# Construction Guidance for Class I Injection Wells

Prepared by Underground Injection Control Permits Section Staff Radioactive Materials Division Office of Waste Texas Commission on Environmental Quality

## DRAFT

## xxx-###

## Drafted: August 2000

## Latest Revision: November 2013

Table of Contents

[1.0 Introduction 4](#_Toc372801548)

[1.1 Purpose 4](#_Toc372801549)

[1.2 Background 4](#_Toc372801550)

[1.2.1 TCEQ’s Class I Underground Injection Control Program 4](#_Toc372801551)

[1.2.2 Rulemaking Relating to this Guidance 5](#_Toc372801552)

[1.3 Acknowledgments 5](#_Toc372801553)

[2.0 Basic Construction Process for Class I Injection Wells 6](#_Toc372801554)

[3.0 Basic Geological Considerations 7](#_Toc372801555)

[4.0 Well Design 8](#_Toc372801556)

[4.1 Design Criteria 8](#_Toc372801557)

[4.2 Contingency Planning Using Offset Data from Area of Review 9](#_Toc372801558)

[4.3 Casing and Tubing Design 9](#_Toc372801559)

[4.4 Drilling 11](#_Toc372801560)

[4.4.1 Equipment Selection and Logistical Considerations 11](#_Toc372801561)

[4.4.2 Drilling Fluids 11](#_Toc372801562)

[4.5 Casing Installation 12](#_Toc372801563)

[4.6 Cementing 12](#_Toc372801564)

[4.6.1 Regulatory Standards 12](#_Toc372801565)

[4.6.2 Methods of Cementing 12](#_Toc372801566)

[4.6.3 Classes of Cement and Types of Additives 13](#_Toc372801567)

[4.6.4 Volumes of Cement 13](#_Toc372801568)

[4.6.5 Strategies for Averting Lost Circulation During Cementing 14](#_Toc372801569)

[4.6.6 Additional Measures to Optimize Quality of Cementing 14](#_Toc372801570)

[4.6.7 Procedures When Cement is Unable to be Circulated to the Surface 16](#_Toc372801571)

[4.7 Completions 16](#_Toc372801572)

[4.8 Testing 17](#_Toc372801573)

[4.8.1 Regulatory Standards 17](#_Toc372801574)

[4.8.2 Spontaneous Potential Logs 18](#_Toc372801575)

[4.8.3 Resistivity Logs 18](#_Toc372801576)

[4.8.4 Natural Gamma Ray Logs 19](#_Toc372801577)

[4.8.5 Caliper Logs 19](#_Toc372801578)

[4.8.6 Compensated Density Logs 19](#_Toc372801579)

[4.8.7 Neutron Porosity Logs 19](#_Toc372801580)

[4.8.8 Dipmeter /Fracture Finder Logs 19](#_Toc372801581)

[4.8.9 Cement Evaluation Logs (Cement Bond with Variable Density Logs) 20](#_Toc372801582)

[4.9 Changes in Design 20](#_Toc372801583)

[4.10 Drilling Through an Existing Waste Plume and Disposal of Cuttings 21](#_Toc372801584)

[5.0 Implementation 22](#_Toc372801585)

[5.1 Regulatory Standards 22](#_Toc372801586)

[5.2 Project Supervision 22](#_Toc372801587)

[5.3 Notification Requirements for State Inspection of Construction Procedures 23](#_Toc372801588)

[6.0 Approval of Construction 24](#_Toc372801589)

[6.1 Information Needed for Approval 24](#_Toc372801590)

[6.1.1 Executive Director Approval of Construction and Completion 24](#_Toc372801591)

[6.1.2 Pre-Operational Reports 25](#_Toc372801592)

[6.2 Criteria for Approval 27](#_Toc372801593)

[6.2.1 Compliance With Application Plans and Specifications, as Modified by Permit Requirements 27](#_Toc372801594)

[6.2.2 Mechanical Integrity Testing 27](#_Toc372801595)

[6.2.3 Construction Performance Standard 28](#_Toc372801596)

[7.0 Summary and Conclusion 30](#_Toc372801597)

[Figure 1 31](#_Toc372801598)

[References Cited 32](#_Toc372801599)

1.0 Introduction

1.1 Purpose

This technical guidance document is intended to assist the reader in interpretation of and compliance with revised Class I injection well construction standards of Title 30, Texas Administrative Code (TAC), Section §331.62, as adopted by the Texas Commission on Environmental Quality (TCEQ or “the Commission”) in May 1995. Pertinent cross references are cited in 30 TAC §331.44 (Corrective Action Standards), 30 TAC §331.65(b)(1) (Completion Report), 30 TAC §331.121 (Consideration Prior to Permit Issuance), and 30 TAC §331.45 (Executive Director Approval of Construction and Completion), as adopted in April 1997.

This guidance document is not intended to modify or supersede the cited regulations or any other regulations of the State of Texas, or any provisions expressly stated in an injection well permit. In the event of apparent conflict between this document and promulgated regulations or permit provisions, the regulations and permit provisions shall take precedence. Furthermore, this document does not represent a compilation of minimum standards, nor is it to be considered as a technical manual of step-wise procedures or technical specifications for construction of Class I injection wells. Legally binding standards applicable to each authorized injection well are provided by rule, and by permit provisions. No part of this document should be interpreted as intending to discourage innovative applications of technology to improve the quality of well construction, particularly in subsurface environments which present potential problems. This document should be used as a supplement to applicable rules, permit documents, and plans and specifications contained in permit applications or any official correspondence providing for amendment of applications. Additional supplemental information may also be obtained from the well construction literature and from qualified consultants familiar with the special requirements of construction and operation of Class I injection wells.

1.2 Background

1.2.1 TCEQ’s Class I Underground Injection Control Program

Subsurface injection of fluid in Texas began over 70 years ago with the onset of sulfur mining by the Frasch process (Knape et al, 1984). By the 1940's, use of injection wells for enhancement of oil and gas production and disposal of brines co-produced with oil and gas led the Railroad Commission of Texas (RCT) to recognize a need for regulation of such activities in order to protect natural resources including fresh water supplies. By 1960, several injection wells were operating for industrial wastewater disposal below underground sources of drinking water. In 1961, the Texas Legislature passed the Injection Well Act to ensure protection of groundwater from subsurface injection of wastes. This act and its subsequent amendments are now codified as Chapter 27 of the Texas Water Code.

The Injection Well Act, which prescribes the permitting and regulation of subsurface injection, splits these responsibilities between the RCT and the TCEQ (through its predecessor agencies). The act gives the RCT primary responsibility for regulating injection activities related to oil and gas and to hydrocarbon storage. The act delegates responsibility to the TCEQ for regulating injection of industrial and municipal wastes, most forms of injection for in-situ recovery of minerals, and certain miscellaneous types of injection.

At the federal level, regulation of underground injection stems from the Safe Drinking Water Act of 1974, as amended in 1977. Under the authority of this federal statute, the U. S. Environmental Protection Agency (EPA) promulgated regulations for underground injection control (UIC) in 1979, with provisions for authorizing administration of federal UIC program responsibilities by qualifying states. Adoption of state UIC rules equivalent in protective stringency to the corresponding federal UIC rules was established as a primary requirement for authorization of state-administered UIC programs. In January 1982, the Texas Department of Water Resources (TDWR), a predecessor of the TCEQ, was granted authority for implementing the federal UIC program for specified classes of injection wells, namely, Class I wells (for injection of industrial and municipal wastes below the lowest underground source of drinking water), Class III wells (for in situ recovery of uranium, sulfur, and sodium sulfate), and most Class V wells (for miscellaneous types of underground injection).

To this date, under permitting criteria which include determinations that a proposed well is in the public interest, entails no impairment of rights, and will afford adequate protection of fresh water from pollution, the Commission and its predecessor agencies have issued approximately 350 Class I injection well permits. As of 2013, 108 Class I injection wells were in use or on standby.

1.2.2 Rulemaking Relating to this Guidance

In 1993, TCEQ staff initiated development of rule revisions for Class I injection well construction standards to meet two objectives: (1) to clarify and refine standards used by the state program since its inception; and (2) to establish performance standards that were more technically consistent and clearer than existing state and federal well construction regulations. These rules were adopted by the Commission in May, 1995.

1.3 Acknowledgments

The initial version of this document was prepared through collaboration of many contributors. Staff wishes to acknowledge the assistance of a volunteer workgroup comprised of members of the regulated community of well operators and consultants who contributed data, text, review, and comment. Staff also acknowledges the helpful review and comments of Task Force 21 (a TCEQ hazardous waste management advisory group) on drafts of this document and on pertinent rules. Finally, appreciation is expressed to EPA Region 6 for support through grant funding and review of drafts of this document and of pertinent rules.

2.0 Basic Construction Process for Class I Injection Wells

The basic design of a Class I waste disposal well is shown in Figure 1. Examination of this figure may help the reader to understand this section and various design aspects discussed in other sections of this document. Class I injection wells are generally constructed by the same rotary drilling methods used for conventional oil and gas production wells. Prior to drilling, access to the well site is established by construction of an all-weather road [30 TAC §331.66(b)(2)]. An adequate area around the well site is developed to accommodate the drilling rig and associated equipment including pumps, tanks, pits, power-generating units, pipe racks, trucks, automobiles, and personnel quarters. Also, during preparation of the site for well construction, provision of a water supply for displacement fluids during drilling and cementing is generally necessary. In drilling a well, a hole is advanced downward from the drilling rig at the land surface, by rotating a bit weighted with heavy steel drill collars on the end of connected lengths of steel drill pipe. The hole is kept full of fluid as the drilling progresses. Pumps maintain circulation of drilling fluid down the inside of the drill pipe, through the bit, and up the outside of the drill pipe to the surface. Circulation of drilling fluids cools and lubricates the bit, lifts rock cuttings out of the hole, and hydraulically overbalances pressure in the penetrated rock formations.

