

Risk of Underground Storage Tank Petroleum and Hazardous Chemical Release After the Implementation
of the 1988 and 2015 Federal UST Technical Requirements

by

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Abstract

Underground Storage Tanks (USTs) are commonly used to store regulated petroleum and hazardous chemicals, but they also may pose a substantial threat to the environment. A UST release, which occurs when the contents of a UST spill or leak into the environment, is one of the greatest threats that a UST system poses. Therefore, in response to the environmental and human health risks from USTs, the U.S. EPA introduced UST technical requirements in 1988 and 2015 that regulate how UST systems are constructed, operated, and maintained. However, there is little information on the effectiveness of these requirements in reducing the risk of release. To calculate risk of release for the USTs regulated under the 1988 and 2015 regulations, I used the UST performance measures reports that contain release and active UST data. For my analysis, risk of release is defined as number of releases per active UST. To estimate the effect of the UST technical guidelines on the risk of release, I used the Mann-Whitney U statistical test to compare the retrospective risk of release between the UST facilities regulated under the 1988 and 2015 technical standards. Results indicate that the risk of release for the USTs regulated under the 1988 regulations was significantly greater than the risk of release for the USTs under the 2015 requirements ($P < 0.01$). The average risk of release per regulated UST was 0.010 for the USTs regulated under the 1988 technical standards, and 0.005 releases/tank for the USTs regulated under the 2015 technical standards. The median risk of release per UST was 0.007 for the 1988 regulated USTs and 0.005 for the 2015 regulated USTs. The relative risk of release per UST for the 1988 regulated USTs in comparison to the 2015 regulated tanks was 2.0 using average risk and 1.4 using median risk. Furthermore, I used the Kruskal Wallis Rank-Sum statistical test to compare the UST risk of release between the 10 EPA regions and found that the risk of release between the regions was different ($P < 0.01$). Some factors that may have influenced the risk of release in this analysis include UST equipment age, release prevention methods, release detection methods, operator training, UST maintenance requirements, and UST facility compliance rates. Further studies on the efficacy of the approved release detection and release prevention methods in reducing releases can help determine which regulatory requirements had a significant role in risk reduction. Additionally, an investigation into the state-managed UST programs in regions with greater risk of release can help determine why the risk of release between EPA regions varies. Tracking and analyzing the risk of UST release, and determining what factors influence this risk, can provide useful data for the regulatory efforts of the EPA and local regulatory agencies.

Introduction

The United States Environmental Protection Agency (EPA) defines an Underground Storage Tank (UST) as a “tank and any underground piping connected to the tank that has at least 10 percent of its combined volume underground” (EPA, 2022a). USTs are commonly used to store petroleum and other chemical substances. As of September 2022, there were 537,706 active USTs and approximately 193,000 UST facilities regulated by the EPA’s UST program (EPA, 2022b). Most of the EPA regulated USTs hold petroleum products, while fewer than 4,000 store other hazardous chemicals (EPA, 2022a). Although USTs were introduced as a convenient and space-saving way to store petroleum and other chemicals in bulk, improperly maintained and operated USTs pose environmental risk.

Until the mid-1980s when the EPA started their UST program, most USTs were made of unprotected steel that easily corroded (EPA, 2022a). Additionally, these older USTs did not have the construction, release prevention and release detection standards that are now required on modern UST systems. The inadequate construction and regulation of USTs before the mid-1980s resulted in numerous petroleum and other hazardous chemical releases that contaminated both soil and groundwater. To mitigate the risk of UST release, Congress passed Subtitle 1 to the Solid Waste Disposal Act through the Hazardous and Solid Waste Amendments in 1984, which established the EPA’s role in regulating USTs (Hazardous and Solid Waste Amendments of 1984, 1984). At the beginning of the EPA UST program,

approximately 2.1 million USTs were regulated (EPA, 2022c). Today, fewer than 600,000 EPA regulated USTs remain due to the closing and removal of substandard and leaking UST systems.

Impact of UST Releases

A UST release occurs when petroleum or other hazardous substances leak, spill, or otherwise emit from a UST system into the environment. Since the inception of the EPA's UST program in 1984, the EPA has recognized 568,981 releases and completed a total of 509,091 clean ups of contaminated sites (EPA, 2022c). UST releases can have significant negative impacts on water quality, soil health, air quality, and overall human health and safety.

