1	15.3	29.0
	150	9.5	5.1	9.2	10.4	11.5	18.4	35.0
	175	11.0	6.9	11.7	13.8	15.8	21.4	40.0
	200	12.6	8.9	15.0	17.8	20.3	25.0	46.0
4	80	5.0	0.4	0.8	0.8	1.7	3.3	6.2
	100	6.3	0.6	1.2	1.3	2.1	4.1	7.8
	125	7.9	0.9	1.8	2.1	2.6	5.2	9.8
	150	9.5	1.3	2.4	2.9	3.1	6.2	11.5
	175	11.0	1.8	3.2	4.0	4.0	7.4	13.7

	200	12.6	2.3	4.2	5.1	5.1	8.3	15.5
	250	15.8	3.5	6.0	7.4	8.0	10.2	19.4
6	125	7.9	0.1	0.3	0.3	0.52	1.0	1.9
	150	9.5	0.2	0.3	0.4	0.6	1.2	2.3
	175	11.0	0.2	0.4	0.5	0.7	1.4	2.6
	200	12.6	0.3	0.6	0.7	0.8	1.6	3.0
	250	15.8	0.5	0.8	1.0	1.0	2.1	3.7
	300	18.9	1.1	8.5	10.0	11.6	12.4	23.0
	400	25.2	1.1	1.9	2.3	2.8	3.2	6.0
8	250	15.8	0.1	0.2	0.3	0.4	0.7	1.2
	300	18.9	0.3	1.2	1.4	1.5	2.5	4.6
	400	25.2	0.3	0.5	0.6	0.7	1.1	2.0
10	300	18.9	0.1	0.3	0.4	0.4	0.8	1.5
	400	25.2	0.1	0.2	0.2	0.2	0.4	0.8

FLUIDS



Incompressible
 ρ is constant

Compressible
 ρ varies

Hazen-Williams Coefficients

Hazen-Williams factor for some common piping materials. Hazen-Williams coefficients are used in the Hazen-Williams equation for friction loss calculation in ducts and pipes. Coefficients for some common materials used in ducts and pipes can be found in the table below:

Material	Hazen-Williams Coefficient - C -
Asbestos Cement	140
Brass	130 - 140
Brick sewer	100
Cast-Iron - new unlined (CIP)	130
Cast-Iron 10 years old	107 - 113
Cast-Iron 20 years old	89 - 100
Cast-Iron 30 years old	75 - 90
Cast-Iron 40 years old	64-83
Cast-Iron, asphalt coated	100
Cast-Iron, cement lined	140
Cast-Iron, bituminous lined	140
Cast-Iron, wrought plain	100
Concrete	100 - 140
Copper or Brass	130 - 140
Ductile Iron Pipe (DIP)	140
Fiber	140
Galvanized iron	120
Glass	130
Lead	130 - 140
Plastic	130 - 150
Polyethylene, PE, PEH	150
PVC, CPVC	150
Smooth Pipes	140
Steel new unlined	140 - 150
Steel	
Steel, welded and seamless	100
Steel, interior riveted, no projecting rivets	100
Steel, projecting girth rivets	100
Steel, vitrified, spiral-riveted	90 - 100
Steel, corrugated	60
Tin	130
Vitrified Clays	110
Wood Stave	110 - 120

Pressure Head

A pressure difference of 5 psi (lbf/in^2) is equivalent to

$$5 \text{ (\text{lbf/in}^2)} \cdot 12 \text{ (in/ft)} \cdot 12 \text{ (in/ft)} / 62.4 \text{ (\text{lb/ft}^3)} = 11.6 \text{ ft of water}$$

$$5 \text{ (\text{lbf/in}^2)} \cdot 12 \text{ (in/ft)} \cdot 12 \text{ (in/ft)} / 847 \text{ (\text{lb/ft}^3)} = 0.85 \text{ ft of mercury}$$

When specific weight of water is 62.4 (lb/ft^3) and specific weight of mercury is 847 (lb/ft^3).

Heads at different velocities can be taken from the table below:

Velocity (ft/sec)	Head Water (ft)
0.5	0.004
1.0	0.016
1.5	0.035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	4.493
18.0	5.037
19.0	5.613
20.0	6.219
21.0	6.856
22.0	7.525

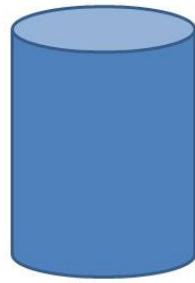
1 ft (foot) = 0.3048 m = 12 in = 0.3333 yd.