When drilling has advanced to a confining rock stratum below the lowest underground source of drinking water (USDW) [30 TAC §331.62(a)(1)(A)], drilling temporarily ceases, the bit and drill pipe are removed from the hole, and open-hole well logging is performed according to rule requirements [30 TAC §331.62(a)(7)]. After logging the hole, a continuous string of pipe called “surface casing” is “made up” (assembled) as it is lowered into the hole. The annular space between the outside wall of the surface casing and the surrounding borehole wall is cemented according to rule requirements [30 TAC §331.62(a)(6)]. After the cement outside the surface casing has hardened, the drill bit on drill pipe is again lowered into the wellbore, and drilling proceeds from the base of the surface casing to the depth of the permitted injection interval in the injection zone. Formation core samples are routinely recovered from the confining zone above the injection zone, and from the injection zone (including the injection interval) as required [30 TAC §331.62(a)(7)(C)].

When the drill bit penetrates to the depth of the injection interval, the bit and drill pipe are removed from the well, and open-hole logs are run to total depth according to rule requirements [30 TAC §331.62(a)(7)]. After logging to total depth, a second string of casing called “long-string” or “protection” casing (smaller in diameter than the surface casing) is installed in the wellbore from total depth to surface [30 TAC §331.62(a)(1)(A)]. The annular space outside the long-string casing is cemented according to rule requirements by techniques similar to those used for cementing the surface casing [30 TAC §331.62(a)(6)].

After cementing the long-string casing, the well is completed in the permitted injection interval by development of an open-hole (uncased) section below the cemented casing, perforation of the long-string casing, or installation of well screen. Injection takes place through tubing which is installed inside the long-string casing according to the considerations listed under 30 TAC §331.62(a)(1)(B). The annular space between the outside of the injection tubing and the inner wall of the surrounding long-string casing is sealed by a mechanical device called a packer at or near the top of the injection zone, and by seals in the wellhead at ground surface. This tubing/long-string casing annulus is filled with corrosion-inhibiting fluid, pressurized, and continuously monitored for leaks [30 TAC §331.62(a)(1)(B), §331.63(d), and §331.64(c) and (d)]. The monitored annulus system constitutes the primary protective barrier between injected wastes and USDWs. However, each casing string and casing cement sheath constitutes an extra protective barrier to keep waste in the authorized injection zone and out of USDWs.

3.0 Basic Geological Considerations

As discussed in references such as Warner and Lehr, 1977, the subsurface geology and geohydrology of a proposed site are major considerations in planning and design of a Class I injection well. Technical literature on well construction in Texas often presents contrasts between drilling and construction considerations as functions of the geologic/geographic regions of the State (Greene et al, 1983). The age of subsurface formations penetrated in drilling Class I injection wells ranges from young (Cenozoic) along the Gulf Coast to old (Paleozoic) in West Texas and the Texas Panhandle. Generally, young Gulf Coast formations are soft and unconsolidated, relative to the harder, more consolidated older formations lying to the north and west. Natural and manmade penetrations of the subsurface (e.g., natural faults and drilled boreholes) into soft unconsolidated rocks, tend to be unstable and naturally close to a greater degree than such penetrations into hard rocks.

Table 1 summarizes specific problems influenced by regional geologic factors which have been encountered in injection well construction in Texas. From the table, one may see that situations which may affect the result of well construction (e.g., lost circulation) may occur in any region of the state. For this reason, site-specific assessments of potential geologic influences on well construction are an essential part of well design and construction planning (see Section 4.2).

Table 1: Problems Encountered in Injection Well Construction in Texas

| Problem | Gulf Coast | East Texas | Central Texas | West Texas | Panhandle |
| --- | --- | --- | --- | --- | --- |
| lost circulation in underpressured formations | √ | √ | √ | √ | √ |
| overpressured formations |  | √ |  | √ |  |
| stuck pipe | √ | √ |  |  |  |
| swelling clays | √ |  |  | √ |  |
| bridging of sediments and drill cuttings in the borehole | √ |  |  |  |  |
| dissolution of salt beds by undersaturated drilling fluids |  |  |  | √ |  |
| fresh water zones as deep as the basement rock |  |  | √ |  |  |
| generation of carbon dioxide gas from injection of acid into carbonate formations |  |  | √ |  |  |
| washouts | √ |  |  |  |  |

4.0 Well Design

4.1 Design Criteria

30 TAC §331.62, which is entitled “Construction Standards,” states: “All Class I wells shall be designed, constructed and completed to prevent the movement of fluids that could result in the pollution of an underground source of drinking water.” 30 TAC §331.62(a)(1) provides specific design considerations, which include:

1. **Design of casing and cement for the life expectancy of the well,** including, for a well injecting hazardous waste, the post-closure care period. The regulations provide for a maximum permit term of ten years, but also allow renewal of permits for additional ten-year periods. Because many underground injection wells in Texas have been in operation under permit authorization for several decades, when designing injection wells, 30 years should generally be considered the typical useful life of a well. Regarding the need for casing and cement design for a well injecting hazardous waste to also be adequate for the period of post-closure care, this period is defined in 30 TAC §331.68(b)(2), in the context of potential groundwater monitoring, as the period required for the pressure in the injection zone to decay to the point where the well's cone of influence no longer intersects the base of the lowermost USDW or freshwater aquifer.
2. **Design to prevent leaks and to permit testing and monitoring**. The rule states that the well must be designed and constructed to prevent potential leaks from the well, to prevent the movement of fluids along the wellbore into or between USDWs, to prevent the movement of fluids along the wellbore out of the injection zone, to permit the use of appropriate testing devices and workover tools, and to permit continuous monitoring of injection tubing, long-string casing and annulus.
3. **Design for compatibility of well materials with fluids.** The rule requires that all well materials must be compatible with fluids which they may be expected to contact, and states that compatibility is assumed if the materials meet or exceed standards of the American Petroleum Institute (API), the American Society for Testing and Materials (ASTM), or the Commission’s executive director. Applicants are advised that the issue of compatibility of well materials be addressed in the design and application phases of an injection well project through testing of the subject materials under exposure to wastes projected to be disposed of in the well, and to formation minerals and brines from or representative of the proposed injection interval. If historical compatibility data from existing wells and waste streams are totally analogous with the compatibility conditions for a new well under consideration, the historical data may be submitted for consideration in lieu of new compatibility data.

All engineering plans and specifications submitted as part of a permit application (and any subsequent changes to the plans) must be prepared and sealed by a professional engineer who is currently licensed as required by the Texas Engineering Practice Act. Refer to 30 TAC §305.50(7).

4.2 Contingency Planning Using Offset Data from Area of Review

The area of review (AOR) around a Class I injection well is defined in 30 TAC §331.42 as the greater of a circle centered at the injection well with a radius of 2.5 miles, or the calculated “cone of influence” (i.e., the area within which the well's pressure effect on the injection interval could drive saline fluids or waste into local USDWs if a conduit were established between the injection interval and the USDW). 30 TAC §331.42 and 30 TAC §331.121(a)(2) specify the types of geologic and well construction data that must be presented in an application for a Class I injection well permit. Beyond these basic requirements, in the 1995 UIC rule revisions, the TCEQ sought to emphasize the importance of good planning during the design and application phases of an injection well project. Planning should include a survey of the AOR or beyond, for any past occurrences of construction problems related to local geologic factors which could adversely affect the quality and effectiveness of proposed casing and cementing installation.

To promote optimum well construction results, 30 TAC §331.121(a)(2)(O) requires that contingency plans identify the types of problems which have been encountered by others who have drilled wells in the area, and describe procedures for responding in an appropriate way to such contingencies if they recur during construction of the proposed injection well. UIC program staff advise protocols similar to those already in use for compiling records on artificial penetrations of the subsurface within the AOR. Such measures may include examining the files of the TCEQ and the RCT, and of private sources such as scout tickets, service companies involved in drilling, mud engineering, casing, cementing, and well logging, and also interviewing persons living or working in the area who may have personal knowledge of the subject. The rule revisions adopted in 1995 expand the normal AOR records search to address such specific problems as past occurrence of lost circulation while drilling or cementing, stuck (differential sticking of) drill pipe or casing, pressure anomalies (kicks or blowouts) encountered during drilling, collapse features suggestive of cavernous or vugular subsurface conditions, or anything that might result in less than 100% filling of annular space outside a well casing with cement.

In drafting the 1995 revision of §331.121(a)(2), the rule writers and commenters did not contemplate that the required contingency plans would necessarily anticipate or address every problem which could happen to a well. The resulting rule, however, expressly requires that such plans address the contingencies of lost circulation zones, sticking of pipe, and other factors that could adversely impact the results of cementing. It is generally not necessary to present detailed histories or chronologies of well problems in the cementing contingency plans, but it is strongly advised to base contingency planning on available quantitative data, such as fluid weights, hydrostatic loads, or other hole conditions at the time of lost circulation or stuck pipe. These data may be found in bit records, mud service company records, cementing company records, drilling contractor records, and scout tickets.

4.3 Casing and Tubing Design

Specific design criteria for the casing strings used in Class I injection wells are found in 30 TAC §331.62(a)(1)(A). In order to comply with this rule in designing a specific well casing program, TCEQ staff recommends that applicants note and follow the considerations and procedures discussed below.

A logical way to design an injection well is to first consider the liquid injection needs and the estimated capacity of the injection interval, and then select injection tubing of adequate size (Greene et al, 1983). Next, determination of the minimum size of the long-string casing can be made through consideration of tubing size and the need for access by downhole tools for workover, logging, testing, and monitoring requirements of rules and permits (see 30 TAC §331.62(a)(1)(A)). Determination of the size of the long-string casing, in turn, influences the minimum size of the surface casing.