Environmental Impacts of Leaking USTs

UST releases are frequently cited as a source of contamination to groundwater and surface water. The 2000 National Water Quality Report noted USTs as the greatest source of ground water contamination from the territories reporting groundwater data (EPA, 2002). In this report, USTs were ranked above septic tanks, landfills, spills, urban runoff, aboveground storage tanks (ASTs), and a variety of other sources of contamination regarding their impact on ground water. The contamination caused by UST releases often contains hazardous chemicals detrimental to both human and ecological health. Benzene, ethylbenzene, toluene, and xylene (BTEX) are common groundwater contaminants found in gasoline and other fuels (Jenkins et al., 2014). Methyl tertiary-butyl ether (MTBE), ethanol and other fuel additives are

also contaminants of concern present in the plumes of leaking petroleum USTs (Jenkins et al., 2014). While the use of MTBE in modern fuels is banned or highly regulated in the USA, ethanol has taken its place as a fuel additive and contaminant of concern. Conversely, ethanol decreases the rate of biodegradation of BTEX in plumes, accentuating the adverse effects of the contaminants from past releases (da Silva et al., 2013; Da Silva & Alvarez, 2002). These plumes can travel far enough from the UST site to pose a risk to drinking water wells that are up to 300 m from the point source (Weaver et al., 2017). A petroleum or hazardous chemical release from a UST can also threaten surface water quality EPA, 2023).

A leaking UST also affects soils. The ecological function, biodiversity, and structure of microbial communities in soils are threatened by petroleum and other chemical contamination. Soils contaminated by petroleum have less microbial biodiversity, nitrogen and carbon prokaryotic activity, soil microbiome complexity, and prokaryotic and nitrogen fixation genes (Gao et al., 2022). Concentrations of petroleum hydrocarbons in soil are also toxic to certain microbes, plants, and other soil fauna (Liu et al., 2021; Tang et al., 2011). Bioaccumulation of chemicals from leaking USTs from soil is also a concern. Both plants and soil fauna bioaccumulate chemicals from contaminated soil (Meudec et al., 2006; Moon et al., 2013; Rafiee et al., 2017). The bioaccumulation of contaminants in producers and primary consumers can affect higher trophic level species through biomagnification (Chormare & Kumar, 2022).

A leaking or improperly operated UST can also affect air quality. Gasoline, the most common product stored at EPA regulated UST sites, is a volatile liquid and gasoline's volatility elevates the risk of vapor release. A leaking UST system storing gasoline can release

vapors directly into the environment, or from spilled product that evaporates (Hilpert et al., 2015). When the hydrocarbons that make up petroleum products are burned, they produce mostly CO₂ and H₂O. However, when they are released into the atmosphere without being burned, these hydrocarbons reach potentially harmful concentrations. Of particular concern in unburned gasoline is benzene, which has both chronic and acute health effects from inhalation exposure (EPA, 2003). While benzene is released into the atmosphere during normal fueling activities, benzene atmospheric concentrations present at leaking UST sites are particularly hazardous (Hallenbeck & Flowers, 1992; Hilpert et al., 2015).

UST releases are hazardous to human health and safety. The CDC recognizes BTEX as a mixture of concern due to their combined neurotoxic effects when inhaled (CDC, 2019). While there is not sufficient data to determine the combined carcinogenic effects of BTEX, benzene is recognized as a carcinogen linked to the development of acute myelogenous leukemia (CDC, 2019). Furthermore, UST releases commonly contaminate drinking water supply with substances hazardous to human health. For example, MTBE's plume dynamics allow it to disperse more rapidly from leaking USTs compared to other common components of gasoline, posing a greater threat to drinking water sources (Shih et al., 2004). Animal studies have shown that MTBE has a carcinogenic effect through oral exposure (Agency for Toxic Substances and Disease Registry, 2022). MTBE from leaking USTs has caused large-scale contamination of drinking water wells, including a high-profile case in Santa Monica, California that caused the city to lose most of its local drinking water sources (Los Angeles Regional Water Quality Control Board & US EPA, 1998). Other contaminants of concern at leaking UST sites include other fuel oxygenates, lead scavengers, and a variety of other

hazardous substances stored in non-petroleum USTs (EPA, 2015b). Leaking USTs also pose an immediate threat to people since they increase the risk of a fire or explosion at a UST facility (EPA, 2022a) .

Preventing and Cleaning Up UST Releases

Preventing and cleaning up UST releases reduces the risk of the human health and ecological impacts posed by petroleum and other chemical contamination of air, water, and soil. Potential human health and ecological improvements include reduced risk of cancer fatality, reduced risk of injury from fire and explosions, restoration of valuable ecosystem functions, and reduced surface-water contamination (Jenkins et al., 2014). The U.S. EPA estimates that the 2015 regulatory update could protect 50 to 240 billion gallons of groundwater per year (Industrial Economics, Inc., 2015). The reuse and development of remediated petroleum brownfields may also prevent development of natural land, allowing undeveloped land to maintain critical habitat and ecosystem services.

There are also economic and land-use effects of preventing and cleaning up UST releases. High-profile UST releases can reduce nearby property values, sometimes by more than 10% (Guignet et al., 2016.; Zabel & Guignet, 2012). In addition, it is estimated that the 2015 UST regulations will avoid costs from \$120 million to \$530 million per year (Industrial Economics, Inc., 2015). This estimated cost reduction is from lower remediation costs, less groundwater contamination and less lost product during a release. Businesses can also benefit from cleaning up UST releases, as restored petroleum brownfields offer land and infrastructure opportunities. Many jurisdictions have implemented tax reductions or financial

incentives for the reuse of petroleum contaminated sites (EPA, 2015a). Some successful examples of salvaged petroleum brownfields include a waterfront boardwalk, affordable housing, business parks, a police station, and more (EPA, 2015a).