Thermal Properties of Water

Temperature - <i>t</i> - (°C)	Absolute pressure - <i>p</i> - (kN/m ²)	Density - <i>ρ</i> - (kg/m ³)	Specific volume - <i>V</i> - (m ³ /kg×10 ⁻³)	Specific Heat - <i>c_p</i> - (kJ/kgK)	Specific entropy - <i>e</i> - (kJ/kgK)
0	0.6	1000	100	4.217	0
5	0.9	1000	100	4.204	0.075
10	1.2	1000	100	4.193	0.150
15	1.7	999	100	4.186	0.223
20	2.3	998	100	4.182	0.296
25	3.2	997	100	4.181	0.367
30	4.3	996	100	4.179	0.438
35	5.6	994	101	4.178	0.505
40	7.7	991	101	4.179	0.581
45	9.6	990	101	4.181	0.637
50	12.5	988	101	4.182	0.707
55	15.7	986	101	4.183	0.767
60	20.0	980	102	4.185	0.832
65	25.0	979	102	4.188	0.893
70	31.3	978	102	4.190	0.966
75	38.6	975	103	4.194	1.016
80	47.5	971	103	4.197	1.076
85	57.8	969	103	4.203	1.134
90	70.0	962	104	4.205	1.192
95	84.5	962	104	4.213	1.250
100	101.33	962	104	4.216	1.307
105	121	955	105	4.226	1.382
110	143	951	105	4.233	1.418
115	169	947	106	4.240	1.473
120	199	943	106	4.240	1.527
125	228	939	106	4.254	1.565
130	270	935	107	4.270	1.635
135	313	931	107	4.280	1.687
140	361	926	108	4.290	1.739
145	416	922	108	4.300	1.790
150	477	918	109	4.310	1.842
155	543	912	110	4.335	1.892
160	618	907	110	4.350	1.942
165	701	902	111	4.364	1.992
170	792	897	111	4.380	2.041
175	890	893	112	4.389	2.090
180	1000	887	113	4.420	2.138
185	1120	882	113	4.444	2.187
190	1260	876	114	4.460	2.236

195	1400	870	115	4.404	2.282
200	1550	863	116	4.497	2.329
220					
225	2550	834	120	4.648	2.569
240					
250	3990	800	125	4.867	2.797
260					
275	5950	756	132	5.202	3.022
300	8600	714	140	5.769	3.256
325	12130	654	153	6.861	3.501
350	16540	575	174	10.10	3.781
360	18680	526	190	14.60	3.921

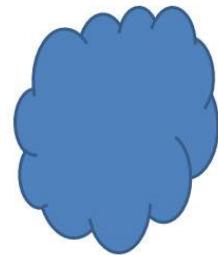
SOLID



LIQUID



GAS



MORE

LESS

EFFORT NEEDED TO COMPRESS

Viscosity Converting Chart

The viscosity of a fluid is its resistance to shear or flow, and is a measure of the fluid's adhesive/cohesive or frictional properties. This arises because of the internal molecular friction within the fluid producing the frictional drag effect. There are two related measures of fluid viscosity which are known as **dynamic** and **kinematic** viscosity.

Dynamic viscosity is also termed "**absolute viscosity**" and is the tangential force per unit area required to move one horizontal plane with respect to the other at unit velocity when maintained a unit distance apart by the fluid.

Centipoise (CPS) Millipascal (mPas)	Poise (P)	Centistokes (cSt)	Stokes (S)	Saybolt Seconds Universal (SSU)
1	0.01	1	0.01	31
2	0.02	2	0.02	34
4	0.04	4	0.04	38
7	0.07	7	0.07	47
10	0.1	10	0.1	60
15	0.15	15	0.15	80
20	0.2	20	0.2	100
25	0.24	25	0.24	130
30	0.3	30	0.3	160
40	0.4	40	0.4	210
50	0.5	50	0.5	260
60	0.6	60	0.6	320
70	0.7	70	0.7	370
80	0.8	80	0.8	430
90	0.9	90	0.9	480
100	1	100	1	530
120	1.2	120	1.2	580
140	1.4	140	1.4	690
160	1.6	160	1.6	790
180	1.8	180	1.8	900
200	2	200	2	1000
220	2.2	220	2.2	1100
240	2.4	240	2.4	1200
260	2.6	260	2.6	1280
280	2.8	280	2.8	1380
300	3	300	3	1475
320	3.2	320	3.2	1530
340	3.4	340	3.4	1630
360	3.6	360	3.6	1730