With sizing of well tubulars accomplished, applicants can then use data from an appropriate source, such as API (1987 and 1989), Bourgoyne, Chenevert and Young (1986) or Rahman and Chilingarian (1995) to select the grade, weight, thickness, collapse pressure, internal yield pressure, and joint strength appropriate for the depths and pressures to be encountered. The design of these casing parameters may be influenced not only by area geologic conditions, but also by earlier injection activities in the general area of the proposed injection well which might have raised the pressures in the injection zone. In selecting casing, applicants must consider appropriate safety factors. Industry standards for safety factors that have generally been used are: for burst pressure, 1.0 to 1.1; for collapse pressure, 1.0 to 1.125; for joint strength, 1.8; and for pipe body, 1.5.

According to State and federal regulations, the surface casing should be set at least into the first confining bed below the lowest USDW, as determined by borehole logs run prior to the casing installation. In some locales, however, the subsurface geologic section may contain more than one USDW, with the individual USDWs being separated by strata containing salt beds or saline-bearing sediments. In this situation, if the uppermost USDW is a major fresh-water aquifer (e.g., the Ogallala or the Edwards), the need to protect it may require installation of an extra string of casing to cover and isolate the salt or saline-bearing strata, before drilling through the base of the lowest USDW for setting of “surface casing.” Installation of the extra casing will safeguard economically important water resources from contamination by saline waters derived from any salt beds or saline-bearing sediments which lie between the upper and lower USDWs.

Materials of the surface casing, or of extra casings added to protect uppermost USDWs, are not normally subjected to the corrosive effects of the injected waste liquids, but applicants should consider the compatibility of casing material with injected wastes in the bottommost joints of the long-string casing below the packer. Casings in and near the injection zone where the waste stream could exert corrosive effects on the well materials are often corrosion-resistant steel alloys or, in some cases, fiberglass.

In some injection wells, it may be necessary to run an additional casing string or liner, intermediate in diameter and length, between the surface casing and the long-string casing. Such an intermediate string may be used to case off high-pressure zones, oil and gas zones, or lost circulation zones encountered above the injection formation.

Strings of pipe may also be mechanically hung from the inside wall of a casing string to function as casing liners. Such liners of corrosion-resistant alloys or fiberglass may be installed directly above and extending through an injection interval, to enable a well to better withstand corrosive effects of waste liquids (Brasier, 1986). Liners have been effectively used to repair casing leaks when cemented in place.

Some innovative retrievable liner systems have been developed especially for injection wells. Such systems have been successfully used, but, like all downhole tools and materials, they are occasionally subject to mechanical failure.

Commission rule 30 TAC §331.62(a)(1)(B) states: “All Class I wells shall inject fluids through tubing with a packer, set at a depth specified by the executive director.” In selecting tubing, applicants should consider length, fluid characteristics, injection pressure, annular pressure, injection rate, volume of injected fluid, temperature conditions, size of casing, and tensile, burst, and collapse strengths.

The injection tubing is always in contact with the waste; therefore, 30 TAC §331.62(a)(1)(B)(ii) requires that the characteristics of injection fluid be considered carefully to insure compatibility of the tubing material with the injected wastes. The injection tubing is constructed of ferrous alloys or non-ferrous materials such as fiberglass. Ferrous alloy tubing subject to corrosion may be coated with non-reactive materials.

The injection tubing is subject to contraction and expansion caused by variations in temperatures, and to tension, compression, and hydraulic pulsation effects. Therefore, to comply with 30 TAC §331.62(a)(1)(B)(vii), applicants should consider adequate safety factors when designing tubing and packer.

4.4 Drilling

4.4.1 Equipment Selection and Logistical Considerations

Plans for drilling should include selection of an appropriate drilling rig for the depths to be penetrated, and weights of drill pipe and casing to be used. Ancillary equipment, such as mud containment and solids control units, blow-out preventers, pumps, engines, personnel quarters, walkways, stairs, etc., should be adequate for safe and effective operations. The International Association of Drilling Contractors (1998) has established a program adapting Occupational Safety and Health Administration (OSHA) standards for use in drilling operations. Site access and general site layout should be planned to offer safe ingress and egress, and a safe operating environment for authorized personnel [30 TAC §331.66(b)(2)].

4.4.2 Drilling Fluids

While drilling through USDWs, operators should take precautions to assure that no contaminants are introduced into these zones. Under certain conditions, operators may wish to use air in place of drilling fluids to drill in shallow depths to reduce the likelihood of contaminating USDWs.

30 TAC §331.62(a)(4)(B) states, “As much as technically practicable and feasible, the hole should be drilled under laminar flow conditions, with appropriate fluid loss control, to minimize hole washouts.” Fluid flow through pipes is considered as either laminar or turbulent. In laminar flow, the fluid moves in layers, or laminae, which are at all times parallel to the direction of flow. In turbulent flow, secondary irregularities (eddies) are imposed on the main, or average, flow pattern. While drilling, it is desirable to maintain laminar flow in the annular space outside the drill pipe to minimize hole enlargement and lost circulation. On the other hand, it is desirable to establish turbulent flow in the annulus outside a casing as cement is being placed there, to maximize cement filling of the annulus and bonding to the casing and rock formations.

Definition of the flow pattern is given by a dimensionless quantity known as the Reynolds number (Gatlin, 1960). Equations have been developed which allow calculations of the critical velocity above which turbulent flow exists and below which the flow is laminar. The critical velocity depends on the plastic viscosity of the fluid, the fluid density, and the pipe diameter. Much research has been published on flow and pressure loss in pipe and annular spaces. Accordingly, charts have been developed which allow the driller to determine downhole pressure losses, velocity of flow, and the critical velocity (Beck, Nuss, and Dunn, 1947, and Bourgoyne, et al, 1991). Drillers are encouraged to use these references to establish limitations or acceptable ranges for circulation pressures and pump rates that will keep the circulated mud in laminar flow while drilling, and in turbulent flow while cementing.

The term “fluid loss” has two different connotations in well drilling:

1. Fluid loss may refer to the filtrate properties of the mud system, i.e., water loss to various formations as a filter cake is formed during mud circulation. This property, which is measured in a filter press at the face, may be critical in "heaving shales,” which are shales containing hydratable clays that absorb the filtrate, swell, and slough into the hole. Decreasing the water loss may prevent such clay swelling and sloughing, although other actions such as (1) changing the mud system to a high calcium content mud; (2) increasing the circulation rate within the laminar flow interval for more rapid removal of particles; (3) increasing mud density for greater wall support; or (4) changing to an oil-based mud (or oil-emulsion mud) may just as effectively be used.
2. Fluid loss may refer to loss of circulation of substantial quantities of drilling fluid (mud) to an encountered formation which exhibits low fluid pressure conditions and high permeabilities (Gatlin, 1960). This condition, which is evident by the complete or partial loss of returning annular mud flow, may critically influence the outcome of casing cement jobs if circulation is lost during pumping of cement slurry (see Section 4.6.5).

4.5 Casing Installation

Two drilling factors largely determine the ease of running casing: (1) straightness of the hole; and (2) ability of the drilling fluids to maintain satisfactory hole conditions.

An inclinometer may be used to control straightness of the hole. This device monitors the degree of deviation of a hole as drilling progresses. By regulating the weight on the bit and the drilling rate, the path of the bit is controlled to drill a straight hole.

Circulating a good drilling fluid is important to clean and condition the hole before installing casing. This helps prevent drill pipe or casing from sticking to the side of the wellbore. Also, if the hole has been sitting open for several hours during logging and testing, it is generally good practice to make a clean-up or wiper trip with the drill string to condition the hole before running casing.

4.6 Cementing

4.6.1 Regulatory Standards

General regulatory requirements for cementing are found in 30 TAC §331.62(a)(5). This rule requires that all Class I wells be cased and cemented to prevent movement of fluids into or between USDWs or freshwater aquifers, and to prevent movement of fluids out of the injection zone. 30 TAC §331.62(a)(6) imposes more specific requirements on cementing of new wells constructed after May 25, 1995, and on wells converted for use as Class I injection wells after that date.

4.6.2 Methods of Cementing

30 TAC §331.62(a)(6)(A) specifies that the pump and plug method (or other method approved by the executive director) must be used to cement Class I injection well casings. This method uses rubber wiper plugs to separate mud, cement, and displacement fluid while being pumped down the casing. A “bottom plug” is pumped down ahead of the cement and is caught on a restriction designed for that purpose in a device called the “float collar” which is positioned near the bottom of the casing (see discussion of float collars in Section 4.6.6). This plug has a thin metal diaphragm imbedded within it that is easily ruptured with pump pressure when the plug seats on the restriction in the float collar. The rupture of the diaphragm allows the cement to be pumped through the bottom plug and float collar, out the bottom of the casing, and into the surrounding casing-borehole annular space. A “top plug” made of solid rubber is placed between the cement slurry and the displacement fluid which follows the cement. When the top plug seats on the bottom plug (which is seated in the float collar), pump pressure rises, indicating that the cement job is complete. This event signaled by the pressure increase is referred to as “bumping the plug.”

Another cementing method routinely approved for use for large-diameter surface casing jobs is the “inner string” or “stab-in” method. With this method, large-diameter casing is cemented through drill pipe, using a special sealing adapter installed on the bottom of the drill pipe which connects into a sealing sleeve built into a specially designed float collar. In this method, which should always be performed using a device installed on the bottom of the casing called a “float shoe” (see Section 4.6.6), a minimum volume of cement can be used to assure circulation of the light-weight lead cement (i.e., the first part of the cement slurry to be pumped) before pumping the denser tail cement. Once the final cement has been pumped and circulated into place outside the casing, the drill pipe is released from the sealing sleeve in the float collar, breaking the connection and allowing the drill pipe to be pulled from the well.