US EPA UST Regulatory History and Technical Requirements

Regulatory History

Due to the environmental and human health and safety risks that leaking USTs cause, Congress passed a series of laws to mitigate their impact (Table 1). While the Resource Conservation and Recovery act (RCRA) of 1976 did not directly regulate USTs, it provided the regulatory framework by giving the EPA the authority to regulate the generation, transportation, treatment, storage, and disposal of hazardous waste (42 U.S.C. § 6901 et seq. (1976)). In 1984, the Hazardous and Solid Waste Amendments (HSWA) of the RCRA created the federal program to regulate USTs. The HSWA is also responsible for the EPA's implementation of the 1988 technical requirements for USTs (40 CFR§280, 1988). The Superfund Amendments Reauthorization Act of 1986 expanded EPA's role in responding to petroleum spills and leaks, created the Leaking Underground Storage Tank (LUST) Trust Fund, and required UST system owners to demonstrate financial responsibility for damages caused by leaking USTs. The Energy Policy Act of 2005 developed guidelines for the operation and maintenance of UST systems, added enforcement provisions to the UST program, and required the EPA to establish a report regarding USTs on Native American territories. Most recently in 2015, the EPA revised the 1988 Underground Storage Tank

regulations and added construction, operator training, maintenance, and UST system testing requirements (40 CFR§280, 2015).

Table 1. Summary of Underground Storage Tank (UST) Regulatory History.

Year	Congressional Actions	Summary of Actions
1976	Resource Conservation and Recovery Act (RCRA) 42 U.S.C. § 6901 et seq. (1976).	Granted EPA authority to manage hazardous waste from cradle to grave
1984	Hazardous and Solid Waste Amendments of RCRA H.R.2867, 98 th US Congress (1983-1984)	- Established federal program to regulate USTs. - Implemented 1988 Technical Requirements
1986	Superfund Amendments Reauthorization Act H.R.2005, 99th Congress (1985-1986)	- Created leaking UST (LUST) trust fund. - Required UST owners to demonstrate financial responsibility for damages caused by UST releases
2005	Energy Policy Act H.R.6, 109th Congress (2005-2006)	- Developed guidelines for operation and maintenance of UST systems. - Added enforcement provisions
2015	2015 Update of UST Technical Requirements 40 CFR§280, 2015	- Updated 1988 operating, construction and maintenance technical requirements. - Removed regulatory exceptions for emergency generator, field constructed and airport hydrant USTs.

1988 and 2015 Operator and Technical Requirements

The 1988 and 2015 technical requirements dictate how UST systems are constructed, operated, and maintained (Table 2, 3). Before the implementation of the 1988 technical requirements, USTs were often constructed of unprotected steel with no methods of release

prevention or detection (EPA, 2022a). Modern UST systems must follow extensive regulatory requirements and follow code of practices from nationally recognized organizations.

Release Detection

EPA-regulated USTs must have release detection methods and equipment for both tanks and lines. Release detection methods are designed to ensure that a leaking UST is detected by an operator so they can begin corrective action. Some EPA approved methods of release detection include secondary containment with interstitial monitoring, manual and automatic tank gauging, statistical inventory reconciliation, tightness testing, groundwater monitoring, and vapor monitoring (EPA, 2014a)

Release Prevention

The objective of EPA's release prevention regulations is to both prevent USTs from leaking and to contain UST leaks and spills, so they do not release into the environment. Examples of release prevention include corrosion protection, secondary containment, spill containment, and overfill prevention (EPA, 2014b). Corrosion protection requires that UST systems are either constructed with non-corrodible materials or are fitted with corrosion protection equipment (e.g., sacrificial anodes). Secondary containment structures prevent leaks from tanks and lines from releasing into the environment. Spill containment structures (spill buckets) are installed around a UST system's fill pipe to prevent spill releases during deliveries. Overfill prevention equipment (e.g., overfill alarm) is designed to prevent a UST from being filled past capacity.

Table 2. 1988 Underground Storage Tank (UST) technical requirements.

1988 Technical Requirements Summary	
40 CFR§280, 1988	
UST Construction	• USTs must be constructed to maintain their integrity throughout operating life. • All tanks and attached piping must be protected from external corrosion. • USTs must use overfill prevention and spill containment devices
UST Operation	• Release Detection methods are required on all EPA regulated UST systems. • Release detection methods, equipment and requirements vary by age of UST system
Release Reporting and Investigation	• UST operators must report suspected releases to the implementing agency. • Suspected releases must be investigated and confirmed
Corrective Actions	• Owners and operators must perform corrective actions in response to a UST release. • Corrective action scope is determined by implementing agency and can include both short term and long-term clean-up plans.
UST Closure Requirements	• Developed requirements for temporary and permanent closure of UST systems.