380	3.8	380	3.8	1850
400	4	400	4	1950
420	4.2	420	4.2	2050
440	4.4	440	4.4	2160
460	4.6	460	4.6	2270
480	4.8	480	4.8	2380
500	5	500	5	2480
550	5.5	550	5.5	2660
600	6	600	6	2900
700	7	700	7	3380
800	8	800	8	3880
900	9	900	9	4300
1000	10	1000	10	4600
1100	11	1100	11	5200
1200	12	1200	12	5620
1300	13	1300	13	6100
1400	14	1400	14	6480
1500	15	1500	15	7000
1600	16	1600	16	7500
1700	17	1700	17	8000
1800	18	1800	18	8500
1900	19	1900	19	9000
2000	20	2000	20	9400
2100	21	2100	21	9850
2200	22	2200	22	10300
2300	23	2300	23	10750
2400	24	2400	24	11200

Various Flow Section Channels and their Geometric Relationships:

Area, wetted perimeter and hydraulic diameter for some common geometric sections like

- rectangular channels
- trapezoidal channels
- triangular channels
- circular channels.

Rectangular Channel

Flow Area

Flow area of a rectangular channel can be expressed as

$$A = b h \quad (1)$$

where

A = flow area (m^2 , in^2)

b = width of channel (m , in)

h = height of flow (m , in)

Wetted Perimeter

Wetted perimeter of a rectangular channel can be expressed as

$$P = b + 2 h \quad (1b)$$

where

P = wetted perimeter (m , in)

Hydraulic Radius

Hydraulic radius of a rectangular channel can be expressed as

$$R_h = b h / (b + 2 y) \quad (1c)$$

where

R_h = hydraulic radius (m , in)

Trapezoidal Channel

Flow Area

Flow area of a trapezoidal channel can be expressed as

$$A = (a + z h) h \quad (2)$$

where

z = see figure above (m , in)

Wetted Perimeter

Wetted perimeter of a trapezoidal channel can be expressed as

$$P = a + 2 h (1 + z^2)^{1/2} \quad (2b)$$

Hydraulic Radius

Hydraulic radius of a trapezoidal channel can be expressed as

$$R_h = (a + z h) h / a + 2 h (1 + z^2)^{1/2} \quad (2c)$$

Triangular Channel

Flow Area

Flow area of a triangular channel can be expressed as

$$A = z h^2 \quad (3)$$

where

z = see figure above (m, in)

Wetted Perimeter

Wetted perimeter of a triangular channel can be expressed as

$$P = 2 h (1 + z^2)^{1/2} \quad (3b)$$

Hydraulic Radius

Hydraulic radius of a triangular channel can be expressed as

$$R_h = z h / 2 (1 + z^2)^{1/2} \quad (3c)$$

Circular Channel

Flow Area

Flow area of a circular channel can be expressed as

$$A = D^2/4 (\alpha - \sin(2\alpha)/2) \quad (4)$$

where

D = diameter of channel

$$\alpha = \cos^{-1}(1 - h/r)$$

Wetted Perimeter

Wetted perimeter of a circular channel can be expressed as

$$P = \alpha D \quad (4b)$$

Hydraulic Radius

Hydraulic radius of a circular channel can be expressed as

$$R_h = D/8 [1 - \sin(2\alpha) / (2\alpha)] \quad (4c)$$

Velocity Head: Velocity head can be expressed as

$$h = v^2/2g \quad (1)$$

where

v = velocity (ft, m)

g = acceleration of gravity (32.174 ft/s², 9.81 m/s²)

Heads at different velocities can be taken from the table below:

Velocity - v - (ft/sec)	Velocity Head - $v^2/2g$ - (ft Water)
0.5	0.004
1.0	0.016
1.5	0.035
2.0	0.062
2.5	0.097
3.0	0.140
3.5	0.190
4.0	0.248
4.5	0.314
5.0	0.389
5.5	0.470
6.0	0.560
6.5	0.657
7.0	0.762
7.5	0.875
8.0	0.995
8.5	1.123
9.0	1.259
9.5	1.403
10.0	1.555
11.0	1.881
12.0	2.239
13.0	2.627
14.0	3.047
15.0	3.498
16.0	3.980
17.0	4.493
18.0	5.037
19.0	5.613
20.0	6.219
21.0	6.856
22.0	7.525

Some Commonly used Thermal Properties for Water

- Density at 4 °C - 1,000 kg/m³, 62.43 Lbs./Cu.Ft., 8.33 Lbs./Gal., 0.1337 Cu.Ft./Gal.
 - Freezing temperature - 0 °C
 - Boiling temperature - 100 °C
 - Latent heat of melting - 334 kJ/kg
 - Latent heat of evaporation - 2,270 kJ/kg
 - Critical temperature - 380 - 386 °C
 - Critical pressure - 23.520 kN/m²
 - Specific heat capacity water - 4.187 kJ/kgK
 - Specific heat capacity ice - 2.108 kJ/kgK
 - Specific heat capacity water vapor - 1.996 kJ/kgK
 - Thermal expansion from 4 °C to 100 °C - 4.2x10⁻²
- Bulk modulus elasticity - 2,068,500 kN/m²

Reynolds Number

Turbulent or laminar flow is determined by the dimensionless **Reynolds Number**.

The Reynolds number is important in analyzing any type of flow when there is substantial velocity gradient (i.e., shear.) It indicates the relative significance of the viscous effect compared to the inertia effect. The Reynolds number is proportional to inertial force divided by viscous force.

A definition of the Reynolds' Number:

The flow is

- **laminar** if $Re < 2300$
- **transient** if $2300 < Re < 4000$
- **turbulent** if $4000 < Re$

The table below shows Reynolds Number for one liter of water flowing through pipes of different dimensions:

Pipe Size										
(inches)	1	1 ?	2	3	4	6	8	10	12	18
(mm)	25	40	50	75	100	150	200	250	300	450
Reynolds number with one (1) liter/min	835	550	420	280	210	140	105	85	70	46
Reynolds number with one (1) gal/min	3800	2500	1900	1270	950	630	475	380	320	210

Linear Motion Formulas

Velocity can be expressed as (velocity = constant):

$$v = s / t \text{ (1a)}$$

where

v = velocity (m/s, ft/s)

s = linear displacement (m, ft)

t = time (s)

Velocity can be expressed as (acceleration = constant):

$$v = V_0 + a t \text{ (1b)}$$

where

V_0 = linear velocity at time zero (m/s, ft/s)

Linear displacement can be expressed as (acceleration = constant):

$$s = V_0 t + 1/2 a t^2 \text{ (1c)}$$

Combining 1a and 1c to express velocity

$$v = (V_0^2 + 2 a s)^{1/2} \text{ (1d)}$$

Velocity can be expressed as (velocity variable)

$$v = ds / dt \text{ (1f)}$$

where

ds = change of displacement (m, ft)

dt = change in time (s)

Acceleration can be expressed as

$$a = dv / dt \text{ (1g)}$$

where

dv = change in velocity (m/s, ft/s)

Water - Dynamic and Kinematic Viscosity

Dynamic and Kinematic Viscosity of Water in Imperial Units (BG units):

Temperature - <i>t</i> - (°F)	Dynamic Viscosity - μ - 10^{-5} (lbs./ft ²)	Kinematic Viscosity - <i>v</i> - 10^{-5} (ft ² /s)
32	3.732	1.924
40	3.228	1.664
50	2.730	1.407
60	2.344	1.210
70	2.034	1.052
80	1.791	0.926
90	1.500	0.823
100	1.423	0.738
120	1.164	0.607
140	0.974	0.511
160	0.832	0.439
180	0.721	0.383
200	0.634	0.339
212	0.589	0.317

Dynamic and Kinematic Viscosity of Water in SI Units:

Temperature - <i>t</i> - (°C)	Dynamic Viscosity - μ - 10^{-3} (N.s/m ²)	Kinematic Viscosity - <i>v</i> - 10^{-6} (m ² /s)
0	1.787	1.787
5	1.519	1.519
10	1.307	1.307
20	1.002	1.004
30	0.798	0.801
40	0.653	0.658
50	0.547	0.553
60	0.467	0.475
70	0.404	0.413
80	0.355	0.365
90	0.315	0.326
100	0.282	0.294

Water and Speed of Sound

Speed of sound in water at temperatures between 32 - 212°F (0-100°C) - imperial and SI units

Speed of Sound in Water - in imperial units (BG units)

Temperature - <i>t</i> - (°F)	Speed of Sound - <i>c</i> - (ft/s)
32	4,603
40	4,672
50	4,748
60	4,814
70	4,871
80	4,919
90	4,960
100	4,995
120	5,049
140	5,091
160	5,101
180	5,095
200	5,089
212	5,062

Speed of Sound in Water - in SI units

Temperature - <i>t</i> - (°C)	Speed of Sound - <i>c</i> - (m/s)
0	1,403
5	1,427
10	1,447
20	1,481
30	1,507
40	1,526
50	1,541
60	1,552
70	1,555
80	1,555
90	1,550
100	1,543

Math Conversion Factors

1 PSI = 2.31 Feet of Water
1 Foot of Water = .433 PSI
1.13 Feet of Water = 1 Inch of Mercury
454 Grams = 1 Pound
2.54 CM =Inch
1 Gallon of Water = 8.34 Pounds
1 mg/L = 1 PPM
17.1 mg/L = 1 Grain/Gallon
1% = 10,000 mg/L
694 Gallons per Minute = MGD
1.55 Cubic Feet per Second = 1 MGD
60 Seconds = 1 Minute
1440 Minutes = 1 Day
.746 kW = 1 Horsepower

LENGTH

12 Inches = 1 Foot
3 Feet = 1 Yard
5,280 Feet = 1 Mile

AREA

144 Square Inches = 1 Square Foot
43,560 Square Feet = 1 Acre

VOLUME

1000 Milliliters = 1 Liter
3.785 Liters = 1 Gallon
231 Cubic Inches = 1 Gallon
7.48 Gallons = 1 Cubic Foot of Water
62.38 Pounds = 1 Cubic Foot of Water

Dimensions

SQUARE: Area (sq. ft) = Length X Width
Volume (cu.ft.) = Length (ft) X Width (ft) X Height (ft)

CIRCLE: Area (sq.ft.) = $3.14 \times \text{Radius (ft)} \times \text{Radius (ft)}$

CYLINDER: Volume (Cu. ft) = $3.14 \times \text{Radius (ft)} \times \text{Radius (ft)} \times \text{Depth (ft)}$

PIPE VOLUME: $.785 \times \text{Diameter}^2 \times \text{Length} = ?$ To obtain gallons multiply by 7.48

SPHERE: $\frac{(3.14)(\text{Diameter})^3}{(6)}$ Circumference = $3.14 \times \text{Diameter}$

General Conversions

Multiply	→	to get
to get	←	Divide
cc/min	1	mL/min
cfm (ft ³ /min)	28.31	L/min
cfm (ft ³ /min)	1.699	m ³ /hr
cfh (ft ³ /hr)	472	mL/min
cfh (ft ³ /hr)	0.125	GPM
GPH	63.1	mL/min
GPH	0.134	cfh
GPM	0.227	m ³ /hr
GPM	3.785	L/min
oz/min	29.57	mL/min

POUNDS PER DAY= Flow (MG) X Concentration (mg/L) X 8.34

AKA Solids Applied Formula = Flow X Dose X 8.34

PERCENT EFFICIENCY = $\frac{\text{In} - \text{Out}}{\text{In}} \times 100$

$$\begin{array}{lll} \text{TEMPERATURE: } & {}^{\circ}\text{F} = ({}^{\circ}\text{C} \times 9/5) + 32 & 9/5 = 1.8 \\ & {}^{\circ}\text{C} = ({}^{\circ}\text{F} - 32) \times 5/9 & 5/9 = .555 \end{array}$$

CONCENTRATION: Conc. (A) X Volume (A) = Conc. (B) X Volume (B)

FLOW RATE (Q): Q = A X V (Quantity = Area X Velocity)