4.6.3 Classes of Cement and Types of Additives

The API has established eight classes of cement based upon suitability for use at various depths and temperatures (Lehr, 1986). In addition, one cementing service company has listed over 50 additives that may be used with any of the cement classes to create a particular cement for each application. Operators are encouraged to use the expertise of specialty consultants available privately and through many cementing companies, to design cement mixtures appropriate for particular circumstances. A number of special cements, including pozzolan-lime, sulfate-resistant, latex, and epoxy-resin cements, for which the API standards have not been established, also have certain applications in disposal wells. The general categories of cement additives include accelerators, retarders, light‑weight additives, heavy‑weight additives, loss‑circulation control additives, water‑loss control additives, and friction reducers.

4.6.4 Volumes of Cement

30 TAC §331.62(a)(6)(A) specifies that cement pumped must be “of a volume equivalent to at least 120% of the volume calculated necessary to fill the annular space between the hole and casing and between casing strings to the surface of the ground.” The executive director may require more than 120% as justified by geologic or other circumstances. This rule also specifies that a caliper tool with two or more arms (see Section 4.8.5) must be used to measure the hole diameter. In regard to any interval of the drilled hole greater than or equal to the maximum readable diameter of the caliper tool, the minimum amount of cement needed for that interval must be “a volume calculated to be equivalent to or greater than 150% of the space between the casing and the maximum measurable diameter of the caliper." 30 TAC §331.62(a)(6)(B) also states that if lost circulation zones or other subsurface conditions are anticipated and/or encountered, which could result in less than 100% filling of the annular space between the casing and the borehole or between the casings, the owner/operator must implement an approved contingency plan submitted according to 30 TAC §331.121(a)(2)(O).

4.6.5 Strategies for Averting Lost Circulation During Cementing

30 TAC §331.121(a)(2)(O) requires the operator to have a contingency cementing plan available for implementation if lost circulation zones or other problems which may affect well construction are encountered (see Section 4.2). Many innovative strategies have been used to combat lost circulation, for example:

1. altering mud properties (primarily density) through use of air, gas, and aerated mud where applicable (Messenger, 1969);
2. spotting plugs containing mud, cement, and lost circulation materials at the depth of the problem zone (Messenger and McNiel, 1954);
3. circulating lost circulation materials both as a cure and as a preventive measure to establish “bridges” across the “thief zone” (lost circulation zone) (Gatlin, 1960, and Howard and Scott, 1951); and
4. cementing through a small-diameter pipe directly through the annulus if the problem zone is shallow enough to be reached by this method.

In Texas, the greatest concern for lost circulation during drilling and cementing occurs in the Panhandle, where operators routinely encounter subnormally-pressured formations and resulting low formation fracture pressures. This problem may, however, also occur in other parts of the state (see Table 1). In these situations, the borehole hydrostatic pressure of fluids normally used in rotary drilling may exceed formation fracture pressure and produce fracturing with associated loss of circulation during drilling or cementing. Also, many formations are naturally fractured and will impose or contribute to lost circulation problems.

The TCEQ staff encourages well operators to consult with experienced drilling and mud engineers to address case-specific conditions in preparation of the required contingency plan.

4.6.6 Additional Measures to Optimize Quality of Cementing

Several devices and procedures that have been generally accepted as sound engineering practice may be used on a case-specific basis to optimize the quality of cementing.

1. **Devices installed in or on a casing string as the string are made up:** A “guide shoe” is installed on the bottom of each casing string to help guide the casing down hole to the setting depth. The shoe is a short length of pipe rounded on the lower end much like a bullet. The shoe contains ports for mud and cement slurry extrusion into the annular space outside the casing string. A “float collar”, a specialized short section of casing, is installed on top of the first (lowest) joint of a casing string. The float collar contains a valve which prevents backflow of wellbore fluids up the inside of the casing during casing installation and cementing. With regard to casing installation, the float collar enables the casing string to be floated at a condition of nearly neutral buoyancy into place in the well. During cementing, the check valve in the float collar holds the cement slurry in place outside of the casing, and resists the slurry's tendency to back flow until the cement sets. As a backup to the float collar’s check valve, a special guide shoe called a “float shoe” which also contains a backflow check valve should be considered for use at the bottom of the casing, as added assurance that no cement backflow will occur.
2. **Multiple “cement stage tools” or “DV (differential valve) tools” installed in a casing string**: Use of these tools, which is permitted under 30 TAC §331.62(a)(6)(A), allows the casing to be completely cemented in separate operations or stages. In many situations, use of such tools may be advisable to prevent downhole formations from being subjected to a single-stage cement slurry hydrostatic pressure sufficient to cause formation fracturing in the wellbore. The stage tool may also be used to place different types of cement outside the same casing. Typically, a stage tool is installed in the casing string at a depth of about one‑half the total well depth, but actual setting depths should be based on consideration of the specific hydrostatic pressures and formation breakdown pressures for each injection well. It is not uncommon to use two stage tools to enable three-stage cementing in areas subject to low fracture gradients and subnormal reservoir pressures.

With a stage tool, the bottom stage of the casing (i.e., below the stage tool) is cemented first. After the bottom-stage cement slurry has been pumped through the tool and casing, to the intended cement position outside the casing, ports in the tool are mechanically opened. The opened ports function as temporary holes in the casing string, through which fluid flow may be established. Upon opening of the ports, excess cement from the bottom stage (i.e., any cement slurry outside the casing above the stage tool ports) must be circulated out of the hole. Removal of such excess cement before it hardens is imperative in order for the top stage of the casing to later be cemented through the opened ports of the stage tool. Fluid circulation within the uncemented top stage is maintained through the open ports while waiting for the bottom-stage cement to harden. When the bottom-stage cement has hardened, the top stage is cemented. The top-stage cement slurry is pumped down the casing, through the stage tool ports, and is displaced upward outside the casing to the surface. After the stage tool ports are mechanically closed, the top stage slurry is held in place outside the casing until the cement hardens.

1. **“Centralizers” and “scratchers” installed on the outside casing wall**: Centralizers employing steel springs may be spaced along the outside of the casing throughout its length to aid in centering the pipe in the hole. Other devices called scratchers may be installed along the outside of the casing in attempt to enhance the cement bond to the formation by removing mud cake from the borehole.
2. **“Parasite air strings” affixed to the exterior of surface casing**: In these applications, the entry port to the casing interior is at a depth near the casing shoe, to allow injection of air into the surface casing while circulating fluids and cement before and during cementing of the long-string casing. Parasite air strings used in this way in conjunction with three-stage cementing can serve to further reduce hydrostatic loading while cementing in areas of low fracture gradients and subnormal reservoir pressure. Before cementing the top stage of the long-string casing, the parasite air string can be filled with cement from its surface downward, as enabled by the opened DV tool ports and the resulting upward circulation of mud in the annulus between the long-string and the surface casings.

Most problems with cement jobs are due to channeling of cement slurry through the wellbore mud as the cement is circulated into the annulus outside the casing to displace the annular mud. Both historical evidence and research has shown that several factors minimize development of cement channeling including straightness of the hole, use of centralizers that provide 70% or greater standoff capability, moving (reciprocating) casing up and down from the rig floor while pumping cement, and maintaining pump rates sufficient to create turbulent flow in the annulus. Another factor which can greatly increase the probability of a successful cement job is proper conditioning of drilling mud before cementing. Reducing the drilling mud's 10-minute gel strength (i.e., reducing its thixotropic nature) so that it is equivalent to the mud's 10-second gel strength will enable a more efficient sweeping of mud from the annulus outside the casing by viscous "preflush" fluids pumped just ahead of the cement slurry and by the cement slurry itself. Effective flushing of mud from the well keeps the cement relatively free of mud contamination. Use of casing wiper plugs ahead of and behind the cement slurry will also minimize mud contamination of the cement.

4.6.7 Procedures When Cement is Unable to be Circulated to the Surface

Despite precautions including those detailed in the cementing contingency plans, a cement job may end prematurely because of a downhole loss of circulation. This outcome is usually caused by the presence of weak formations or “thief zones” into which a large portion of the cement flows.

When an operator fails to return cement to the surface, a temperature log and cement bond log should be run according to service company recommenda­tions concerning the optimal time following the cementing job to assess the condition of the hardened cement downhole. Additional tests may confirm whether the performance standard in 30 TAC §331.62(a)(5) has been met (see Section 6.2.3). If the performance standard has not been met, it will be necessary, under the authority of 30 TAC §331.62(a)(5), for the permittee to propose to the TCEQ an alternate secondary or remedial method of completing the cementing which will allow demonstration of the construction performance standard.

Alternate cementing methods may include perforating the casing and squeezing cement through the perforations to obtain satisfactory isolation of the injection zone and protection of the USDW. Another method would be cementing into the unfilled annulus through a thin work string (trim pipe); however, this method is likely to be effective only to depths of several hundred feet (Lehr, 1986). Several remedial cementing attempts could become necessary, but if remedial cementing cannot correct the situation to meet the performance standard, the well cannot be approved for injection.

4.7 Completions

Perforated-casing (cased-hole) completions are most commonly used for bottom‑hole completion of waste disposal wells in Texas. The screen and gravel pack method, and to a lesser extent, the open-hole method, are also used in bottom-hole completions.

Perforated-casing completions are used in formations of intermediate or low strength, with tendencies to cave in under injection conditions or under the chemical influence of the waste fluids. The casing may be selectively perforated at the depth of the most permeable sands. With this completion method, the interval of casing through the injection zone should be of a chemically-resistant material. In perforated-casing completions, the formation face is more accessible to acid treatments and other well stimulation techniques than in a well with gravel packing. Costs of this completion method are intermediate among the three completion methods discussed here.