Table 3. 2015 Underground Storage Tank (UST) technical requirements.

2015 Technical Requirements Update Summary	
40 CFR§280, 2015	
UST Construction	• Under-Dispenser Containment (UDC) required for fuel dispensers installed after 10/11/16. • Tanks installed after 4/11/16 must have secondary containment.
UST Operation	• Secondary containment with interstitial monitoring is the required method of release detection for tanks and piping installed after 4/11/16. • 30 Day Walkthrough Inspection of spill prevention and release detection equipment • Annual Walkthrough inspection of containment sumps and handheld release detection equipment.
UST Operator Training	• UST facilities must have designated and trained Class A, B and C operators. ○ Class A- Primary party responsible for UST operation and maintenance. ○ Class B- Party responsible for day-to-day operations ○ Class C- On site personnel responsible for immediate response to UST issues and emergencies (gas station attendant)
UST Testing	• Annual test of release detection equipment by certified tester. • Triennial tests of spill containment, containment sumps and overfill prevention equipment by certified tester.
Removed Deferrals	• Emergency generator USTs • Field-constructed tanks • Airport Hydrant Systems

Risk of Release Comparison: 1988 and 2015 Technical Requirements

Purpose and Research Question

The 1988 and 2015 technical requirements of UST systems were intended to both reduce the risk of petroleum and hazardous chemical releases from USTs, and to detect the releases that were occurring. The 2015 technical requirements were implemented to further improve the UST performance measures that were observed after the implementation of 1988 UST technical requirements. Therefore, I asked: Did the risk of UST release change after the implementation of the 2015 technical requirements? The primary objectives of my UST Risk of Release Analysis are to:

- Estimate risk of detected release after the implementation of the EPA's 1988 technical UST requirements.
- Estimate risk of detected release after the implementation of the EPA's 2015 technical UST requirements.
- Determine if there is a statistically significant difference in risk of UST release between the 1988 and 2015 regulated USTs
- Determine if there is a statistically significant difference in risk of UST release between the different EPA regions.

UST Performance Measures Data

Each fiscal half-year, the EPA releases a UST performance measures report that notes total active tanks, confirmed release actions, clean-ups initiated, and more (EPA, 2022c, Figure 1). Using the UST performance measure report, I estimated and compared the risk of release between USTs regulated under both the 1988 and 2015 federal UST requirements. Furthermore, using the regional UST performance measures data, I calculated if there was a significantly different risk of release between EPA regions.

While the UST performance reports are available from 1987-2022, I did not use the data from 1987-1991 in my risk comparison analysis. Under 40 CFR§280, 1988, release detection requirements were phased in during a 5-year period, allowing some UST systems to go unmonitored during this period. The 1992 UST performance report was used as a starting point to calculate the releases that occurred between 1992 and 1993.

LUST Corrective Action Measures for End-of-Year FY 2022
(Cumulative through September 30, 2022)

Region	State	Confirmed Releases Actions This Year	Confirmed Releases Cumulative	Cleanups Initiated Cumulative	Cleanups Completed Actions This Year	Cleanups Completed Cumulative	Cleanups Backlog
State Data by Region							
1	CT	76	3,823	3,774	61	2,757	1,066
	MA	25	6,721	6,692	66	6,417	304
	ME	58	3,289	3,232	64	3,245	44
	NH	11	2,745	2,742	10	2,213	532
	RI	16	1,513	1,513	18	1,372	141
	VT	1	2,190	2,189	9	1,655	535
Region 1 Subtotal		187	20,281	20,142	228	17,659	2,622
2	NJ	349	18,871	16,892	308	13,794	5,077
	NY	96	30,651	30,601	147	30,193	458
	PR	3	1,091	849	4	548	543
	VI	1	40	38	0	35	5
Region 2 Subtotal		449	50,653	48,380	459	44,570	6,083
3	DC	9	1,037	969	11	928	109
	DE	9	2,974	2,925	17	2,946	28
	MD	67	13,023	13,023	92	12,688	335
	PA	226	18,579	18,533	311	15,617	2,962
	VA	135	13,021	12,846	174	12,742	279
	WV	33	3,859	3,851	42	3,419	440
Region 3 Subtotal		479	52,493	52,147	647	48,340	4,153
4	AL	54	12,363	12,242	93	11,491	872
	FL	130	34,059	33,309	480	25,141	8,918
	GA	188	15,223	15,154	299	14,601	622
	KY	138	17,491	17,482	145	16,892	599
	MS	140	8,639	8,339	131	8,115	524
	NC	243	27,563	25,168	774	25,539	2,024
	SC	130	10,798	10,566	180	8,589	2,209
	TN	111	16,044	16,044	112	15,944	100

Figure 1. Underground Storage Tank (UST) Performance Measures Report Example (EPA, 2022c).

