AN OVERVIEW OF INJECTION WELL HISTORY IN THE UNITED STATES OF AMERICA

J. E. Clark and D. K. Bonura
E.I. du Pont de Nemours & Co., Inc., P. O. Box 3269
Beaumont, Texas 77704 USA

R. F. Van Voorhees
Bryan Cave LLP, 700 Thirteenth St. N.W.
Washington, D.C. 20005-3960 USA

Injection of liquids into underground formations through wells was started by the petroleum industry. In the 1930s it was common practice to dispose of produced brine through injection wells. The first report of shallow industrial waste injection was in the mid-1930s. Since the early 1950s, injection wells have been used for fluids associated with industrial facilities. Injection wells were regulated by the various states with no national oversight program.

The Safe Drinking Water Act (SDWA) was passed in 1974 to address underground injection issues from a national approach and includes all types of injection wells. Class I wells are used to inject hazardous and non-hazardous fluids below any underground sources of drinking water (USDW). Class II wells inject brine fluids associated with oil and gas production. Class III wells pertain to *in situ* mining wells. Class IV wells (banned except for remediation) handled disposal of hazardous liquids into or above USDWs. Class V wells relate to geothermal and other wells that do not fall into the previous categories. The United States Environmental Protection Agency (US EPA) has implemented Underground Injection Control (UIC) rules and regulations since the early 1980s as an outcome of the SDWA, in order to protect citizens from exposure and reduce risk to human health and the environment.

In 1984 Congress passed an expansion of the Resource Conservation Recovery Act (RCRA). This Act, in essence, banned hazardous disposal unless the demonstration was made that the injected fluid would be protective of human health and the environment. In 1988 EPA promulgated rules and regulations dealing with the land disposal ban for Class I injection wells (40CFR §124, 144, 146, and 148). These regulations established a mechanism for making the demonstration of 10,000-year flow and containment of injected fluid or chemical fate transformation within the injection zone.

The primary objective of deepwell disposal is to permanently isolate injected fluids from the biosphere. In 1989 EPA did a qualitative and comparative risk study and found that Class I injection is a safe and effective technology due to its very low risk to human health and the environment. In this study, EPA also found that underground injection of hazardous fluids was rated the lowest risk in comparison with other operations such as municipal waste combustion. Based on EPA regulations, Class I injection wells are constructed and monitored to assure protection against any toxic releases to the environment.

A recent quantitative risk analysis agrees with EPA studies that deepwell injection is a low-risk management practice. The risk associated with a Class I hazardous injection well for the loss of waste containment to the lowermost USDW is less than one in one million. The loss of injectate isolation probability is low due to redundancies in well construction barriers and geological requirements that provide multiple safety factors.

PRIOR TO EPA UIC REGULATIONS

Underground injection is the disposal of liquid waste material into isolated geologic strata, placing the wastes in portions of the earth's crust that are free from the usual effects of the hydrologic cycle regulated under 40 CFR Part 267, Subpart G and Parts 146 and 148 (US EPA, 1989, p. 5). The primary objective of deepwell injection is to permanently isolate disposed fluids from the biosphere. Injection of fluids into underground formations in the United States of America (US) through wells began in the 1930s by the petroleum industry for disposal of produced brines associated with oil and gas production (Brasier and Kobelski, 1996, p. 1). The first report of shallow industrial waste injection was in the mid-1930s. However, that practice lasted only a few days because injected fluid found its way back to the surface where other wells penetrated the 800-foot deep sand (Harlow, 1939). DuPont drilled the first deep industrial waste injection well in Texas in 1949 and began operations in the early 1950s. In 1950, there were four injection wells and by the early 1960s there were 30 injection wells (Smith, 1996, p. 10). Texas was the first state to adopt regulations (1961) regarding industrial injection wells (Warner, 1973, p. 692). Early regulation of underground injection was traditionally a state responsibility under specific disposal well statues, water well statutes, oil and gas regulations, or surface waste pollution control statutes (Walker and Cox, 1973, p. 5-6). State regulations were not uniform in water quality levels' protection for potential usable groundwaters (Figure 1). Federal control over underground disposal of radioactive wastes was under the direction of Atomic Energy Commission under the Atomic Energy Act of 1954 and pre-empted state control of underground injection (Walker and Cox, 1973, p. 9).