FLOW RATE (gpm): Flow Rate (gpm) = 2.83 (Diameter, in)² (Distance, in)
Height, in

$$\% \text{ SLOPE} = \frac{\text{Rise (feet)}}{\text{Run (feet)}} \times 100$$

$$\text{ACTUAL LEAKAGE} = \frac{\text{Leak Rate (GPD)}}{\text{Length (mi.)} \times \text{Diameter (in)}}$$

$$\text{VELOCITY} = \frac{\text{Distance (ft)}}{\text{Time (Sec)}}$$

N = Manning's Coefficient of Roughness

R = Hydraulic Radius (ft.)

S = Slope of Sewer (ft/ft.)

$$\text{HYDRAULIC RADIUS (ft)} = \frac{\text{Cross Sectional Area of Flow (ft)}}{\text{Wetted pipe Perimeter (ft)}}$$

$$\text{WATER HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960}$$

$$\text{BRAKE HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Efficiency}}$$

$$\text{MOTOR HORSEPOWER} = \frac{\text{Flow (gpm)} \times \text{Head (ft)}}{3960 \times \text{Pump Eff.} \times \text{Motor Eff.}}$$

$$\text{MEAN OR AVERAGE} = \frac{\text{Sum of the Values}}{\text{Number of Values}}$$

TOTAL HEAD (ft) = Suction Lift (ft) X Discharge Head (ft)

$$\text{SURFACE LOADING RATE} = \frac{\text{Flow Rate (gpm)}}{(\text{gal/min/sq.ft.}) \times \text{Surface Area (sq. ft)}}$$

$$\text{MIXTURE} = \frac{(\text{Volume 1, gal})(\text{Strength 1, \%}) + (\text{Volume 2, gal})(\text{Strength 2, \%})}{(\text{Volume 1, gal}) + (\text{Volume 2, gal})}$$

$$\text{DETENTION TIME (hrs.)} = \frac{\text{Volume of Basin (gals)} \times 24 \text{ hrs.}}{\text{Flow (GPD)}}$$

$$\text{SLOPE} = \frac{\text{Rise (ft)}}{\text{Run (ft)}} \quad \text{SLOPE (\%)} = \frac{\text{Rise (ft)}}{\text{Run (ft)}} \times 100$$

POPULATION EQUIVALENT (PE):

1 PE = .17 Pounds of BOD per Day

1 PE = .20 Pounds of Solids per Day

1 PE = 100 Gallons per Day

LEAKAGE (GPD/inch) = $\frac{\text{Leakage of Water per Day (GPD)}}{\text{Sewer Diameter (inch)}}$

CHLORINE DEMAND (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L)

MANNING'S EQUATION

τQ = Allowable time for decrease in pressure from 3.5 PSI to 2.5 PSI

τq = As below

$$\tau Q = (0.022) (d_1^2 L_1) / Q \quad \tau q = \frac{[0.085]}{q} [(d_1^2 L_1) / (d_1 L_1)]$$

Q = 2.0 cfm air loss

θ = .0030 cfm air loss per square foot of internal pipe surface

d = Pipe diameter (inches)

L = Pipe Length (feet)

$$V = \frac{1.486 R^{2/3} S^{1/2}}{v}$$

V = Velocity (ft./sec.)

v = Pipe Roughness

R = Hydraulic Radius (ft)

S = Slope (ft/ft)

HYDRAULIC RADIUS (ft) = $\frac{\text{Flow Area (ft. 2)}}{\text{Wetted Perimeter (ft.)}}$

WIDTH OF TRENCH (ft) = Base (ft) + (2 Sides) X $\frac{\text{Depth (ft 2)}}{\text{Slope}}$