Methods

To begin the risk assessment, I calculated the risk of release for each fiscal half-year between 1992-2014 and from 2015-2022 using the data from the UST performance measures. In addition, I calculated the risk of release per fiscal half-year for each EPA region. I used these data sets for the statistical tests in my analysis.

$$\text{Fiscal Half Risk of Release} = \left(\frac{\# \text{ of Confirmed Releases}}{\# \text{ of Regulated Tanks}} \right)$$

Using the average risk of release for the 1988 and 2015 regulated USTs, I calculated the relative risk of release between the two data sets. While this computation illustrates the difference in the risk of release between 1988 and 2015 regulated UST data sets, statistical testing was necessary to determine if there was a significant difference between the data sets.

$$\text{Relative Risk of Release} = \frac{\text{Risk of Release}_{1988}}{\text{Risk of Release}_{2015}}$$

Due to the skewed distribution of the 1988 and 2015 datasets, I used the non-parametric Mann-Whitney U test (Wilcoxon rank-sum test) to compare the risk of release. The Mann-Whitney U test is commonly used to compare the difference in two independent samples when the sample sizes are small, and the distribution is not normal (Boston University School of Public Health, 2017). The hypotheses for the Mann-Whitney U test are:

H₀: The two populations are equal.

H₁: The two populations are not equal.

To run the Mann-Whitney U test, I used the statistical software environment R and a 5% level of significance ($\alpha = 0.05$). A p-value of ≤ 0.05 indicates a statistically significant difference between the two populations.

To determine if there was a difference in the risk of release between the 10 EPA regions, I used R to run the Kruskal-Wallis test. The Kruskal-Wallis test is often considered the non-parametric equivalent to the one-way ANOVA test and can be used with three or more independent variables (University of Virginia Library, 2021). Like the Mann-Whitney U test, the Kruskal-Wallis does not assume normally distributed data and establishes if the independent groups have the same median. The hypotheses for the Kruskal-Wallis test are:

H₀: The medians are equal between populations.

H₁: At least one median is different.

A p-value of ≤ 0.05 indicates that the null hypothesis should be rejected and that the medians are not equal between populations. After completing the Kruskal-Wallis test, I proceeded to the Pairwise Wilcoxon Rank Sum tests to determine which EPA regions had significantly different risks of release from each other (Massachusetts Institute of Technology, n.d.). A p-value of ≤ 0.05 would indicate that one region's risk of UST release is significantly different than another region.

1988 vs 2015 UST Release Analysis Results

Table 4. Risk of release between 1988 and 2015 regulated tanks.

UST Dataset	Average Risk of UST Release (Release/Regulated Tank)	Median Risk of UST Release (Release/Regulated Tank)
1988 Regulated USTs	0.010	0.007
2015 Regulated USTs	0.005	0.005
Relative Risk	2	1.4
$\frac{\text{Risk of Release}_{1988}}{\text{Risk of Release}_{2015}}$		

Based on the average risk of UST release, the risk of release was two times greater in the 1988 regulated USTs compared to the 2015 regulated USTs (Table 5). Using the median risk of UST release, the risk of release was 1.4 times greater in the 1988 regulated USTs

compared to the 2015 regulated USTs (Table 5). The box and whisker chart below provides a visual representation of this risk of release comparison (Figure 2).

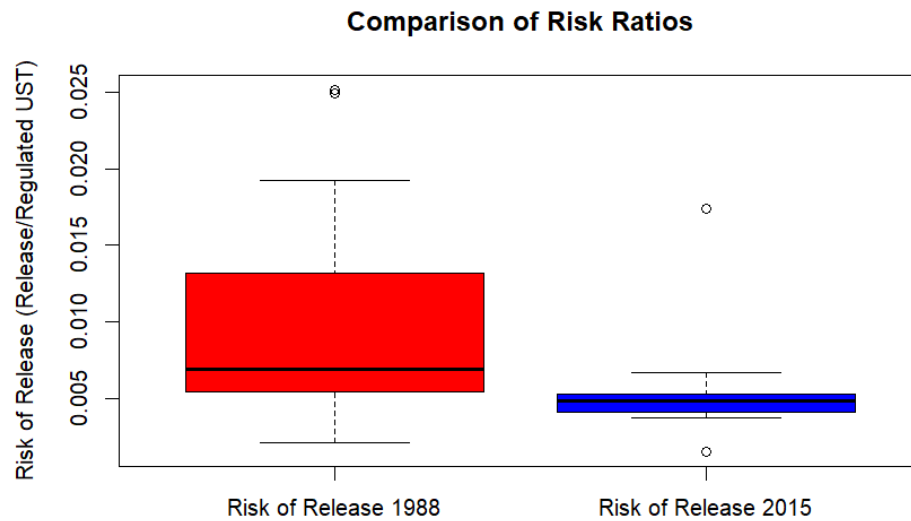


Figure 2. R-Boxplot, risk of Underground Storage Tank release 1988 and 2015.