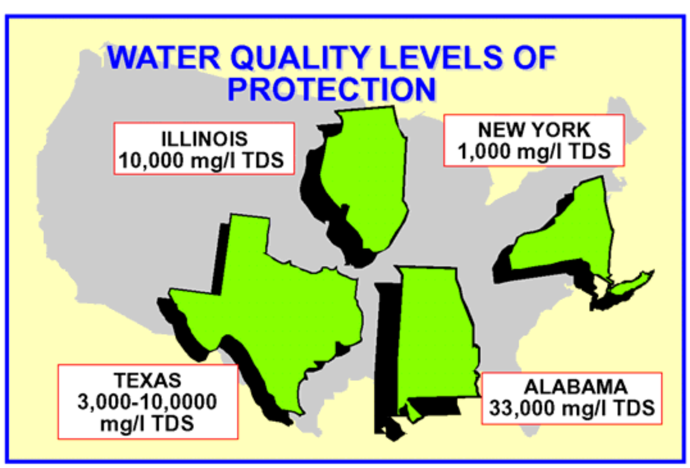

Figure 1. Historical levels of water quality protection (after Walker and Cox, 1973, p. 7).

By the early 1970s, the number of injection wells was approximately 250 (Warner, 1973, p. 688), nearly a 10-fold increase over the 1960 well total (Figure 2), and EPA was concerned about the increasing number of injection facilities that might be avoiding surface waste treatment. EPA published an Administrative Decision Statement No. 5 guidance in 1970 (the same year as creation of the Agency) regarding EPA policy for placement of fluid in the subsurface to prevent contamination of groundwaters (Hall and Ballentine, 1973, p. 790). Passage of the Federal Water Pollution Control Act Amendments (Public Law 92-500) in 1972 gave EPA control of surface waters. Some regulation and permitting of underground injection occurred under this statute, but the authority for control of injection was uncertain. This law did not have clear legal standards for regulating injection. It did, however, require states to regulate injection wells as a prerequisite for federal funding of area-wide waste-treatment management of surface waters. Oil and gas were exempt from federal control because they were not classified as pollutants under the 1972 amendments.

EPA UIC REGULATIONS

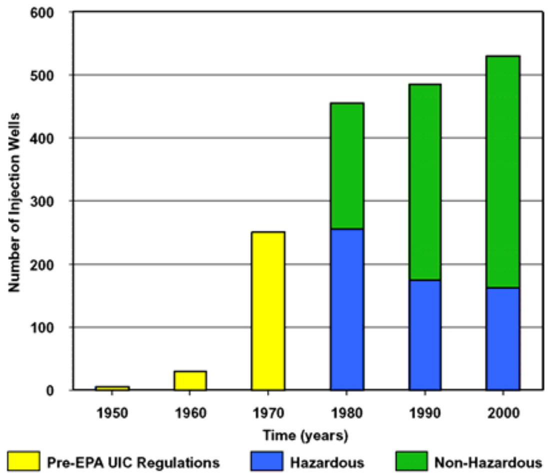

Figure 2. Approximate number of Class I injection wells by decade.

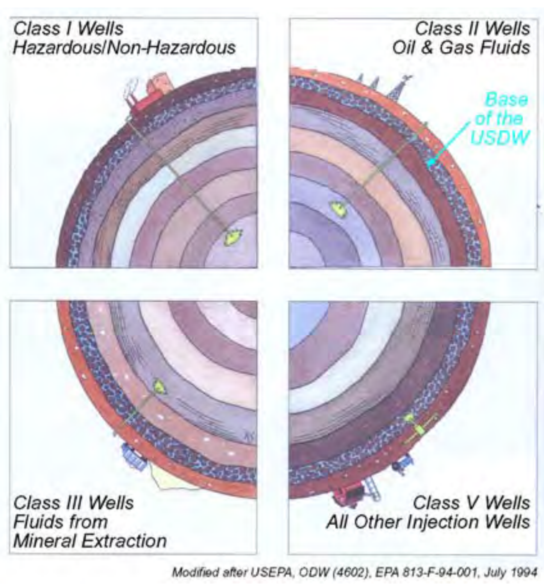

Figure 3. EPA injection well classification system (modified from US EPA, 1994a).