Formula/Conversion Table

$$\text{Acid Feed Rate} = \frac{(\text{Waste Flow}) (\text{Waste Normality})}{\text{Acid Normality}}$$

$$\text{Alkalinity} = \frac{(\text{mL of Titrant}) (\text{Acid Normality}) (50,000)}{\text{mL of Sample}}$$

$$\text{Amperage} = \text{Voltage} \div \text{Ohms}$$

$$\text{Area of Circle} = (0.785)(\text{Diameter}^2) \text{ OR } (\pi)(\text{Radius}^2)$$

$$\text{Area of Rectangle} = (\text{Length})(\text{Width})$$

$$\text{Area of Triangle} = \frac{(\text{Base}) (\text{Height})}{2}$$

$$\text{C Factor Slope} = \text{Energy loss, ft.} \div \text{Distance, ft.}$$

$$\text{C Factor Calculation} = \text{Flow, GPM} \div [193.75 (\text{Diameter, ft.})^{2.63} (\text{Slope})^{0.54}]$$

$$\text{Chemical Feed Pump Setting, \% Stroke} = \frac{(\text{Desired Flow}) (100\%)}{\text{Maximum Flow}}$$

$$\text{Chemical Feed Pump Setting, mL/min} = \frac{(\text{Flow, MGD}) \text{ Dose, mg/L} (3.785 \text{ L/gal}) (1,000,000 \text{ gal/MG})}{(\text{Liquid, mg/mL}) (24 \text{ hr / day}) (60 \text{ min/hr})}$$

$$\text{Chlorine Demand (mg/L)} = \text{Chlorine dose (mg/L)} - \text{Chlorine residual (mg/L)}$$

$$\text{Circumference of Circle} = (3.141)(\text{Diameter})$$

$$\text{Composite Sample Single Portion} = \frac{(\text{Instantaneous Flow}) (\text{Total Sample Volume})}{(\text{Number of Portions}) (\text{Average Flow})}$$

$$\text{Detention Time} = \frac{\text{Volume}}{\text{Flow}}$$

$$\text{Digested Sludge Remaining, \%} = \frac{(\text{Raw Dry Solids}) (\text{Ash Solids}) (100\%)}{(\text{Digested Dry Solids}) (\text{Digested Ash Solids})}$$

$$\text{Discharge} = \frac{\text{Volume}}{\text{Time}}$$

$$\text{Dosage, lbs/day} = (\text{mg/L})(8.34)(\text{MGD})$$

$$\text{Dry Polymer (lbs.)} = (\text{gal. of solution})(8.34 \text{ lbs/gal})(\% \text{ polymer solution})$$

$$\text{Efficiency, \%} = \frac{(\text{In} - \text{Out}) (100\%)}{\text{In}}$$

Feed rate, lbs/day = $\frac{(\text{Dosage, mg/L}) (\text{Capacity, MGD}) (8.34 \text{ lbs/gals})}{(\text{Available fluoride ion}) (\text{Purity})}$

Feed rate, gal/min (Saturator) = $\frac{(\text{Plant capacity, gal/min.}) (\text{Dosage, mg /L})}{18,000 \text{ mg/L}}$

Filter Backwash Rate = $\frac{\text{Flow}}{\text{Filter Area}}$

Filter Yield, lbs/hr/sq. ft = $\frac{(\text{Solids Loading, lbs/day}) (\text{Recovery, \% / 100\%})}{(\text{Filter operation, hr/day}) (\text{Area, ft}^2)}$

Flow, cu. ft./sec. = (Area, Sq. Ft.)(Velocity, ft./sec.)

Food/Microorganism Ratio = $\frac{\text{BOD, lbs / day}}{\text{MLVSS, lbs}}$

Gallons/Capita/Day = $\frac{\text{Gallons / day}}{\text{Population}}$

Hardness = $\frac{(\text{mL of Titrant}) (1,000)}{\text{mL of Sample}}$

Horsepower (brake) = $\frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3,960) (\text{Efficiency})}$

Horsepower (motor) = $\frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3960) (\text{Pump, Eff.}) (\text{Motor, Eff.})}$

Horsepower (water) = $\frac{(\text{Flow, gpm}) (\text{Head, ft})}{(3960)}$

Hydraulic Loading Rate = $\frac{\text{Flow}}{\text{Area}}$

Leakage (actual) = Leak rate (GPD) ÷ [Length (mi.) x Diameter (in.)]