Table 5. Results of Mann-Whitney U Test.

Mann-Whitney U Test (UST Risk Release 1988 and 2015 Regulated USTs)		
Mann-Whitney U Test Type	Hypotheses	P-Value
Two-Sided	H_0 : The two populations are equal. H_1 : The two populations are not equal.	<0.01 H_0 is rejected.
One-Tailed Test 1988 Risk > 2015 Risk	H_0 : 1988 UST Risk of Release is not greater than 2015 Risk of Release. H_1 : 1988 UST risk of Release is Greater than 2015 Risk of Release	<0.01 H_0 is rejected.
One-Tailed Test 1988 Risk < 2015 Risk	H_0 : 1988 UST Risk of Release is not less than 2015 Risk of Release. H_1 : 1988 UST risk of Release is less than 2015 Risk of Release	>0.05 H_0 is accepted.

Summary: The results of the Mann-Whitney U test support that the UST risk of release between the 1988 and 2015 regulated USTs are different (Table 6). Furthermore, the

one-tailed test supports that the risk of release in the 1988 regulated USTs are greater than the 2015 regulated USTs.

Regional Risk Release Analysis

Table 6. Regional Underground Storage Tank (UST) risk of release.

<u>EPA Region</u>	<u>Average Risk of UST Release</u> <u>(1992-2022)</u>	<u>Median Risk of UST</u> <u>Release (1992-2022)</u>
One	0.005	0.005
Two	0.012	0.010
Three	0.007	0.007
Four	0.011	0.005
Five	0.011	0.008
Six	0.005	0.003
Seven	0.007	0.004
Eight	0.010	0.008
Nine	0.007	0.006
Ten	0.008	0.004

Table 7. Results of Kruskal Willis Rank-Sum Test.

Kruskal Willis Rank-Sum Test	
(Regions 1-10 Comparison of Risk Release	
Hypotheses	P-Value
<i>H₀: All populations come from same distribution.</i>	<0.01
<i>H₁: At least one population is from different distribution.</i>	H ₀ is rejected.

Table 8. Pairwise Wilcoxon Rank Sum Test on EPA Regional Underground Storage Tank Release Data, P-Values.

Pair	One	Two	Three	Four	Five	Six	Seven	Eight	Nine
Two	< 0.001	NA	NA	NA	NA	NA	NA	NA	NA
Three	< 0.001	0.005	NA	NA	NA	NA	NA	NA	NA
Four	0.065	0.001	0.152	NA	NA	NA	NA	NA	NA
Five	< 0.001	0.306	0.048	0.004	NA	NA	NA	NA	NA
Six	0.006	< 0.001	< 0.001	< 0.001	< 0.001	NA	NA	NA	NA
Seven	0.362	< 0.001	0.001	0.011	< 0.001	0.028	NA	NA	NA
Eight	< 0.001	0.446	0.032	0.003	0.955	< 0.001	< 0.001	NA	NA
Nine	0.728	0.005	0.255	0.255	0.011	0.284	0.847	0.014	NA
Ten	0.669	< 0.001	0.022	0.046	0.001	0.124	0.923	< 0.001	0.759

Summary: The Kruskal-Willis Rank Sum Test supports that there is a statistically significant difference in the risk of UST release between the ten EPA regions (Table 8). Furthermore, the Pairwise Wilcoxon Rank Sum test shows which EPA regions come from a different distribution when paired (Table 9).

Risk of UST Release Comparison: Discussion and Conclusion

Risk Comparison – UST Release 1988 and 2015 Regulated USTs

The UST risk of release calculations showed that the average risk and median risk of UST release was greater for the 1988 regulated USTs than the 2015 regulated USTs (Table 5, Fig.1) The results of the Mann-Whitney U statistical test comparing the risk of release of the 1988 and 2015 regulated USTs supported a significant difference in risk ($P < 0.01$), and that the risk of UST release under the 1988 regulations was greater than the USTs regulated under the 2015 regulations ($P < 0.01$). This difference could be due to both regulatory and external factors.

Release Detection

The greatest risk of UST release since the EPA started tracking releases was noted in the second fiscal half of 1993 (0.024 releases/UST). By this period, all EPA-regulated USTs were required to implement a method of release detection. Since this was the first time that many UST systems had a method of release detection, it is possible that USTs that were leaking for some time were finally detected. Before release detection and release reporting

requirements were implemented, leaking USTs would often go undiscovered and unreported, making it difficult to estimate the risk of release before release detection was required. Many leaking and otherwise inadequate USTs were permanently closed in the years following implementation of the 1988 UST regulations, further influencing the risk of release (EPA, 2022).