Screen and gravel pack completions are basically open-hole completions used for low strength unconsolidated sands. This completion method is used in wells in Southeast Texas and along the Gulf Coast to control sand inflow to the wellbore. Well screens for this method are made of stainless steel, fiberglass, or plastic. “Gravel packing” involves emplacement of sand of a selected uniform grain size to fill the space between the borehole and the well screen.

Open-hole completions are used in hard rock formations. In these completions, casing is set above the injection interval. The injection interval is left uncased (open hole), allowing the entire permitted injection interval to receive the injected waste streams. These completions have the advantage of exposing more of the injection interval to the injected fluids, since no barriers lie between the injected fluids and the formation. Open-hole completions are also generally the least expensive of completion types.

After completion, the well should be produced to clean up the formation until a representative sample of formation water from the injection interval is obtained prior to injectivity testing [30 TAC §331.62(a)(8)]. The volume of representative formation water produced should be sufficient to determine injection zone characteristics and compatibility with the planned waste stream(s).

Injection tubing is used in each of the completion methods described. Installation of injection tubing in a well includes setting a packer to provide a mechanical seal between the injection tubing and the surrounding long‑string casing. When the packer is set inside the casing at or near the top of the injection zone, the annular space above the packer between the injection tubing and the long‑string casing becomes isolated from the injection zone. This annular space should be filled with a corrosion-­inhibiting brine or other suitable non-reactive liquid, and it should be monitored by a wellhead gauge, continuous recorder, and a fluid‑level sight gauge to detect leaks in tubing, casing, or packer. The annulus fluid should have sufficient density to control static reservoir pressures when release of the packer and removal of tubing become necessary for remedial workovers.

Numerous models of packers are available, basically in two forms: retrievable and permanent. Packers may either be set with a work string or wire line before installation of tubing into the packer sealing assembly, or be made up into the tubing string and set at a pre-determined packer depth. It is generally appropriate to set the packer at a depth opposite a laterally persistent impermeable stratum within the injection zone, so that consistency is maintained between naturally-occurring and engineered barriers to upward fluid flow at the packer setting depth. In any case, the packer setting depth must be approved by the executive director as required in 30 TAC §331.62(a)(1)(B).

4.8 Testing

4.8.1 Regulatory Standards

The standards found in 30 TAC §331.62(a)(7) prescribe the minimum logs and tests to be conducted while drilling and constructing a Class I injection well. This subsection of the rules requires that all logs and tests be interpreted by the service company which processed the logs or conducted the test, or by other qualified persons. For persons interested in learning more about geophysical well logs, an abundance of literature is available from well logging companies, providing technical information concerning recording and interpretation of well logs. According to 30 TAC §331.62(a)(7)(a)(A)(i), deviation checks must be conducted on all holes at sufficiently frequent intervals to assure that avenues for fluid migration in the form of diverging holes are not created during drilling.

Diverging holes can be formed if a deviation from true vertical has occurred which could cause the bit to start a new hole when drilling is resumed after any drilling interruption. As noted previously, deviation of the hole from vertical adversely affects cement bonding, unless the casing is adequately centralized. Research and historical experience suggests that off-centered pipe is a primary reason for cement channeling and poor bonding. The principal reason for off-centered pipe is vertical deviation of the hole. Except in cases of intentionally deviated holes to horizontally offset the bottom of the well from the surface location, a strong effort should be made to keep the hole as straight as possible, with particular concern being warranted when the hole deviates above six degrees or changes more than two or three degrees over a hundred-foot interval. Whether or not the hole is intentionally deviated, an adequate casing centralizer program should be designed and implemented to promote optimal cementing results.

Open-hole logging requirements specified in 30 TAC §331.62(a)(7)(A) for all drilled holes before casing is installed include the following logs: spontaneous potential; resistivity; natural gamma-ray; and caliper. Before intermediate casing and long-string casing is installed, there is an additional requirement that a compensated density and/or neutron porosity log, and dipmeter/fracture finder log be run. After casing installation and cementing, a cement bond/variable density log and a temperature log must be run on all casing strings. In addition, after cementing, a casing inspection log must be run and an inclination survey must be performed on intermediate and long-string casing. According to 30 TAC §331.62(a)(7)(A), the executive director may also require the performance of any other log or test as necessary to demonstrate attainment of the well construction performance standard of 30 TAC §331.62(a)(5).

Well logs record various properties of the formations penetrated and/or assess various aspects of well construction. Open-hole logs that are run before casing installation become the permanent and only record of certain formation measurements (e.g., identification of USDWs) which are not repeatable after the formation is isolated behind casing and cement. Examples of the uses of open-hole logs include defining the capacity of the rock to contain fluids, determining the relative amount of these fluids, and evaluating the ability of the fluids to flow through the rock.

Sections 4.8.2 through 4.8.9 provide a brief discussion of each required log.

4.8.2 Spontaneous Potential Logs

The spontaneous potential (SP) curve is a recording of depth versus the difference between the potential of a movable electrode in the borehole and the fixed potential of a surface electrode. It is generally recorded on the left track of a log in conjunction with a recording of resistivity versus depth on the right track of the log, but it may also be recorded along with other logs such as the sonic log. The SP is used for the following purposes:

1. to detect permeable strata;
2. to locate stratigraphic boundaries and correlate stratigraphic units;
3. to determine values of formation-water resistivity (Rw); and
4. to give qualitative indications of shale content of beds.

4.8.3 Resistivity Logs

In conventional resistivity logs, the logging tool passes currents through the formation and measures the resulting voltages from which formation resistivity is determined. Resistivity logs were developed primarily to determine the fluid content of porous formations, but they are also used to determine porosity, permeability, and saturation of fluids and gases contained in the reservoir rocks. Resistivity is almost always recorded on the right-hand track of a printed log. Commission staff recommends two general types of resistivity logs: (1) focused lateral logs in carbonates and environments which must be drilled using salt muds; and (2) induction logs in sandstones.

4.8.4 Natural Gamma Ray Logs

The gamma ray log is a measurement of the natural radioactivity of subsurface formations. In sedimentary rocks, this log normally reflects the shale content of the formations. The gamma ray log, which can be recorded in both open-hole or cased wells, is the tool most often used in correlations with other previously recorded logs. It is frequently a substitute for the SP log and is almost always presented on the left-hand portion of the printed log. It is also used to observe movement of introduced radioactive material in radioactive tracer surveys to determine well mechanical integrity.

4.8.5 Caliper Logs

Caliper logs are used to measure the diameter of the uncased borehole or the wellbore after tubular goods (casing, liners, tubing, packers, etc.) have been installed. Caliper logging tools have one or more spring-actuated arms or pads which are pulled along the walls of the borehole or wellbore. 30 TAC §331.62(a)(6)(A) requires the use of a two-dimensional caliper tool to measure the hole diameter. This means that the minimum acceptable caliper log must employ at least a four-arm caliper tool which will measure the hole size in two dimensions (X and Y axes) at all depths. Six-pad (six-arm) caliper tools offer a still more accurate description of the hole size and shape, and resistivity-imaging devices offer more accuracy than the six-arm caliper devices. Borehole volume may be indicated automatically on the log from caliper data. By knowing the volume occupied by the casing, one can make a very accurate determination of the volume of cement necessary to fill the annulus outside each casing (see cement volume requirements of 30 TAC §331.62(a)(6)).

4.8.6 Compensated Density Logs

Of all the log measurements that are sensitive to porosity in rock, the density measurement is the most important, because it provides a bulk density value that is most sensitive to effective formation porosity. The density log is often run in association with the caliper log, as both logs require the logging tool to be in good contact with the borehole wall.

4.8.7 Neutron Porosity Logs

The neutron log is often an excellent correlation tool, especially in cased holes, and is often run in conjunction with density logs. This log commonly provides the best depth control for perforating in carbonate reservoirs where thin-porosity stringers are the completion target. The various neutron devices (many tool models are available) are used primarily to determine rock porosity under a variety of conditions: in empty holes (cable-tool or air-drilled), in fluid-filled holes, and in cased holes (empty or filled). Neutron logs also provide information on lithology, and differentiate between fluids and gases when compared with data from other porosity tools.

4.8.8 Dipmeter /Fracture Finder Logs

The primary function of these pad-scanning tools and associated logs in injection wells is to determine the presence of fracturing and to interpret its extent in the injection zone and the confining zone. Modern pad-scanning tools can detect thin borehole changes related to natural features of the borehole/formation interface. The data obtained may also be used to make interpretations of structural dip and sedimentary structures, which may be useful in interpreting the local geology at some sites.

30 TAC §331.62(a)(7)(A)(iii)(I) requires a dipmeter/fracture finder log for intermediate or long-string casing. Staff considers this requirement to mean that the log must be run from the base of the surface casing to the total depth of the well. Such logging within the surface casing would be meaningless in detection of fractures or other natural anomalies in the borehole wall. The TCEQ’s UIC program’s guidance on the dipmeter/fracture finder log recommends (1) that logged data be processed only in the depth intervals of the injection zone and confining zone; and (2) that the results and interpretation of the processed portion of the logged data be submitted in the well completion report. Unprocessed portions of the log should be archived for possible future processing. The well operator is responsible for the archiving of the data; however, most logging companies archive the recorded data indefinitely for further processing when needed.

The specific adaptation of pad-scanning tools to determine the presence and orientation of fractures is valuable in reservoir analysis. Fractures provide enhanced permeability in particular directions as influenced by the orientation of principal stresses, thereby influencing the pressure regime and configuration of the waste plume. Information based on interpretation of fracture-finding devices should be incorporated into predictive modeling of reservoir pressure and waste plume development and into evaluation of pressure fall-off tests.