Enactment of the SDWA in 1974 ratified EPA's underground injection policy position and required the Agency to promulgate minimum injection well requirements of state programs to prevent endangerment of USDWs (Brasier and Kobelski, 1996, p. 2). EPA and state agencies conducted detailed reviews of injection practices during the late 1970s which were incorporated into the final UIC regulations promulgated by EPA in 1980 (Brasier and Kobelski, 1996, p. 3). With the 1980 regulations, a national standard was established protecting current and potential drinking water sources with <10,000 mg/l total dissolved solids (TDS) that could serve as a public water system. Minimum technical requirements for siting, construction, operation, testing, monitoring, and plugging and abandonment were established. Additionally, five classes of injection wells were established (Figure 3). Class I wells are used to inject hazardous and non-hazardous fluids below any underground sources of drinking water (USDW). Class I wells may be industrial or municipal. Class II wells inject brine fluids associated with oil and gas production. Class III wells pertain to *in situ* mining. Class IV wells (banned except for remediation) handled disposal of hazardous or toxic liquids into or above USDWs. Class V wells relate to geothermal and other wells that do not fall into the previous categories. This paper primarily addresses Class I wells excluding municipal wells.

The 1980 UIC regulations strengthened well standards by requiring multiple layers of protection between injected fluid and USDWs. One of the few problem wells prior to UIC regulations was due to well construction materials being incompatible with unpermitted low pH injectate. Pre-1980 EPA regulations did not require a packer, injection tubing, an annulus system, an alarm system, or monitoring of well parameters such as pH. Figure 4 is an event-tree for this 1975 incident which shows that the problem would not have occurred after implementation of the 1980 UIC regulations. In this case, injected fluids entered an unpermitted saline aquifer. The problem was remediated by using the injection well and additional wells to pump fluids out (US EPA, 1985, p. 11).

A majority of states approved and codified the 1980 regulations from 1982-1984. As of 2002, 33 states and 3 territories have UIC primacy, EPA retained primacy for 10 states, 2 territories, Washington D.C., and all Indian tribes; EPA and states share primacy for 7 states (US EPA, 2002).

CLASS I HAZARDOUS WELL REGULATIONS

In 1984, the Hazardous and Solid Waste Amendments (HSWA) prohibited land disposal of hazardous waste, including underground injection (the "land-ban" restriction), unless the EPA could determine that the disposal would not adversely affect human health and the environment (Smith, 1996, p. 9).

In a 1985 Report to Congress on injection of hazardous waste, the EPA Office of Drinking Water stated that underground injection "was considered a method to isolate wastes (that could not be easily treated) from the accessible environment by placing them into deep formations where they would remain for geologic time" (US EPA, 1985, p. 3). The report included an inventory of hazardous wells and also looked at hydrogeology, engineering, mechanical integrity tests, monitoring waste characteristics, and noncompliance incidents.