Release detection requirements for regulated UST systems became even more stringent with the approval of the 2015 UST technical requirements. UST systems that were upgraded or installed after April 11, 2016 were required to use interstitial monitoring as their method of release detection (40 CFR§280, 2015). To perform interstitial monitoring of tanks and piping, the UST systems must have secondary containment that prevents the contents of a leaking UST from entering the environment. Vapor and groundwater monitoring, methods of release detection approved on UST systems installed before April 11, 2016 , require a release of petroleum or other chemicals into the environment before a release can be detected. Furthermore, release detection methods such as statistical inventory reconciliation (SIR) or Automatic Tank Gauge tests do not require a secondarily contained UST system for release detection. The 2015 UST technical requirements also implemented an annual test of release detection equipment, including probes, sensors and monitors that would notify the UST operator of a leaking UST. Functional release detection equipment is essential for early detection of leaking tanks and piping that could prevent or mitigate the environmental impact of a UST leak.

Release Prevention

The release prevention standards initiated during the 2015 UST regulatory update were intended to reduce the risk of a UST release by both containing and preventing spills and leaks. The 2015 UST regulatory update introduced Under-Dispenser Containment (UDC) requirements on all dispensers installed after October 11, 2016 (40 CFR§280, 2015). This requirement was implemented because fuel dispensers were found to be a significant source of petroleum contamination. A study in South Carolina found that nearly half of all facilities sampled had soil contamination in the under-dispenser area (EPA, 2004). The 2015 regulatory update also introduced triennial testing of spill containment structures (spill buckets) and piping containment sumps (Figure 2, 3). Spill buckets are basins designed to capture spills that occur during fuel deliveries (US EPA, 2005). Piping containment sumps are constructed to contain leaks from double-walled UST piping and access important UST equipment (EPA, 2005). The triennial tightness testing was implemented to ensure that these structures that contain spills and leaks are structurally sound and will prevent UST releases into the environment. These spill and leak containment structures can have an impact on the risk of UST release.

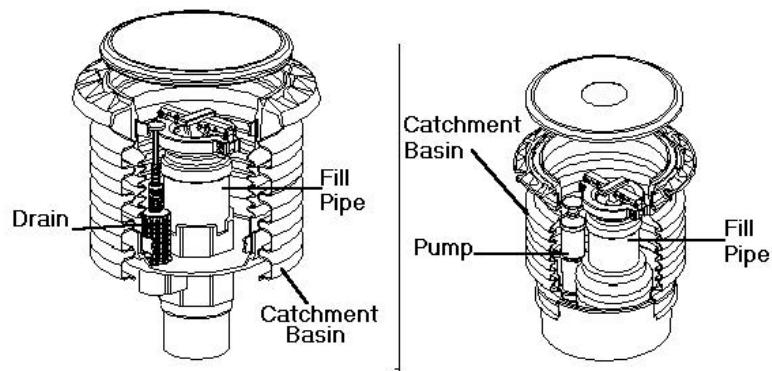


Figure 3. Spill bucket (EPA 2014b).



Figure 4. Piping containment sump (Nevada DEP, N.D.).

The 2015 UST Technical Requirements also introduced triennial testing of overfill prevention equipment. A UST overfill occurs when a tank is filled beyond working capacity, which can result in a massive release of petroleum and other chemicals into the environment. The 2015 triennial testing of overfill prevention devices is designed to ensure that approved

equipment such as overfill alarms, automatic shutoff devices and flow restrictors will activate during an overfill event (EPA, 2014a).

Operator Training and Walkthrough Inspections

UST operator training requirements were also introduced with the 2015 UST Technical Requirements. The operator training requires that each UST facility is assigned a Class A and B operator that are formally trained in how to responsibly operate an UST system in compliance with local and federal regulations (EPA, 2015d). These operators would be trained and tested in subjects such as release detection, release prevention, environmental and regulatory consequences of releases, emergency response, and more (EPA, 2015d). The class A/B operators are also responsible for training the Class C operators, which are the on-site staff who are the first responders to UST related emergencies. It is expected that UST facilities managed by employees who are trained in how to operate and maintain UST systems would experience fewer releases.

UST operators are required to perform both monthly (30-day) and annual walkthrough inspections of their facilities under the 2015 UST technical guidelines (EPA, 2015c). The 30-day inspection requires operators to inspect and maintain their spill buckets and fill pipes. Additionally, the release detection equipment is checked during the 30-day walkthrough to ensure that it is operating normally and not indicating that a release has occurred. The annual walkthrough inspection consists of an inspection of piping containment sumps and any handheld release detection equipment used for manual release detection. The 30-day and

annual walkthrough inspections could reduce the risk of release by allowing the site operators to recognize and respond to UST issues before an incident occurs that causes a release.

Regional Risk Comparison of UST Releases

The Kruskal-Wallis Rank-Sum test supported that there is a difference in the risk of release between EPA regions. This difference in risk of release could be due to differences in state regulations and enforcement.

All UST facilities in the United States are required to at least meet the regulations implemented by the EPA. Most states have state program approval, which allows states to manage and enforce their own UST program (EPA, 2022b, Figure 4). In states without state program approval, the EPA will work with state regulators for enforcement actions. Some states go well above and beyond the EPA regulations for USTs. For example, in California, UST sites are required to have spill containment testing annually instead of every three years (California Code of Regulations, Title 23, Division 3, Chapter 16, 2020).