4.8.9 Cement Evaluation Logs (Cement Bond with Variable Density Logs)

Federal and State UIC rules requiring a “cement bond with variable density log” for each well casing string are not intended to constitute any endorsement of proprietary products by the same or similar names. Therefore, staff advises use of the general designation “cement evaluation logging" as the required type of logging to help assess cementing results.

The type of survey chosen should be the one appropriate for the most objective and accurate interpretation, given the particular casing or liner, cement, and hole conditions. Two basic types of cement evaluation tools are available: (1) the older tool in which a sonic wave is propagated axially along the casing; and (2) the more modern tool in which a pulse of ultrasonic energy is transmitted radially and echoed from the casing. The ultrasonic tool generally produces results that are more accurate, and it is recommended for most wells. In certain situations, however, the older tool or a combination of the two types should be used for best results. The well construction plan submitted to the TCEQ should include an explanation of the method of cement evaluation that is to be used.

4.9 Changes in Design

30 TAC §331.62(a)(3) provides requirements for changing plans and specifications for well construction and well workovers. It is recognized that after a well has been permitted, and before or during drilling or workovers, situations could arise which were not contemplated during the planning and permitting stage. Also, during this time period, technical advances may bring improvements in material specifications and construction methods which could be beneficially incorporated into well construction. Any changes from the approved plans and specifications submitted in the permit application must be approved in writing by the executive director in the form of a minor modification or amendment depending on the type of change. These changes will be approved only if they provide protection standards equivalent to or greater than those of the original design.

Changes to the cementing of the surface casing as discussed in 30 TAC §331.62(a)(3)(A) requires written approval prior to execution of the change. In this case, a minor modification application with a written description of the proposed change, including any additional data necessary to evaluate the request and any revisions to the permit application must be submitted, reviewed and approved before the changes to the cementing can be implemented.

A change in the location of the injection interval to a location not reviewed during the permit application process as discussed in 30 TAC §331.62(a)(3)(B) requires an amendment to the permit. In this case, either a minor or major amendment application with revisions to the permit application addressing the geology of the new injection interval, redesign of the well, recalculation of the maximum allowable surface pressure and the predicted pressure build-up, reassessment of artificial penetrations and the need for corrective action, and any other revisions to the permit application addressing the revised injection interval depth must be submitted, reviewed and approved. The operator may not inject into any unauthorized zone until the amendment is approved.

Any other changes, including but not limited to the number of casing strings, changes in the size or material of intermediate and production casings, changes in the completion of the well, changes in the exact setting of screens or injection intervals within the permitted injection zone, and changes in the type of cement used, or method of cementing as discussed in 30 TAC §331.62(a)(3)(C) are considered minor changes requiring a minor modification to the permit application. If these changes are known prior to drilling or workover of the well, the minor modification application with a detailed written description of the changes and any revisions to the permit application should be submitted and approved prior to drilling the well or conducting the workover. If these changes are proposed during drilling or workover of the well, information regarding the change should be provided to the executive director for immediate oral approval. Subsequently, a minor modification application with a detailed written description of the changes and any revisions to the permit application should be submitted for written approval. The minor modification must be approved before operation of the well may be granted.

4.10 Drilling Through an Existing Waste Plume and Disposal of Cuttings

If a new Class I injection well is constructed in the general vicinity of an existing injection well, a plume of wastewater may be encountered if the drill bit penetrates the existing well’s injection zone. In this event, injected waste could be circulated to surface in the drilling fluid of the well under construction. Because of the possible existence of hazardous constituents in such waste plumes, precautions to isolate the drilling fluid while drilling through the zone of possible contamination should be taken. Possible reservoir pressure increases caused by previous injection of wastes into the zone should also be dealt with by assuring adequate weights of drilling fluid to confine such encountered pressures. Prediction of current pressure conditions may be made from the fall-off tests required annually on existing wells. All drill cuttings should be isolated, tested, and appropriately disposed. If the drilling fluid is found to be contaminated, it should be managed as either contaminated industrial waste or hazardous waste, as indicated by testing. Provisions for appropriate training and personal protective equipment should be made if contamination is expected (see Section 4.4.1).

5.0 Implementation

5.1 Regulatory Standards

Agency rule 30 TAC §331.62(a)(2) states: “Except as specifically required in the terms of the disposal well permit, the drilling and completion of the well shall be done in accordance with the requirements of this chapter and all permit application plans and specifications.”

Permit specifications pertaining to well construction should take precedence over permit application plans and specifications or well construction rules, because the Commission has authority to include in any permit terms and conditions reasonably necessary to protect fresh water from pollution [30 TAC §331.5]. Therefore, all aspects of implementation of construction plans should be governed primarily by the permit document.

A copy of each of the documents listed below should be kept at the construction site and be made available to all persons responsible for well construction:

1. the permit;
2. the plans and specifications of the permit application;
3. any changes in plans and specifications made in accordance with 30 TAC §331.62(a)(3); and
4. the injection well rules of 30 TAC Chapter 331.

To avoid confusion, only current authorized versions of these documents should be available at the site; i.e., earlier versions should be replaced by the current ones.

If circumstances develop during the construction process which necessitate a departure from the plans and specifications of the permit application, then any proposed changes must be approved according to 30 TAC §331.62(a)(3). As specified by this rule, changes requiring only written approval by the executive director must provide standards of protection equivalent to or greater than those of the original design criteria (see Section 4.9). The executive director will evaluate the proposed changes as expeditiously as possible to minimize waiting time for contractors and subcontractors. Use of telefax, overnight express mail, and electronic mail (e-mail) will expedite response on the requested changes.

5.2 Project Supervision

Commission rule 30 TAC §331.62(a)(9) states: “All phases of well construction and all phases of any well workover shall be supervised by qualified individuals acting under the responsible charge of a licensed professional engineer, with current registration pursuant to the Texas Engineering Practice Act (Texas Civil Statutes Article 3271a), who is knowledgeable and experienced in practical drilling engineering and who is familiar with the special conditions and requirements of injection well construction.”

Also, as specified by 30 TAC §331.65(a)(1), the well completion report necessary for approval to operate under 30 TAC §331.45 requires inclusion of specified items prepared and sealed by a licensed professional engineer.

5.3 Notification Requirements for State Inspection of Construction Procedures

Commission rule 30 TAC §331.62(a)(10) states: “The executive director shall have the opportunity to witness all cementing of casing strings, logging and testing. The permittee shall submit a schedule of such activities to the executive director at least 30 days prior to commencing drilling of the well. The executive director shall be given at least 24-hour notice before each activity in order that a representative of the executive director may be present.”

On-site witnessing and inspection of the above cited activities is a basic UIC program activity addressed in the Program Description in TCEQ’s Program Authorization documents approved by EPA. The UIC program staff will witness as many of such procedures as possible. Customer service objectives of the Commission and its federally-authorized UIC program may be most efficiently met by having a representative of the executive director's staff on location during casing installation, logging and testing, for direct consultations with permittees, concerning compliance with applicable regulations. Notification of scheduling of well-site procedures to satisfy the above-cited rule should be made to the executive director's UIC program staff of the Radioactive Materials Division (RMD), Office of Waste (OOW).

It is recognized that original construction schedules in most cases will be subject to day-to-day modification, because some procedures will take less time than planned and others will take longer. Therefore, it is recommended that frequent updates be provided to the UIC program staff (RMD, OOW) by telephone call, telefax, or electronic mail (e-mail), throughout the course of well construction, logging, and testing. The rule requires updated notice “at least 24-hours before each activity.” This requirement is intended to notify the executive director’s staff that a particular well-site procedure is imminent, and that most of the prerequisite well-site procedures have been satisfactorily completed. This requirement further provides opportunity for detailed communication between the well operator (or responsible contractor) and the executive director's staff concerning travel arrangements and scheduling to witness the subject construction procedures, procedures for admittance of the inspector to the site, and the identity of construction supervisory staff to be on location. It is recommended that communications in response to the “24-hour” notice requirement of the rule, be made not more than 48 hours prior to the planned procedure, so that scheduling details will be as current as possible. It is also encouraged that additional communications take place between the well operator (or responsible contractor) and the executive director's staff, at the initiation of either party, within the 24-hour period prior to performance of the subject well-site procedures, to minimize possible waiting time by any of the parties concerned.

In the event that program resources do not allow any well-site procedures to be witnessed by the executive director's staff, this will be communicated to the well operator or responsible contractor as soon as it is determined. In such cases, the executive director's staff will provide information (e.g., home telephone numbers, mobile phone numbers, and pager numbers) to the well operator or responsible contractor to allow for consultation by telephone or telefax on a 24-hour basis including nights, weekends, and holidays, to minimize any delays in the progress of well-site procedures.

6.0 Approval of Construction

6.1 Information Needed for Approval

6.1.1 Executive Director Approval of Construction and Completion

Commission rule 30 TAC §331.45 lists data and procedures that the executive director must approve in determining whether to certify the construction and completion of an injection well.