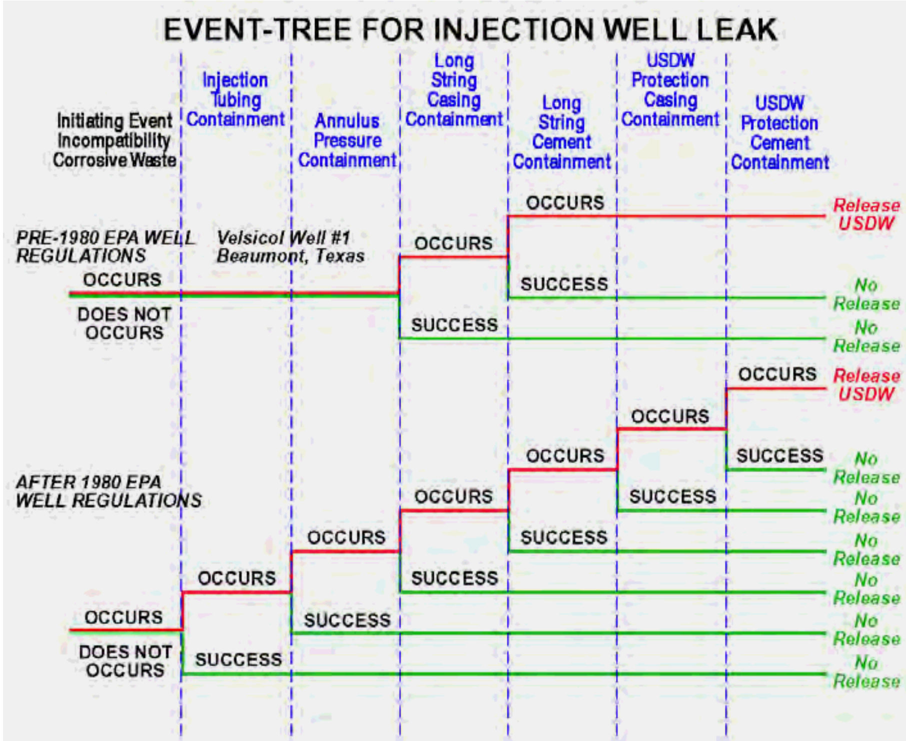

Figure 4. Event-tree for a 1975 injection well leak pre- and post-1980 EPA well regulations.

From 1986 to 1988, State and Federal agencies, environmental groups, and industry particpated in negotiated rulemaking ("Reg-Neg") to implement the land-ban provision of HSWA (US EPA, 1991 p. 10). Although the Reg-Neg group did not achieve complete consensus, the US EPA (1988) strengthened the regulatory requirements for hazardous injection wells by establishing the no-migration demonstration for hazardous constituents. "The 1988 UIC regulations … offer additional protection by requiring operators of Class I hazardous wells to complete no-migration petitions to demonstrate that the hazardous constituents of their wastewater will not migrate from the injection zone for 10,000 years, or that characteristic hazardous wastewater will no longer be hazardous by the time it leaves the injection zone." (US EPA, 2001, p. xiii). EPA also stated "After 10,000 years of containment constituents would either be immobilized or otherwise be at non-hazardous levels throughout the injection zone." (US EPA, 1988, Federal Register, Tuesday, July 26, 1988, p. 28122). An environmental group which had withdrawn from the Reg-Neg process in the final stages challenged the 1988 EPA UIC Hazardous Waste Disposal Injection Restrictions and Requirements. The US Court of Appeals for the D.C. Circuit ruled in EPA's favor and upheld the 1988 regulations, leaving the No-Migration Exemption program for Class I hazardous waste injection wells in place *(Natural Resources Defense Council v. US EPA, 907, F.2d 1146 (D.C. Cir. 1990).*

RISK ANALYSIS

Figure 5 indicates that risk assessment is based on actual exposure as related to concentration and time. Human health or environmental risk from underground injection is extremely low because the potential exposure is removed—that is, injected waste is confined for at least 10,000 years or rendered non-hazardous (US EPA, 1997, p. E-6).

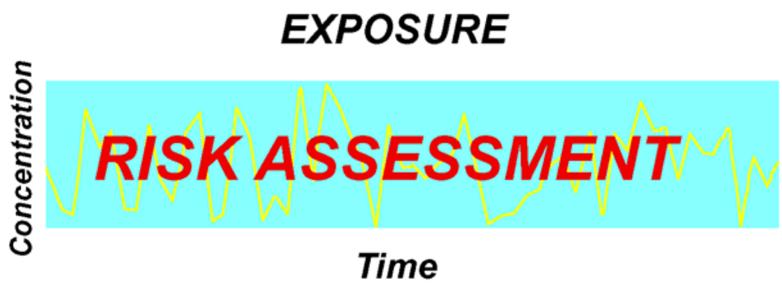

Figure 5. Risk is based on exposure as related to concentration and time.