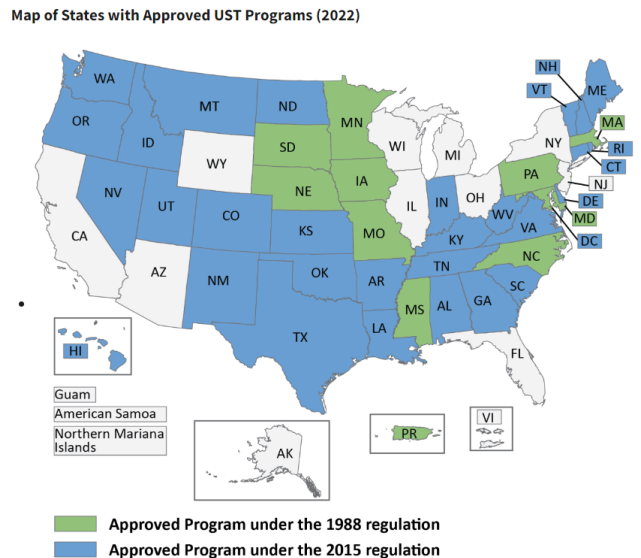


Figure 5. States with state program approval (EPA 2022b).

Regional UST regulation compliance rates also vary between EPA regions. The most recent UST performance measures report indicated that the technical compliance rates varied from 44% to 80% depending on the region (EPA, 2022c). Additionally, a state's ability to perform UST site inspections may influence both compliance rates and risk of release. In Louisiana, Sullivan & Achyut (2017) found that increased inspection frequency improved compliance rates with UST regulations. They found that an inspection frequency of at least every three years improved UST regulatory compliance rates, and that UST facilities with older and lower capacity tanks had a lower compliance rate. Furthermore, they also determined that if the increased inspection rate resulted in 7.13 fewer releases over the course of three years, the benefit of avoided cleanup cost would be greater than the cost of the compliance inspections (Sullivan & Achyut, 2017).

Limitations, Regulatory Suggestions, and Conclusion

Study Limitations

A major limitation of my study was the use of non-parametric statistical tests instead of parametric tests. Small sample sizes and skewed data distributions did not allow for parametric statistical tests that assume normal distributions. Parametric tests have greater statistical power than non-parametric tests, and can also provide useful data (e.g., confidence intervals) that non-parametric tests cannot (Hoskin, n.d.).

Additionally, my study does not differentiate between the impact of the 1988 and 2015 UST regulations on UST releases and other factors. Since there is a delay between UST regulatory implementation and compliance, older USTs without any form of release prevention were included in the 1988-2014 release risk data. These unprotected USTs may have increased the risk of release while not being representative of most of the USTs regulated under the 1988 technical requirements.

Research and Regulatory Recommendations

Further research is needed to determine what factors are currently influencing the risk of UST release, and how the UST release rate could be lowered. It would benefit the EPA to categorize the cause of release (e.g., overfill, line leak, tank leak) in their UST performance reports. These data can be used to determine what the primary factors influencing UST release risk are, and where future regulatory efforts should be focused. Additionally, more research is needed to demonstrate the effectiveness of specific release detection and release prevention equipment and methods in reducing the risk of release. In the past, estimates on clean-up cost

savings and environmental benefits have been made regarding the implementation of the UST technical requirements (Industrial Economics, Inc., 2015). Further risk reduction data exhibiting the effectiveness of specific UST release detection and prevention measures could demonstrate to the public how expensive UST system upgrades can be both an economic and environmental benefit.

There are still many states that do not have state program approval (SPA) under the 2015 UST technical requirements. Only 29 states and the District of Columbia have EPA UST program approval under the 2015 regulations (EPA, 2022b). It should be required that states obtain state program approval within a certain period so state officials are better able to enforce the most recent and effective regulations. While all regulated UST sites must follow the federal UST regulations, some states agencies are still unable to enforce the regulations updated in the 2015 technical UST requirements. For example, New York's petroleum bulk storage program inspectors can inspect for compliance with the 2015 federal regulations, but the only enforcement action they can take is reporting any federal program deficiencies to the EPA (NYSDEC, n.d.). Lack of enforcement actions and inspection may lead to lower compliance rates and a greater risk of UST release.

Conclusion

My results support that the risk of release of the UST facilities regulated under the 1988 technical requirements is greater than the risk of release of UST facilities regulated under the 2015 technical requirements. Results also showed that the risk of release varied between EPA regions. Some factors that may influence the risk of UST release include UST

equipment age, release prevention methods, release detection methods, operator training, UST maintenance requirements, and UST facility compliance rates. To better understand how UST regulations and other factors affect the risk of release, the EPA should track how the risk of UST release has changed over time and if regulations have influenced this risk.

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