Mean = Sum of values ÷ total number of values

Mean Cell Residence Time (MCRT) = $\frac{\text{Suspended Solids in Aeration System, lbs}}{\text{SS Wasted, lbs / day} + \text{SS lost, lbs / day}}$

Organic Loading Rate = $\frac{\text{Organic Load, lbs BOD / day}}{\text{Volume}}$

Oxygen Uptake = $\frac{\text{Oxygen Usage}}{\text{Time}}$

Percent efficiency = $[(\text{In} - \text{Out}) \div \text{In}] \times 100$

Pounds per day = (Flow, MGD) (Dose, mg/L) (8.34)

Population Equivalent = $\frac{(\text{Flow MGD})(\text{BOD, mg/L})(8.34 \text{ lbs / gal})}{\text{Lbs BOD / day / person}}$

RAS Suspended Solids, mg/l = $\frac{1,000,000}{\text{SVI}}$

RAS Flow, MGD = $\frac{(\text{Infl. Flow, MGD})(\text{MLSS, mg/l})}{\text{RAS Susp. Sol., mg/l} - \text{MLSS, mg/l}}$

RAS Flow % = $\frac{(\text{RAS Flow, MGD})(100 \%)}{\text{Infl. Flow, MGD}}$

Reduction in Flow, % = $\frac{(\text{Original Flow} - \text{Reduced Flow})(100\%)}{\text{Original Flow}}$

Slope = $\frac{\text{Drop or Rise}}{\text{Run or Distance}}$

Sludge Age = $\frac{\text{Mixed Liquor Solids, lbs}}{\text{Primary Effluent Solids, lbs / day}}$

Sludge Index = $\frac{\% \text{ Settleable Solids}}{\% \text{ Suspended Solids}}$

Sludge Volume Index = $\frac{(\text{Settleable Solids, \%})(10,000)}{\text{MLSS, mg/L}}$

Solids, mg/L = $\frac{(\text{Dry Solids, grams})(1,000,000)}{\text{mL of Sample}}$

Solids Applied, lbs/day = (Flow, MGD)(Concentration, mg/L)(8.34 lbs/gal)

Solids Concentration = $\frac{\text{Weight}}{\text{Volume}}$

Solids Loading, lbs/day/sq. ft = $\frac{\text{Solids Applied, lbs / day}}{\text{Surface Area, sq. ft}}$

Surface Loading Rate = $\frac{\text{Flow}}{\text{Rate}}$

Total suspended solids (TSS), mg/L =
(Dry weight, mg)(1,000 mL/L) ÷ (Sample vol., mL)

$$\text{Velocity} = \frac{\text{Flow}}{\text{Area}} \quad \text{OR} \quad \frac{\text{Distance}}{\text{Time}}$$

$$\text{Volatile Solids, \%} = \frac{(\text{Dry Solids} - \text{Ash Solids})}{\text{Dry Solids}} (100\%)$$

$$\text{Volume of Cone} = (1/3)(0.785)(\text{Diameter}^2)(\text{Height})$$

$$\text{Volume of Cylinder} = (0.785)(\text{Diameter}^2)(\text{Height}) \quad \text{OR} \quad (\pi)(r^2)(h)$$

$$\text{Volume of Rectangle} = (\text{Length})(\text{Width})(\text{Height})$$

$$\text{Volume of Sphere} = [(\pi)(\text{diameter}^3)] \div 6$$

$$\text{Waste Milliequivalent} = (\text{mL}) \quad (\text{Normality})$$

$$\text{Waste Normality} = \frac{(\text{Titrant Volume}) \quad (\text{Titrant Normality})}{\text{Sample Volume}}$$

$$\text{Weir Overflow Rate} = \frac{\text{Flow}}{\text{Weir Length}}$$

Conversion Factors

1 acre = 43,560 square feet

1 cubic foot = 7.48 gallons

1 foot = 0.305 meters

1 gallon = 3.79 liters

1 gallon = 8.34 pounds

1 grain per gallon = 17.1 mg/L

1 horsepower = 0.746 kilowatts

1 million gallons per day = 694.45 gallons per minute

1 pound = 0.454 kilograms

1 pound per square inch = 2.31 feet of water

1% = 10,000 mg/L

Degrees Celsius = (Degrees Fahrenheit - 32) (5/9)

Degrees Fahrenheit = (Degrees Celsius * 9/5) + 32

64.7 grains = 1 cubic foot

1,000 meters = 1 kilometer

1,000 grams = 1 kilogram

1,000 milliliters = 1 liter

144 square inches = 1 square foot

1.55 cubic feet per second = 1 MGD

1 meter = 3.28 feet

π = 3.141

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