Figure 6 shows the results of a 1989 EPA qualitative and comparative risk study by the Office of Solid Waste and Emergency Response (OSWER). This study determined that injection of hazardous waste in Class I wells is safe and effective because of its very low risk to human health and the environment. The EPA study of Class I wells found that injection of waste is safer than burying them in landfills, storing them in tanks, or burning the waste in incinerators (US EPA, 1994b).

EPA conducted a study on the "Analysis of the Effects of EPA Restrictions on the Deep Injection of Hazardous Waste" (1991). This report concluded that hazardous deepwell injection under EPA's current regulations is a safe technology and the UIC regulations would have prevented the few reported incidents regarding underground injection (1991, p. 8 and 9). This report describes in detail how EPA regulations prevent Class I hazardous wells from endangering USDWs.

Figure 6. Office of Solid Waste and Emergency Response (OSWER) risk assessment (US EPA, 1989).

The Land Disposal Program Flexibility Act of 1996 (Public Law 104-119) required EPA to conduct a study regarding the risks associated with Class I non-hazardous injection. The 2001 Report to Congress "Class I Underground Injection Control Program: Study of the Risks Associated with Class I Injection Wells" was their response. The study found that there are multiple safeguards against failure of Class I non-hazardous and hazardous industrial waste wells or the migration of injected fluids (US EPA, 2001, p. xii). Siting criteria minimize the potential for waste migration, and inspections, well testing, and passive monitoring systems can detect malfunctions before fluids escape the injection system (US EPA, 2001, p. xiii). After several decades of Class I well operations, only four significant cases of injectate migration have been documented, and none of these affected a drinking water source (US EPA, 2001, p. xiii). In summary, the probability of losing waste confinement is low. Historical problems were the result of practices that are not allowed under current UIC regulations. Redundant monitoring systems and multiple protective construction layers reduce failure possibilities. Furthermore, in the unlikely event a well should fail, the geologic and siting criteria are additional safety factors in preventing the movement of injectate toward USDWs (US EPA, 2001, p. xiii).

Rish and others (1998) quantitatively estimated the risk of loss of waste containment and movement of injectate into a USDW from a Class I hazardous injection well to be less than one in one million. This risk category agrees with EPA studies that deepwell injection is a low-risk management practice. The two failure scenarios dominating risk that waste isolation is lost are: 1) the possibility that a transmissive microannulus develops in the cemented borehole outside of the long string casing, and it extends from the injection zone up past the confining zones, and 2) the possibility of inadvertent future extraction of injected waste.

The loss of injectate isolation is low due to EPA regulations requiring proper geological siting, buffer aquifer(s), multiple layers of well construction barriers, continuous monitoring systems, and annual mechanical testing. Rish and others (1998) determined that the annulus pressure system is a critical barrier in preventing contamination to USDWs, but displays high reliability due to the presence of automatic alarms, shut-offs, and full-time operators. Figure 7 is a fault tree that begins with the assumption that the annulus pressure is less than the injection pressure (probability 1.0E+00; the actual probability of this occurrence is 5.8E-04). Then, the chances of an automatic alarm failing to function (probability 3.0E-04) in combination with a full-time operator failing to respond to the alarm (probability 5.0E-05) results in a loss of injectate containment probability of 1.5E-08. Therefore, an automatic alarm system and a full-time operator are the keys to preventing loss of injectate containment. An automatic alarm system and a full-time operator are required by UIC regulations for hazardous wells, and many states have adopted this requirement for non-hazardous wells by regulatory requirement (e.g., Texas) or by permit requirement (e.g., Louisiana).