1. for Class I wells, other than salt cavern disposal wells and associated salt caverns:
2. actual as-built drawings and well completion data;
3. all logging and testing data;
4. a demonstration of mechanical integrity;
5. anticipated maximum pressure and flow rate at which the permittee will operate;
6. results of injection zone and confining zone testing as required in 30 TAC §331.62(a)(7)(C), §331.62(a)(8), and 30 TAC §331.65(a);
7. the actual injection procedure;
8. the compatibility of injected wastes with fluids in both the injection zone and the confining zone and with materials used to construct the well;
9. the calculated area of review and cone of influence based on data obtained during logging and testing of the well and the formation, and where necessary, revisions to the information submitted under 30 TAC §331.121;
10. the status of corrective action required for defective wells in the area of review;
11. compliance with the casing and cementing performance standard in 30 TAC §331.62(a)(1), and, where necessary, with changes to the permit to provide for additional testing and/or monitoring of the well to insure the continuous attainment of the performance standard; and
12. compliance with the cementing requirements of 30 TAC §331.62(a)(6)(A).
13. for Class I wells authorized to inject only nonhazardous desalination concentrate or nonhazardous drinking water treatment residuals:
14. all available logging and testing program data on the well;
15. a demonstration of mechanical integrity;
16. anticipated maximum pressure and flow rate at which the permittee will operate;
17. the results of the formation testing program;
18. the actual injection procedure;
19. the compatibility of injected wastes with fluids in both the injection zone and minerals in both the injection zone and the confining zone; and
20. the status of corrective action on defective wells in the area of review.
21. for salt cavern disposal wells and associated salt caverns:
22. actual as-built drilling and well completion data;
23. all logging, coring, and testing program data on the well and salt pilot hole;
24. a demonstration of mechanical integrity of the well;
25. the anticipated maximum wellhead and casing seat pressures and flow rates at which the well will operate during cavern development and cavern waste filling;
26. results of the salt cavern injection zone and salt cavern confining zone testing program as required in 30 TAC §331.163(e)(3);
27. the injection and production procedures for cavern development and cavern waste filling;
28. the compatibility of injected materials with the contents of the salt cavern injection zone and the salt cavern confining zone, and with the materials of well construction;
29. land subsidence monitoring data and groundwater quality monitoring data, including determinations of baseline conditions for such monitoring throughout the area of review;
30. the status of corrective action required for defective wells in the area of review;
31. actual as-built specifications of the well's surface support and monitoring equipment; and
32. conformity of the constructed well system with the plans and specifications of the permit application.

6.1.2 Pre-Operational Reports

30 TAC §331.65(a) addresses pre-operational reports pertaining to new Class I wells, including wells converting to Class I status. The required reports must address four topics: (1) well completion; (2) notification of local authorities; (3) notification of the time and date of well start-up; and (4) written approval by the executive director of construction and completion. Details pertaining to each of these topics are summarized below.

1. **Well completion**. Within 90 days after the completion or conversion of the well, the permittee must submit a report to the executive director. The report must include a surveyor's plat showing the exact location relative to survey lines, the latitude and longitude of the well, and a certification that a notation on the deed to the facility property or on some other instrument which is normally examined during a title search has been made, stating the surveyed location of the well, the well permit number, and its permitted waste streams. The permittee must also include in the report the following information, prepared and sealed by a professional engineer with a current license pursuant to the Texas Engineering Practice Act (Texas Civil Statutes Article 3271a):
2. actual as-built drilling and well completion data,
3. all logging and testing data,
4. a demonstration of mechanical integrity,
5. anticipated maximum pressure and flow rate at which the permittee will operate,
6. results of injection zone and confining zone testing program as required in 30 TAC §331.62(a)(7) and (8) and in 30 TAC §331.65(a),
7. adjusted formation pressure increase calculations, fluid front calculations, and updated cross-sections of the confining and injection zones, based on the data obtained during construction and testing,
8. the actual injection procedure,
9. the compatibility of injected wastes with fluids in both the injection zone and the confining zone, and with materials used to construct the well,
10. the calculated area of review and cone of influence based on data obtained during logging and testing of the well and the formation, and where necessary, revisions to the information submitted under 30 TAC §331.121,
11. the status of corrective action required for defective wells in the area of review,
12. a well data report on forms provided by the executive director,
13. compliance with the casing and cementing performance standard in 30 TAC §331.62(a)(4), and
14. compliance with the cementing requirements in 30 TAC §331.62(a)(5).
15. **Notification of local authorities.** The permittee shall provide written notice to the executive director, in a manner specified by the executive director, that a copy of the permit has been properly filed with the health and pollution control authorities of the county, city, and town where the well is located.
16. **Notification of the time and date of well start-up**. The permittee shall notify the executive director in writing of the anticipated well start-up date. Compliance with all pre-operational terms of the permit must occur before the beginning of injection operations.
17. **Written approval by the executive director of construction and completion.** Before operations begin, the permittee must obtain written approval from the executive director, in accordance with 30 TAC §331.65(a)(4).

In complying with the above rules for approval of well construction and completion, the permittee should mark reports and other items specified for submission to the executive director, to the attention of the UIC staff of the Radioactive Materials Division, Office of Waste. Submission of two copies of all documents is requested to assure appropriate review and storage of information.

With regard to 30 TAC §331.65(a)(2), neither the current executive director nor his predecessors have specified a particular manner in which notification of local authorities is to be done. It is, however, advised that a copy of the subject written notice (1) be provided in the completion report specified under 30 TAC §331.65(a)(1); (2) cite the applicable rule [30 TAC §331.65(a)(2)] to which it responds; and (3) include copies of all applicable documentation verifying the filing of a copy of the permit with the local government authorities.

6.2 Criteria for Approval

6.2.1 Compliance With Application Plans and Specifications, as Modified by Permit Requirements

The rules relating to approval of well construction and completion, as modified by permit requirements, are given in the following parts of 30 TAC:

§331.62(a)(2), relating to plans and specifications;

§331.45, relating to executive director approval of construction and completion; and

§331.65(a)(1), relating to pre-operational reports, specifically the completion report.

The current standard shell permit for Class I injection wells incorporates these and other rules by reference. Therefore, the permittee and well construction contractors should refer to a copy of the applicable rules in all matters of well construction, completion, and approval for operation.

6.2.2 Mechanical Integrity Testing

The relevant rules for demonstration of mechanical integrity of a Class I injection well before approval to operate are found in the following parts of 30 TAC Chapter 331:

§331.4, requiring mechanical integrity;

§331.43, specifying mechanical integrity standards, EPA approval of logs and tests for demonstrating mechanical integrity, and approval to use methods not previously approved by the EPA;

§331.45(1)(B) and (C), relating to the type of information that must be reviewed in making a determination whether to grant approval of construction and completion;

§331.62(a)(7)(A), specifying the minimum required mechanical integrity testing during construction and completion; and

§331.65(a)(1), relating to type of data that must be included in the completion report.

The following 30 TAC rules are also relevant to mechanical integrity testing:

§331.63(i), requiring a demonstration of mechanical integrity following major workovers;

§331.63(k), requiring mechanical integrity maintenance at all times including periods of temporary disuse (abandonment) of injection wells; and

§331.64(d), requiring annual demonstration of mechanical integrity in all Class I injection wells.

Readers should refer to the most recent version of Tceq Class I UIC Guidelines for Mechanical Integrity Tests and Related Cased Hole Wireline Logging (the “MIT Guidelines”) available from the TCEQ UIC staff, Radioactive Materials Division, Office of Waste. To minimize problems in making mechanical integrity demonstrations for Class I injection wells using non-standard procedures, well operators or authorized well contractors may consult with the TCEQ Class I UIC staff concerning the details of such test proposals whenever a departure from the methods specified in TCEQ's MIT Guidelines is necessitated or desired.

6.2.3 Construction Performance Standard

The construction performance standard for Class I wells in 30 TAC 331.62(a)(5) states: “All Class I wells shall be cased and all casings shall be cemented to prevent the movement of fluids along the borehole into or between USDWs or freshwater aquifers, and to prevent movement of fluids along the borehole out of the injection zone.”

In developing the Class I well construction performance standard, agency staff discussed the meaning of the phrase “to prevent movement of fluids out of the injection zone” in 30 TAC §331.62(a)(5) with EPA staff and with members of Task Force 21. From these discussions, it became clear to the participating parties that these words from the construction performance standard should not be interpreted as requiring a demonstration that “there will be no migration of hazardous constituents from the injection zone,” as is required by the EPA under 40 CFR §148.20. Such demonstration for EPA approval is based on modeling of waste migration within the injection zone by way of natural formation porosity and permeability, and not by way of channeling along the borehole exterior to the casing. Instead, the subject phrase in 30 TAC §331.62(a)(5) should be interpreted to mean that casing cement must be adequate to prevent movement of fluids out of the injection zone by way of channels or other defects in the cement.

The construction performance standard of 30 TAC §331.62(a)(5) is, in effect, a more stringent version of the federal mechanical integrity standard in 40 CFR §146.8(a). UIC programs authorized to implement Part 146 are charged with assuring through mechanical integrity demonstrations, that “(1) there is no significant leak in casing, tubing, or packer; and (2) there is no significant fluid movement **into an underground source of drinking water** (emphasis added) through vertical channels adjacent to the injection wellbore” [40 CFR §146.8(a)].

40 CFR §146.68(d) provides additional mechanical integrity requirements for Class I hazardous waste injection: annulus pressure tests and testing of bottom-hole cement by means of an approved radioactive tracer survey must be performed annually; a temperature, noise, or other approved log must be run at least every five years to test for fluid movement along the borehole; and casing inspection logs must be run upon well workovers. Although §146.68(d) implies that the bottom-hole cement needs to prevent the kind of “significant fluid movement” prohibited in §146.8(a), it is only in 40 CFR §148.20(a)(2)(iv) that the implication is found, if not the express requirement, that the §146.8(a)(2) mechanical integrity standard for wells injecting hazardous waste subject to the federal land disposal restrictions, allows no “fluid movement...through vertical channels” out of the injection zone. Also noted, is that in construction of new wells for hazardous waste injection, 40 CFR §146.65(c)(4) only requires that cement “not allow fluid movement behind the wellbore” in cases of remedial cementing where cement cannot be recirculated to surface during the primary cement job.