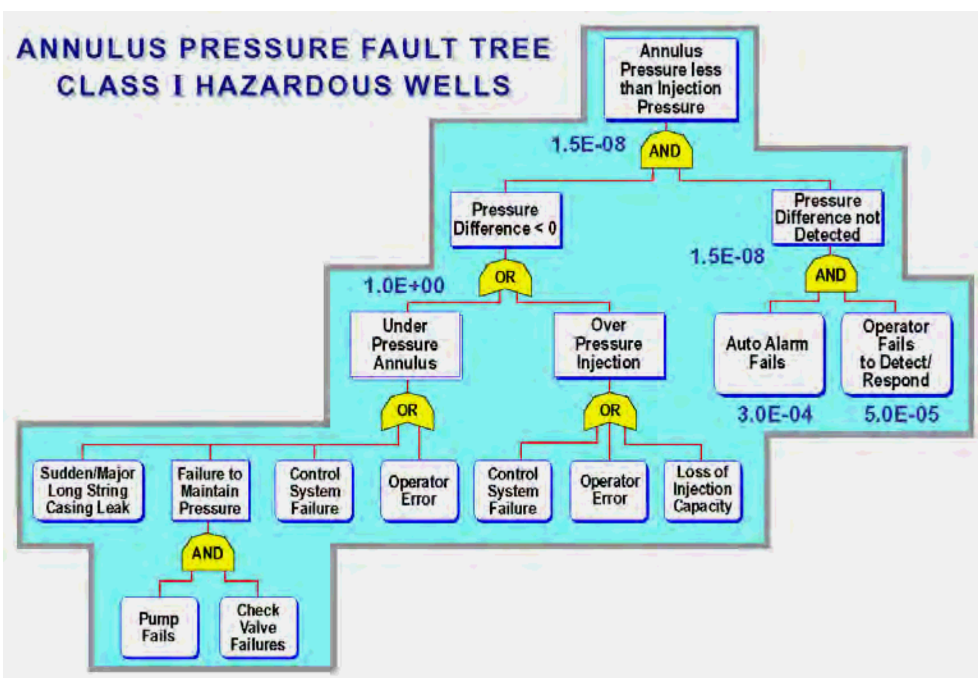

Figure 7. Annulus pressure fault tree for Class I hazardous wells. The risk of loss of containment (injected fluid moves into a USDW) is less than one in a million (Rish et al., 1998).

SUMMARY

Prior to UIC regulations in 1980, only four significant cases of injectate migration occurred due to Class I hazardous well operations, and none of these affected a drinking water source. Since 1980, with the implementation of the UIC program of the SDWA, no cases of USDW contamination have occurred due to stringent siting, construction, operation, and testing requirements for Class I hazardous and non-hazardous wells. Those few instances of contamination prior to 1980 would not have occurred had the 1980 regulations been in place. Injection of hazardous and non-hazardous waste into Class I injection wells since 1980 has been, and continues to be, a low-risk method management of liquid wastes that has proven to be safe and effective. The following table summarizes important events in the history of underground injection, primarily Class I injection. Additional information about UIC program in the United States may be found at: http://www.epa.gov/safewater/uic.html.

UIC Timeline

1930 —	Petroleum industry injection disposal of saltwater from oil and gas production
1935 —	Dow injects spent brine into shallow industrial well
1949 —	DuPont drilled first industrial deepwell
1961 —	Texas first state to enact injection well laws
1970 —	EPA Subsurface Emplacement Policy
1972 —	Federal Water Pollution Control Act Amendments
1974 —	Safe Drinking Water Act with Federal UIC Program
1980 —	First US EPA UIC regulations promulgated
1982-84 —	State primacy programs; US EPA direct implementation
1984 —	Hazardous and Solid Waste Amendments with Land Disposal Ban
1985 —	Report to Congress on Injection of Hazardous Waste
1988 —	US EPA No-Migration Exemption Regulations
1989 —	US EPA OSWER Comparative Risk Project
1991 —	Report to Congress on Restrictions of Deep Injection of Hazardous Waste
1996 —	Land Disposal Program Flexibility Act
2001 —	Report to Congress on Land Disposal Program-Study of the Risks Associated Underground Injection Wells

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