From the above discussion, it follows that for equivalency with federal mechanical integrity regulations, Texas would only need to prohibit fluid movement from Class I wells into underground sources of drinking water, with EPA retaining responsibility to prohibit fluid movements out of the injection zone for certain Class I wells. However, in rulemaking which included public participation along with review and comment from EPA, TCEQ imposed a requirement more stringent than the federal regulation for mechanical integrity, through the construction performance standard of 30 TAC §331.62(a)(5), requiring all Class I wells to be cemented “to prevent the movement of fluids along the borehole into or between USDWs or freshwater aquifers, **and to prevent movement of fluids along the borehole out of the injection zone”** (emphasis added highlighting the TCEQ rule requirement that is not required by EPA for state programs authorized to implement 40 CFR 146). Through the construction performance standard of 30 TAC §331.62(a)(5), the top of the injection zone and the base of the USDW, therefore, become the critical depths to which the 40 CFR §146.8 “no significant fluid movement” standard for mechanical integrity is keyed. Consequently, demonstration of mechanical integrity subject to 30 TAC §331.43(a) must include full consideration of the construction performance standard of 30 TAC §331.62(a)(5). Specifically, the construction performance standard provides the basis for determining which vertical fluid movements outside the casing are significant and thereby indicate a lack of mechanical integrity, i.e., those that exit the injection zone or enter USDWs. Demonstration that a well meets the construction performance standard necessarily includes evaluation of EPA-approved logs and tests for mechanical integrity, along with all available data from drilling, logging, coring, casing, cementing, and operational monitoring of the well.

In regard to the applicability of cement bond (cement evaluation) logging to the construction performance standard, such logs are required by rule to be run after cementing of all casing strings. These logs are also part of the available data which may be helpful in interpreting EPA-approved logs and tests for mechanical integrity, upon which the demonstration that a well meets the construction performance standard may be based. Together with all available geologic and construction data, logs for evaluation of cement may also provide useful information in situations where the construction performance standard cannot be demonstrated. In these instances, cement bond logs may be useful in formulating plans for remedial cementing sufficient to meet the construction performance standard. Indications of cement bond quality at critical points in the well (e.g., at the top of the injection zone and at the base of underground sources of drinking water) may be used as a basis for requiring more frequent monitoring of well mechanical integrity under 30 TAC §331.4.

Provided that all applicable plans and specifications contained in the permit application, as modified by permit provisions and/or the executive director’s approval under 30 TAC §331.62(a)(3), have been followed, wells demonstrating attainment of the construction performance standard through approved combinations of mechanical integrity logs and tests will not require remedial cementing. It should be noted, however, that the construction performance standard and associated rule amendments of 30 TAC §331.62 are not intended to supersede any EPA requirements found in 40 CFR Chapter 148. In any case, a well that fails the performance standard must either be repaired or be plugged and abandoned [30 TAC §331.44(b)(7)].

7.0 Summary and Conclusion

The TCEQ UIC staff hopes this document will enhance understanding of the construction standards and overall regulatory program for Class I waste disposal wells in the State of Texas. The staff has attempted to emphasize throughout this document that careful attention to detail in planning of well construction and in studying applicable permit provisions and rules will maximize the quality of well construction, and as a result, will maximize protection of human health and the environment. Comments for improvement of these guidelines are welcome at any time.

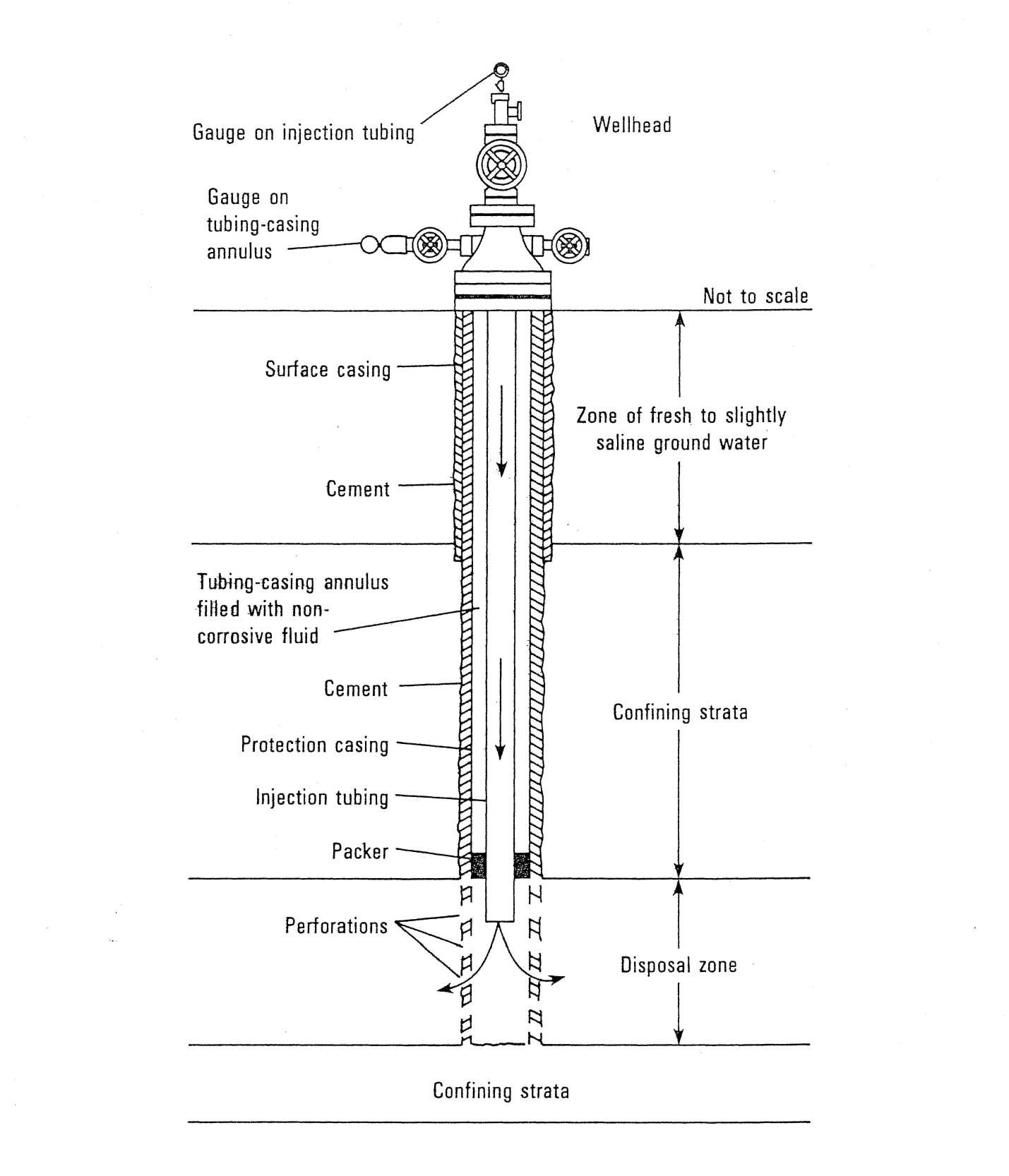


Figure 1

References Cited

American Petroleum Institute (API), 1987, Performance Properties of Casing, Tubing, and Drilling Pipe: API Bulletin 5C2, Washington D. C., 33 p.

American Petroleum Institute (API), 1989, Formulas and Calculations for Casing, Tubing, Drill Pipe, and Line Pipe Properties: API Bulletin 5C3, Washington D. C., 40 p.

Beck, R. W., Nuss, W. F., and Dunn, T. H., 1947, The Flow Properties of Drilling Muds, in American Petroleum Institute: Drilling and Production Practices : American Petroleum Institute, p. 9.

Bourgoyne, A. T. et al, 1991, Applied Drilling Engineering: Society of Petroleum Engineers, Richardson, Texas, 502 p.

Gatlin, C., 1960, Petroleum Engineering - Drilling and Well Completions: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 93 p.

Greene, C. J. et al, 1983, Underground Injection Control Technical Assistance Manual - Subsurface Disposal and Solution Mining: Texas Department of Water Resources, Report 274, 61 p.

Howard, G. C. and Scott, P. P., 1951, An Analysis and the Control of Lost Circulation, in Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. 192: Dallas Texas, p. 171-182.

International Association of Drilling Contractors (IADC), 1998, Accident Prevention Reference Guide: IADC, Houston, Texas, 250 p.

Knape, B. K. et al, 1984, Underground Injection Operations in Texas - A Classification and Assessment of Underground Injection Activities: Texas Department of Water Resources, Report 291, 187 p.

Lehr, J. H., 1986, Underground Injection - A Positive Advocate, in Proceedings of the International Symposium on Subsurface Injection of Liquid Wastes: National Water Well Association, Dublin Ohio, p. 51-56.

Messenger, J. U. et al, 1969, How to Combat Lost Circulation: Oil and Gas Journal, 52 p.

Messenger, J. U., and McNiel, J. S., 1954, Lost Circulation Corrective - Time Setting Clay Cement, in Transactions of the American Institute of Mining and Metallurgical Engineers, Vol. 195, Dallas, Texas, p. 59-64.

Rahman, S. S., and Chilingarian, G. V., 1995, Casing Design Theory and Practice: Elsevier Science B.V., Amsterdam, The Netherlands, 365 p.

Schlumberger, 1989, Log Interpretation Principles/Applications: Schlumberger Wireline & Testing, Sugarland, Texas, 197 p.

Texas Engineering Practice Act: Texas Civil Statutes Article 3271a.

Texas Natural Resource Conservation Commission (TNRCC), 1998 , Class I UIC Guidelines for Mechanical Integrity Tests and Related Cased Hole Wireline Logging: TNRCC, Austin, Texas, 5 p.

Underground Injection Control: Title 30 Texas Administrative Code, Chapter 331.

Warner, D. L., and Lehr, J. H., 1977, An Introduction to the Technology of Subsurface Wastewater Injection: U. S. Environmental Protection Agency, Publication Number EPA-600/2-77-240, 345 p.